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# Three Dimensions of Central Bank Credibility and Inferential Expectations: The Euro Zone

December 19, 2018

**Abstract**

We use the behavior of inflation among Eurozone countries to provide information about the degree of credibility of the European Central Bank (ECB) since 2008. We define credibility along three dimensions–official target credibility, cohesion credibility and anchoring credibility–and show in a new econometric framework that the latter has deteriorated in recent history; that is, price setters are less likely to rely on the ECB target when forming inflation expectations.

JEL Classification: C51, D84, E31, E52.

Keywords: credibility; inflation; expectations; anchoring; monetary union; inferential expectations

## 1 Introduction

The 2007/8 global financial crisis exposed large inconsistencies among member countries of the European Monetary Union (EMU). Significant inflation differentials compounded over time to generate large differences in real exchange rates and current account imbalances, raising doubts about the viability of the union. This suggests that central bank credibility, at least in a monetary union, is multi-dimensional and the usual measure of credibility, normally interpreted as the commitment to follow well-articulated and transparent rules and policy goals (Bordo and Siklos, 2014), may not suffice.

We use the behavior of inflation among the Eurozone countries to provide information about the degree of credibility of the European Central Bank (ECB). Our model offers two distinct advantages: first, the setup is able to econometrically extract information about inflation expectations from observed inflation data alone, that is, without any reference to survey data or market price-based measures. This allows for a simple single-equation specification, which is typically more robust to specification error than a system of equations.

Second, our econometric model has the innovative feature that discrete changes in the marginal effects of information are endogenous. In our setup some explanators in regressions can seem to be insignificant most of the time but may suddenly become highly significant, namely when agents revise their beliefs and reweight the importance attached to alternative sources of information.[1]

[1] This feature ties in nicely with Scharnagl and Stapf (2011) who, by looking at option-implied prob-

We generalize Lucas (1972), showing how private sector inference affects the time series properties of inflation. Within this inferential expectations (IE) framework (Menzies and Zizzo, 2009) we define three dimensions of credibility - *official target credibility*, *cohesion credibility* and *anchoring credibility* - and show theoretically as well as empirically that a central bank need not be equally credible along all dimensions. Estimation for the Euro zone reveals that since the crisis, official target and cohesion credibility have been maintained but at a cost of detioriating anchoring credibility.

The paper proceeds as follows. In the following section we define and discuss three dimensions of central bank credibility. Section 3 reviews the theory of inferential expectations (IE) and derives a new Phillips curve, the IE Phillips curve, based on the classic Lucas islands model. In section 4 we show how the IE Phillips curve relates to credibility, which serves as the basis for the econometric work in section 5. This is followed by a discussion and conclusion in Section 6.

# 2 Three Dimensions of Credibility

Credibility is a central concern for central banks, both in theory and in practice. Academic interest in credibility can be attributed, in no small measure, to the rational expectations revolution. As Blinder (2000) points out, under certain assumptions, including rational expectations, a fully credible central bank is able to disinflate entirely costlessly, without any loss in output, which is to say, the sacrifice ratio is zero. Even without rational expectations, if expectations matter, a central bank's credibility will influence how its monetary policy actions affect both the real and nominal sides of the economy. Early work on central bank credibility was motivated by the problem of an inflation bias, as in Kydland and Prescott (1977) and Barro and Gordon (1983a,b). Concern for the inflation bias has been largely superseded by a concern to minimize the stabilization bias, which is integral to monetary policy analysis in New Keynesian models.[2]

A large literature asks how credibility relates to central bank transparency, reputation and independence (e.g. Faust and Svensson, 2001) and how it can be built and maintained. Over the past 15 years or so, a consensus has emerged that inflation targeting is the best way, at least in practice, for a central bank to build and maintain credibility. (See, for example, Bernanke and Mishkin, 1997, Svensson, 1997, Bernanke et al., 1999., and Walsh, 2009.)

The interest in and concern for credibility is palpable also in policy making circles. Central bankers are acutely aware of the need to influence and control the private sector's expectations as these will determine how effective and costly their policy choices are, now and in the future. Central bank credibility is considered a hard won asset that, under no circumstances, should be squandered.

In a thorough historical analysis Bordo and Siklos (2014), citing Cukierman (1986), define central bank credibility as a commitment to follow well-articulated and transparent rules and policy goals. In particular, credibility refers to the extent to which

ability density functions of future inflation, point out that, "a high variation in inflation expectations covers the risk of sudden expectation swings towards extreme outcomes." (p. 248)

[2]See Clarida, Gali and Gertler (1999) for an early review and Gali (2015) for an extensive overview of this vast literature.

the public believes that a shift in policy has taken place when, indeed, such a shift has actually occurred. They interpret credibility in terms of inflation performance:

> "Credibility is a flow like variable that changes *as observed inflation is seen to deviate from a time varying inflation objective*, which need not be explicit or publicly announced. Credibility is also partially determined by the relative importance the central bank attaches to real and nominal objectives. Regular economic shocks and the manner in which the central bank manipulates monetary policy dictate how credibility evolves over time. [...] As Cukierman (1986, page 5) again points out '...the ability of monetary policymakers to achieve their future objectives depends on the inflationary objectives of the public. These inflationary expectations depend, in turn on the public's evaluation of the credibility of the monetary policy makers...'" [p. 5, our italics]

Credibility is a complicated and subtle concept. The public is well served by a simple metric so that it can hold the central bank accountable and optimally set prices and wages. Thus, Bordo and Siklos and many others use the gap between observed inflation and an inflation objective or target. The wider this gap is or the longer it is sustained, the less credible a central bank is thought to be.

This measure of credibility is both intuitive and sufficiently transparent to be of use to the public but it unnecessarily limits credibility to a single dimension.

What if a central bank announces an official target yet actual inflation settles around a constant level different from the official target (the unofficial target) and inflation expectations become anchored to this unofficial target? The gap between observed inflation and the unofficial target will remain small and short-lived, but is it appropriate to state that the central bank is credible?

When commentators refer to central bank credibility, or well anchored expectations, they typically assume that the unofficial and official inflation targets coincide. But there exist more nuanced discussions. Fuhrer (2011) provides a good example:

> "well-anchored inflation expectations require two things from the central bank. First, the central bank must have an inflation goal [target] that is known to the private agents in the economy, and second, the central bank must move its policy rate in a way that systematically pushes the inflation rate toward that goal." (p. 474)

Fuhrer's first requirement corresponds to our *official target credibility*, while his second corresponds to our *anchoring credibility*. Yet he only considers well anchored expectations to refer to a combination of the two when he refers to pushing inflation 'towards *that* goal' (our italics), rather than some other inflation target.[3]

[3] See also Demertzis et al. (2008). Two notable exceptions, which separately consider the degree to which expectations are anchored to a constant and the gap between that constant and the official target, see Mehrotra and Yetman (2018a,b) and Kowalczyk, Lyziak and Stanislawska (2013). Their focus is entirely different, however. The former proposes an alternative measure of inflation anchoring which uses multiple-horizon fixed-event forecasts while the latter is concerned with forecast distributions using probabilistic survey questions.

And consider the central bank of a monetary union whose mandate is to target an average rate of inflation for the entire union. Is a central bank which presides over a union in which all member countries have the same inflation rate more credible than a central bank whose member countries have diverging inflation rates but the same average? The latter may not be the central bank's 'fault' but diverging inflation rates complicate the central bank's core mission of targeting average inflation, even more so when the central bank has other mandates such as low unemployment or financial stability.

In a monetary union such as the Euro zone persistent inflation differentials lead to significant real imbalances, which may ultimately compromise the central bank's ability to meet its inflation target and even threaten the entire union and existence of its central bank. This is why Euro accession requires entrants to meet an inflation criterion *individually*. Indeed, it is not possible for two countries to join the European monetary union if their average inflation rate is close to the ECB target but their individual inflation rates significantly deviate. (See Darvas and Wolff, 2014.)

When the survival of the central bank as an institution is uncertain, labelling it credible merely because on average inflation remains close to the target seems to miss a very important aspect of monetary policy, namely that the policy regime is stable and thus credible in the sense that it will survive. From the perspective of an individual Euro member country, the survival of the union, or at least the country's continued membership in the union, is arguably central to any projections about future inflation. Consider two scenarios in which the average Euro area inflation rate is the same but in scenario 1 the individual country inflation rates barely differ from each other, whereas in scenario 2 individual country inflation rates differ widely. In scenario 2, for a firm or household in a union member country, any policy, or announcement, by the ECB directed at fulfilling its core mission of keeping the average Euro area inflation rate at, or near, the official target will ring hollow, if there is a real possibility that the member country, which already has, say, a high inflation rate, will leave the ECB and pursue its own monetary policy. Indeed, this would especially be the case if the reason for leaving the Euro was that its inflation rate was high and difficult to bring down (though this is hypothetical – we are not claiming this for the Eurozone now). This must affect national inflation expectations.

This seems plausible, whether or not the final decision of a member country to remain within the union is outside the ECB's control – and, more generally, whether or not country-specific policies that create the divergence in national inflation rates, and thus increase the probability of a union dissolution, are beyond the ECB's direct control. It seems to us that what really matters for decision makers in the member countries is the extent to which ECB policies and announcements, given the constraints a monetary union imposes, are reliable indicators for the formation of domestic inflation expectations. This issue was already anticipated not long after the ECB's inception. Expressing concern that the ECB presidents of national central banks have a majority in the Governing Council, *The Economist* argued that:

> "The Governing Council is supposed to set interest rates according to conditions in the euro area as a whole, but there is a risk that national governors will be unduly influenced by conditions in their home country. Small countries may also carry undue weight in the system... A weak centre, com-

bined with strong national interests, could create conflicts that undermine the whole system's credibility." [quoted in de Haan et al., 2004, p. 5]

The idiosyncratic behaviour of national inflation rates, which are affected by national variables, such as wages, domestic competitiveness conditions, etc., is also the primary motivation for van der Cruijsen and Demertzis (2011), whose results clearly indicate that national inflation expectations behave differently than Euro area inflation expectations.

Diverging inflation rates are, however, not only a problem for a monetary union such as the Euro zone, where members are sovereign states, but also for large, diverse countries such as Australia, Canada or the USA. These countries typically have other mechanisms to counter diverging inflation rates, such as fiscal transfer systems and high labor mobility, but the regional disparities do compromise their central banks' abilities to deliver on their (multiple) mandates.

We make these distinctions explicit and define three dimensions of credibility:

1. A central bank has *official target credibility* if underlying inflation is equivalent to the announced target. If underlying inflation settles at another level, then this constitutes an unofficial inflation target.[4]

2. *Cohesion credibility* captures the degree of inflation divergence among the monetary union's regions. Little inflation divergence among regions/countries means that the monetary union has fewer real imbalances within it, making the monetary union more likely to survive and monetary policy thus more stable and credible.

3. *Anchoring credibility* refers to the degree of attachment of price setters' inflation expectations to the central bank's inflation target, whether official or unofficial.

Cohesion credibility is one of our innovations in this paper. We find it has been maintained throughout the past decade, in part because the 2007/8 global financial crisis and the subsequent European sovereign debt crisis forced the ECB and other policy makers in the union to adopt policies that attenuated the real exchange rate misalignments. Had these extraordinary policy measures not been taken, the official asseveration by the ECB and the member countries' leaders of the union's survival (and thus, implicitly, its ability to meet its inflation target) would have lacked credibility.[5]

[4]There is a clear difference between credibility and predictability, with credibility implying predictability but not the other way around. Consider the following example: Peter, every time he is invited to Bob's house for dinner, promises to be on time but shows up an hour late. His behavior will be perfectly predictable (at least to Bob) but his promise to be on time will be deemed lacking credibility. Of course, the likely response will be for Bob to invite Peter an hour earlier, anticipating Peter's tardiness, but if it weren't for Peter's lack of credibility, Bob would not need to adjust his behavior.

[5]Clearly, the interdependence between monetary and fiscal policy is crucial, especially in a monetary union of sovereign nations with limited provisions for cross-border fiscal transfers. There is a large literature on the optimal structure of a monetary union, with an emphasis on the different implications of fiscal versus monetary dominance. (For an early overview of this debate in the context of the European Monetary Union see Beetsma and Debrun, 2004.) We will not weigh into this discussion, but rather accept the institutional arrangements as they are.

# 3 An Inferential Expectations Phillips Curve

## 3.1 Inferential Expectations (IE)

In the coming sections we will investigate the issue of central bank credibility using a Phillips curve based on Inferential Expectations (IE). Economists have long emphasized the importance of expectations for macroeconomic outcomes, and IE is one departure from Rational Expectations (RE) which nests RE as a special case. Under IE, agents form expectations as though they are doing a hypothesis test.

Informally, agents have an opinion about the state of the world. It could be something as simple as 'the ECB is targeting 2 per cent inflation'. Then they make imperfect observations on any variable that bears on that statement, such as a member's increasingly precarious fiscal position which might tempt the authorities to inflate away debt, but they do not change beliefs with every adverse observation. Instead, they hold onto their opinion about the state of the world despite the cumulated evidence. When so much evidence cumulates against their opinion that it appears unsustainable, they swiftly abandon it.

More formally, their maintained belief is their null hypothesis ($H_0$), their measure of cumulated evidence is a test statistic, and their rejection region is defined by a single significance level $\alpha$, which may be drawn from a distribution. If they reject $H_0$, we assume they switch to RE. It follows that in the special case where $\alpha$ is always unity, IE agents continually reject the null and embrace RE. This is the basis for the earlier claim that IE nests RE.

IE has two very plausible implications. First, agents can notice data without changing their minds, which is a feature of a hypothesis test when someone is in possession of information that speaks against a null, but the test statistic falls short of a rejection region. That this is plausible can be seen from this quote by Alan Greenspan about the build-up to the subprime mortgage crisis:

> "While I was aware a lot of these [sub prime] practices were going on, I had no notion of how significant they had become until very late. I didn't really get it until very late in 2005 and 2006."
>
> Alan Greenspan CBS "60 minutes" 16 Sept. 2007

The second implication of IE is that a relatively small bit of information can be the proverbial 'straw that breaks the camel's back'. In a hypothesis test this occurs if a relatively uninformative observation nonetheless takes a test statistic into a rejection region. Under RE, which in this case equates to Bayes rule, the flip in beliefs (from complete belief of the null to complete belief of the alternative) can only occur if the information is extremely informative.

For the purposes of comparison, we will mimic a switch in beliefs from $H_0$ at time $t$ to $H_1$ at time $t+1$ using Bayes rule. This is equivalent to holding $H_1$ with a vanishingly small probability $\varepsilon$ in period $t$, which becomes our prior, and then with probability $1-\varepsilon$ in $t+1$. We then let $\varepsilon$ approach zero to approximate 'believing' $H_0$ in $t$ and $H_1$ in $t+1$.[6] If the last parcel of information is $I_{t+1}$, then Bayes rule says it must be highly

[6] It can be shown that if $H_1$ is believed with $\varepsilon_1$ in period $t$ and $1-\varepsilon_2$ in $t+1$, then the result goes through even if $\varepsilon_1$ and $\varepsilon_2$ approach zero at different rates.

informative:[7]

$$\begin{aligned}\Pr(H_1 \mid I_{t+1}) &= \left(\frac{\Pr(I_{t+1} \mid H_1)}{\varepsilon \Pr(I_{t+1} \mid H_1) + (1-\varepsilon)\Pr(I_{t+1} \mid H_0)}\right)\varepsilon = 1-\varepsilon \\ &\implies \lim_{\varepsilon\to 0} \frac{\Pr(I_{t+1} \mid H_1)}{\Pr(I_{t+1} \mid H_0)} = \lim_{\varepsilon\to 0}\left(\frac{1-\varepsilon}{\varepsilon}\right)^2 = \infty\end{aligned}$$

As well as having plausible implications, IE has a number of plausible micro-foundations. Carroll (2003) shows, using household survey data, that a parsimonious and tractable model of expectations is 'infrequent rational expectations' where the rationality can be thought of as coming from consulting 'experts' who are convey the rational expectation to the agent. Clearly, this is equivalent to a hypothesis where one either holds to a belief ($H_0$), or forms a rational expectation ($H_1$).

The second micro-foundation comes from the decision-theoretic framework of Cohen et al. (2018). Agents conduct an inference problem with switching costs, and a cost of not switching associated with holding onto incorrect beliefs. The optimally generated band of inaction balances the two costs, and turns out to be equivalent to a confidence interval. This makes the band of inaction describable as a two-sided hypothesis test—in other words IE is an 'as if' theory of optimal decision making.

In view of what we consider to be reasonable implications and foundations, our modelling strategy is an extension of the IE work on central banking by Henckel et al. (2011). We treat beliefs about the central bank inflation target as a null belief in a hypothesis test, where $H_0$ corresponds to the official target value. In the case of the ECB we will treat this value as 2 percent.[8]

We posit an IE Phillips curve of the following form:

$$\pi = \beta H_0 + (1-\beta) E[\pi] + \sum_i \gamma_i X_i + \eta. \tag{1}$$

Aggregate inflation $\pi$ depends on the inferential expectations of price setters, a fraction $\beta$ of whom fail to reject $H_0$ and a fraction $1-\beta$ of whom reject $H_0$ and work out the rational expectation of inflation, based on (1). The variable $H_0$ is the value inflation takes under the null, which in our analysis is 2 percent for the ECB. The $X_i$ are other explanators, variables like the output gap, which are zero in the steady-state. The estimation error $\eta$ is assumed to be i.i.d. We can simplify the above equation by noting that, when agents adopt rational expectations, they can use (1) to solve for $E[\pi]$:

$$E[\pi] = \beta H_0 + (1-\beta) E[\pi] + \sum_i \gamma_i X_i \qquad \implies \qquad E[\pi] = H_0 + \sum_i \frac{\gamma_i}{\beta} X_i,$$

which can be substituted into (1) to obtain the IE Phillips curve:

$$\pi = H_0 + \sum_i \frac{\gamma_i}{\beta} X_i + \eta. \tag{2}$$

[7] In the event of quasi-Bayesian (under)adjustment, where the bracketed term in the first line is raised to a power less than unity, it can be shown that the last bit of information must be even more powerful to accomplish a switch in beliefs.

[8] The European Central Bank (ECB) 'aims at inflation rates of below, but close to, 2% over the medium term'. (http://www.ecb.int/mopo/html/index.en.html) We adopt 2% as the target in our estimation.

Equation (2) is noteworthy because the marginal impacts of the $X_i$'s depend upon the proportion of agents that are anchored onto $H_0$. The more they abandon the inflation target (the lower $\beta$) the more they must rely on other variables for their expectations, which magnifies their marginal impacts. Thus, a testable implication of the IE Phillips curve is that all the coefficients on the $X_i$'s will rise by the same proportion when agents abandon the null. It is a noteworthy feature of many crises that previously unimportant variables can become more important, and (2) is a new (and testable) model of why this might be so.[9]

## 3.2 Steady-State $\beta$

A key parameter in (2) is $\beta$ and we now characterize it both in, and out of, the steady-state. By steady-state we mean that the equation error and the $X_i$'s in (2) are zero, which implies $\pi = H_0$ for any value of $\beta$; that is, the value of inflation under the null hypothesis is the rational expectation. We can now work out the steady-state value of $\beta$ knowing that any value of $\beta$ is consistent with a steady-state for $\pi$, and that the null belief about inflation is true in the steady-state.

Because the population of agents forming inflation expectations is heterogeneous, we assume that agents take an i.i.d. draw of a test size $\alpha$ from a common density for $\alpha$. For example, a group of 'classical statisticians' might draw $\alpha = 0.05$ and 0.10 with equal probability. Since $H_0$ is true in the steady-state, then $\beta$ must be the proportion of agents believing the null under $H_0$, which is $1 - \alpha$ if $\alpha$ is a single number and $1 - E[\alpha]$ if $\alpha$ has a distribution.[10]

All that is required to calculate steady-state $\beta$ is the mean of the density of $\alpha$. For example, our 'classical statisticians' have $E[\alpha] = 0.05/2 + 0.10/2$ and hence $\beta = 1 - 0.075 = 0.925$. However, based on the wide range of $\alpha$'s elicited in Menzies and Zizzo (2012) we here assume $\alpha$ is uniform across support $(0, 1)$ implying $E[\alpha] = 0.5$ and $\beta = 0.5$.

[9] Thus our model adopts the last three recommendations of the Rebuilding Macroeconomic Theory Program (Vines and Wills, 2018): the inclusion of financial frictions (which we do not do), limiting RE, adding heterogeneous agents and having more realistic microfoundations (like Carroll 2003). The project, described in Vol. 34, Issue 1, of the Oxford Review of Economic Policy, is a summary of the written and verbal contributions by the volume's many authors. A comment that the econometric explanatory power of variables can intensify during a crisis, as we have modelled in (2), is attributed to Olivier Blanchard.

[10] In more detail, we make the standard assumption that the choice of test size and the compiling of evidence, which gives the p-value, are independent, viz. $f_{P\alpha} = f_P f_\alpha$, where $f$ is a probability density function. A null is not rejected if the p-value $P > \alpha$, allowing us to write $\beta$ as follows:

$$\beta = \int_0^1 \int_\alpha^1 f_{P\alpha} dP d\alpha = \int_0^1 \left( \int_\alpha^1 f_P dP \right) f_\alpha d\alpha.$$

Under the null, the density of any p-value is uniform, since under $H_0$, $Pr(P < x) = x$ for any test size $x$. We recognize this as a cdf, namely $F_P(x) = x$, implying $f_P(x) = 1$. Integrating the bracketed term on the RHS above using $f_P = 1$, gives the following result:

$$\beta = \int_0^1 (1 - \alpha) f_\alpha d\alpha = 1 - E[\alpha].$$

When we later run a regression like (2) it will be impossible to separately identify the $\gamma$'s and $\beta$. However, if we assume the model is in a steady-state prior to the shock (the 2008 crisis) we can infer both $\gamma$ and, if we attribute any rise in the estimated coefficient to $\beta$, the new value of $\beta$.

### 3.3 Non-Steady-State $\beta$: An IE Lucas Islands Model

We now characterize $\beta$ out of the steady-state using an extension of Lucas (1972, 1973) to capture the idea that agents in individual countries face a signal extraction problem when disentangling domestic inflationary impulses from Euro-wide inflationary impulses. It is a fitting framework for the European context, where agents are constantly processing pan-European information about the state of European institutions, inflationary pressure and fiscal sustainability, alongside relevant national information. Using IE we obtain a function that is very close to Lucas's (1973) form, but with a more realistic information requirement.

Suppose a country, say Italy, draws a country inflation target $\pi^{CB}$ from the Euro-wide inflation meta-distribution $\pi^{CB} \sim N\left(\pi^{EU}, \sigma_{CB}^2\right)$. Agents in Italy have an interest in knowing the true value of $\pi^{CB}$ but only observe a noisy signal of it, $\pi = \pi^{CB} + v$ with $v \sim N(0, \sigma_v^2)$.[11] Assuming $\pi^{CB}$ and $v$ are independent, $\pi \sim N\left(\pi^{EU}, \sigma_{CB}^2 + \sigma_v^2\right)$, from which a standard Bayesian solution follows:

$$\pi_{\text{Lucas}} = E\left[\pi^{CB} \mid \pi^{EU}, \pi, \sigma_{CB}^2, \sigma_v^2\right] = \frac{\sigma_v^2}{\sigma_{CB}^2 + \sigma_v^2}\pi^{EU} + \frac{\sigma_{CB}^2}{\sigma_{CB}^2 + \sigma_v^2}\pi. \tag{3}$$

If inflation rates are replaced with price levels and the shocks are redefined as money and idiosyncratic ("island") cost shocks, we obtain the familiar 'Lucas Islands' (1973) solution.

The solution (3) requires knowledge of all variances, whereas it is arguably more realistic to assume that agents do not know $\sigma_{CB}^2$. In spite of agents knowing less, the IE solution has the same qualitative properties as the Lucas solution. Remarkably, the coefficents on the null and alternative hypotheses are functions of the same weights in (3), and the signs of the partial derivatives with respect to these weights are identical.

The IE solution begins with the hypotheses:

$$\begin{aligned} H_0 &: \pi^{CB} = \pi^{EU} \\ H_1 &: \pi^{CB} = E[\pi], \end{aligned} \tag{4}$$

which is to say that each agent anchors $\pi^{CB}$ onto the known constant $\pi^{EU} = 2\%$ until they have sufficient evidence against it based on the noisy signal $\pi$. At that point they form a rational expectation of inflation, or ask an expert to do so (Carroll, 2003). As above, we assume that in a setting where a proportion $\beta$ believes the null, the aggregate belief relevant for a country's Phillips curve is the convex combination of the beliefs weighted by $\beta$ and $1 - \beta$, namely $\beta\pi^{EU} + (1 - \beta) E[\pi]$. We now demonstrate that $\beta$ is an increasing function of the Lucas ratio $\sigma_v^2 / \left(\sigma_{CB}^2 + \sigma_v^2\right)$.

[11] It is most natural to think of $v$ being related to direct measures of the Italian inflation rates, or price components of the CPI. However, it can be anything that makes it hard to see what the central bank is actually doing by adding noise to inflation. For example, if the spectre of fiscal profligacy looms, then the $v$ might be an amalgam of data related to fiscal issues.

As identified in (4), the null belief $\pi^{CB} = \pi^{EU}$ is equivalent to $\sigma_{CB}^2 = 0$ and so the only variance relevant for the hypothesis test is $\sigma_v^2$.

The rejection rule for the hypothesis test is

$$\text{Reject H}_0 \text{ if } \frac{\left|\pi - \pi^{EU}\right|}{\sigma_v} > Z_{\alpha/2} \Leftrightarrow \left(\frac{\pi - \pi^{EU}}{\sigma_v}\right)^2 > \chi_{1,\alpha}^2.$$

The probability this occurs depends on the full variance of $\pi$, ensuring $\beta$ is a function of $\sigma_v^2 / \left(\sigma_{CB}^2 + \sigma_v^2\right)$:

$$\begin{aligned}\beta &= \Pr\left(\frac{\left(\pi - \pi^{EU}\right)^2}{\sigma_v^2} \leq \chi_{1,\alpha}^2\right) \\ &= \Pr\left(\frac{\left(\pi - \pi^{EU}\right)^2}{\sigma_{CB}^2 + \sigma_v^2} \leq \frac{\sigma_v^2}{\sigma_{CB}^2 + \sigma_v^2}\chi_{1,\alpha}^2\right) \\ &= \Pr\left(\chi_1^2 \leq \frac{\sigma_v^2}{\sigma_{CB}^2 + \sigma_v^2}\chi_{1,\alpha}^2\right) \leq 1 - \alpha.\end{aligned}$$

The $\chi^2$ distribution is shown in figure 1:

*(Insert Figure 1 here)*

The probability that $H_0$ is believed is $\beta$, the shaded area. It is less than the area up to $\chi_{1,\alpha}^2$, namely $1 - \alpha$. As the ratio $\sigma_v^2 / \left(\sigma_{CB}^2 + \sigma_v^2\right)$ rises, the shaded area rises, establishing that $\beta$ is increasing in $\sigma_v^2 / \left(\sigma_{CB}^2 + \sigma_v^2\right)$.

To reiterate, the IE solution delivers identical signs of the partials with respect to $\sigma_{CB}^2$ and $\sigma_v^2$ as the classic model but without the informational burden of agents having to know the economy-wide variance $\sigma_{CB}^2$. The IE model is thus more reasonable in terms of calculation—a frequentist test is simpler than a signal extraction problem—and in terms of the assumed information known by the agents.

## 3.4 The Credibility Cube

The IE Phillips curve can be used to discuss and estimate credibility in the Euro area following the tumultuous events after 2008. Since we are not in possession of the distribution of p-values or chosen test sizes for European countries, we will proceed by estimating an IE Phillips curve and testing for changes in coefficients that might signal an erosion of *anchoring credibility*. That is, if the explanators for inflation rise proportionally in unison, it may signal (according to (2)) that $\beta$ is falling. Furthermore, estimating across a panel of Euro-area countries will allow us to see if underlying inflation rates cluster around the 2 percent target (*cohesion credibility*), and, if the underlying inflation rates differ from the official 2 percent target (*official target credibility*).

We can represent our econometric answers to these question on a three dimensional 'credibility cube' (figure 2):

*(Insert Figure 2 here)*

The official target credibility axis lies along the bottom left-hand side. Inflation equal to the official target gives maximum credibility.

The cohesion credibility axis is shown at the bottom right-hand side: all countries having the same inflation rate ($\sigma^2_{CB} = 0$) gives maximum credibility.

The anchoring credibility axis lies along the closest edge. When $\beta$, the proportion of agents believing the null, equals 100% (at point 0 in figure 1) there is maximum credibility. As we rise along the vertical anchoring credibility axis, $\beta$ approaches zero and there is declining credibility.

At point 0 the central bank has maximum credibility on all three dimensions. At the top-most point on the page, diagonally opposite from 0, the central bank has minimum credibility on all three dimensions.

# 4 IE in a Country Specific Phillips Curve

We now specify an IE Phillips curve for each country in the Euro-zone. Consider the specific form,[12]

$$\pi_t = \pi_t^e + \gamma_1 \pi_t^{en} + \gamma_2 e_t + \eta_t, \tag{5}$$

where $\pi_t$ denotes four-quarter-ended inflation, expressed in percent, in period $t$, $\pi_t^e$ expected inflation, $\pi_t^{en}$ is energy price inflation, $e_t$ is marginal cost, and $\eta_t$ is an i.i.d. shock.

This is a Lucas supply function, augmented with a term for energy prices $\pi_t^{en}$, which is important empirically for Europe. We are not interested in the determinants of $e_t$ in general equilibrium and therefore assume that $e_t$ has a zero mean but we leave unspecified whether it is auto-correlated. It is straightforward to use a mapping of real marginal cost to output or unemployment to rewrite (5) so that $e_t$ becomes an output gap.

There is no forward-looking inflation expectation term, as in the New Keynesian Phillips curve, since the IE Phillips curve was derived differently. Prices are assumed to be perfectly flexible, providing firms with the opportunity to set prices anew in each period. Any price stickiness arises endogenously due to informational and cognitive costs among price setters, rather than imposing a Calvo (1983) or Rotemberg (1982) type restriction. This is broadly in the spirit of the more recent research on rational inattention (Sims, 2003, and Woodford, 2009).[13]

[12] For simplicity we drop country-specific subscripts on the variables.

[13] The empirical success of forward-looking expectations is mixed. While forward-looking terms have been shown to have some explanatory power in some cases, especially in more structural models such as Smets and Wouters (2007, 2010), in many others they are statistically insignificant or relatively small, compared to backward-looking expectations. See Rudd and Whelan (2007) and Galí, Gertler and Lopez-Salido (2005).

The New Keynesian Phillips curve, when estimated under the assumption of full-information rational expectations, has several shortcomings, including its inability to adequately deal with lags, instability and structural breaks, its low out-of-sample prediction power, and its sensitivity to the economic gap variable used. See Coibion et al. (2017) for a deeper discussion and a Phillips curve model that tries to overcome these problems by directly including inflation expectations survey data.

Instead, as above, expected inflation is the consensus belief of experts about the true inflation target of the central bank, $\pi^{CB}$. In particular, we assume that in each Eurozone country a continuum of experts, after studying the economy and the central bank, separately guess $\pi^{CB}$. These within-country guesses are averaged and form a *consensus belief* which substitutes for $\pi^e$ in the first term on the RHS of (5) in each country's Phillips curve.[14]

Consistent with the model of Carroll (2003), we assume that price setters have inferential expectations (IE), that is, they guess $\pi^e$ using a statistical hypothesis test. We further assume that each individual price setter has her own significance level $\alpha_i$ and p-value and that a hypothesis test is conducted with a draw from $f_{P\alpha}$.

In many circumstances it might be natural to assume that the IE test statistic is some function of the gap between observed inflation and its target (here, the 2% ECB 'target'). For example, this was the assumption of Henckel et al. (2011). However, for the recent sovereign debt crisis, it is both realistic and convenient to assume that the danger to credibility does not stem from the recent inflation history. It is realistic because inflationary concerns relate to the doubts about the fiscal sustainability of the Euro venture itself (Borgy et al., 2011),[15] and it is convenient because the independence of $\beta$ and lagged inflation makes our estimation below simpler.[16]

There would be no inference problem for the experts in the model described in (5) if $\pi^{CB}$ were common knowledge *and* credible. However, it is possible that the central bank has lost partial control of the monetary policy process and that the link between national inflation rates and the European Central Bank's policy setting is weakened. For individual Eurozone countries this is as if the monetary authority targeted a value of inflation different from the official value. Using the notion of official target credibility, as previously defined, we denote the *announced* (official) inflation target as $\pi^*$, and the unofficial inflation target, the level of inflation around which actual inflation tends to settle, as $\pi^{CB}$.[17] To the extent that $\pi^{CB}$ differs from $\pi^*$, official target credibility is eroded.

Assuming heterogeneity in inflation expectations across countries is justified by the strongly divergent behavior of national inflation rates within the Eurozone despite a common monetary policy. Figure 3 shows inflation rates (four-quarter-ended) for Germany, Greece, Ireland, Italy, Portugal and Spain for March 2001-December 2014. We also show the European rate for comparison. Not only do inflation rates differ substantially across countries but their first derivatives sometimes have opposite signs. Over a long period, like a decade or more, an inflation differential of, say, one percentage

[14] When (5) is modelled for the Euro area, the 'islands' of the 'Lucas Islands' (1973) model are the expectations in each country.

[15] We do not need to assume this however; inflationary concerns could be due to a range of economic factors and, as long as they include recent inflation history, this would be compatible with our framework.

[16] The dependence between the proportion of agents holding onto beliefs and lagged values of the dependent variable makes the $\beta$ in the chartists/fundamentalists framework (Ahrens and Reitz, 2000, and Frankel and Froot, 1986), which is similar to our $\beta$, very challenging to estimate. Our assumption is a reasonable shortcut for this particular context which makes estimation straightforward.

[17] Alternatively, though we do not consider this likely for the Euro area, an inflation bias may be present, implying a wedge between the official inflation target and the actual equilibrium value, and this is imperfectly observed by experts. This latter possibility is in the spirit of Barro and Gordon (1983a, 1983b) and Henckel et al. (2011).

point cumulates to a large price level differential. Of course, as all Eurozone countries share the same currency, differences in domestic price levels constitute *relative* price changes. Because these relative price differences may persist for decades, driving large *real* exchange rate differences, organizations like the OECD continue to compile and speak of national inflation rates.[18]

*(Insert Figure 3 here)*

As discussed earlier, in the IE framework it is a common convention to adopt rational expectations as the alternative hypothesis (Menzies and Zizzo, 2009; Henckel et al., 2011). Adopting that convention at a country level means the null hypothesis for price-setting agents in, say, Italy, is that the ECB really is pursuing $\pi^{CB} = 2\%$ in that country, but if experts do not believe this, they work out $E[\pi]$. Algebraically, $\pi^e$ becomes $\beta\pi^{CB} + (1-\beta)E[\pi]$ and we solve the model to obtain a form like (2).

In the next section we estimate an IE Phillips curve for each country in the Euro area to describe any changes in the three dimensions of credibility since 2008. The econometric model maps onto the three dimensions of credibility as follows:

- Official target credibility refers to the proximity of targeted inflation to the announced target $\pi^*$. In our estimation framework a natural measure for this is the distance from the target $\left|\widehat{\pi}^{CB} - \pi^*\right| = \left|\widehat{\pi}^{CB} - 2\right|$.
- Cohesion credibility $\sigma_{CB}$ refers to the standard deviation of inflation across countries. The smaller, the better.
- Anchoring credibility refers to the proportion of agents $\beta$ who believe $H_0$. If the proportion drops, moving up along the front edge of the credibility cube, credibility is lost.

It turns out to be useful to split the countries into core and peripheral groups, since the evolution of credibility is very different for the two.

# 5 Estimates of Credibility

## 5.1 An Estimable Form of the Model

Our measures of credibility in this section use a restricted form of the following equation, derived from equation (2):

$$\begin{aligned}\pi_{it} &= \theta_1 D_t P_i + \theta_2(1-D_t)P_i + \theta_3(1-P_i)D_t + \theta_4(1-D_t)(1-P_i) \\ &\quad + \frac{\theta_5}{1-\theta_6 D_t - \theta_7 D_t P_i}\pi_{it}^{en} + \frac{\theta_8}{1-\theta_9 D_t - \theta_{10} D_t P_i} ygap_{it} + \eta_{it}; \qquad (6) \\ &\quad i = 1,\ldots,N, \quad t = 1,\ldots,T,\end{aligned}$$

[18] See http://stats.oecd.org/index.aspx?queryid=22519.

where $i$ is a country index and $t$ a time index. The variables $\pi_{it}$, $\pi_{it}^{en}$, and $ygap_{it}$ are respectively inflation, energy price inflation and the output gap in country $i$ in period $t$. Since the dummy $D_t$ switches on in the Great Recession (Sept 2008 onwards) and the dummy $P_i$ switches on for the 'periphery' of the currency union (Portugal, Ireland, Italy, Greece and Spain), we can interpret the coefficients as a two dimensional matrix of Core/Periphery and Pre/Post crisis, giving four states of nature: Core pre-crisis, Core post-crisis, Periphery pre-crisis and Periphery post-crisis. This matrix, along with descriptions of the parameters' meanings, is presented in Table 1.

*(Insert Table 1 here)*

We used quarterly data from 2001 Q1 to 2014 Q4. The Euro was phased in between 1999 (electronic payments) and 2002 (notes and coins) and so we judged that the entry of Greece into the Euro zone in March 2001 was a reasonable cue.

Inflation ($\pi$) and energy price growth relative to trend ($\pi^{en}$) are both four-quarter-ended.[19] The output gap is a deviation of the log of GDP from an OLS trend. As a robustness check, we also obtained an annual output gap from the OECD, and smoothed it. We use our own quarterly series (the OLS residuals) but, as we shall see, the main results are robust to using the smoothed annual output gap figures.[20] As Figure 4 shows, movements in the two output gaps align fairly closely for most countries:

*(Insert Figure 4 here)*

Since (6) is non-linear in parameters, non-linear least squares is used for estimation. Results for five models are presented in Table 2. The last two columns are sensitivity analyses, where the model is run: without energy prices, and, with the smoothed OECD annual output gap (with energy prices put back in).

*(Insert Table 2 here)*

[19] The mean of four-quarter-ended energy CPI is subtracted from the raw series over March 2001 until December 2014.

[20] Data was collected from 1998, and four-quarter ended price changes therefore began in 1999. Initial attempts to map the annual output gap data from the OECD onto the quarterly OLS residuals of log output onto a linear trend from 1998 onwards ran into serious difficulties when the OLS residuals over 1998-2000 showed large negative gaps in Austria, France, Ireland, Italy, Luxembourg and the Netherlands, while the OECD ones showed positive or only marginally negative ones. In the end we used OLS residuals from 2001 based on a regression of log output on trend over the whole period, namely 1998-2014. These matched smoothed OECD annual figures well, where the smoothing was accomplished by letting the annual figure apply in each quarter of the year and then linking the December quarters by a linear trend. As can be seen in the chart, smoothing in this way seemed to match the peaks of the two output gap measures.

Model 1 in Table 2 provides estimates of parameters as they appear in (6). In order to be consistent with the IE theoretical model, we first need to verify that any coefficients of exogenous variables change by the same proportion when anchoring credibility is lost. This in turn implies testing $\theta_6 = \theta_9$ and $\theta_7 = \theta_{10}$. F-tests result in acceptance of both of these hypotheses ($p = 0.84$ and $p = 0.71$,respectively). Hence these two restrictions were imposed. Also, 2 percentage points were subtracted from the dependent variable to give a new regression equation (Model 2) in which the first four coefficients represent departures from the official target of 2 percent:

$$\begin{aligned} \pi_{it} - 2.0 &= \theta_1 D_t P_i + \theta_2 (1 - D_t) P_i + \theta_3 (1 - P_i) D_t + \theta_4 (1 - D_t)(1 - P_i) \\ &\quad + \frac{\theta_5}{1 - \theta_9 D_t - \theta_{10} D_t P_i} \pi_{it}^{en} + \frac{\theta_8}{1 - \theta_9 D_t - \theta_{10} D_t P_i} ygap_{it} + \eta_{it}. \end{aligned}$$

An F-test of the joint hypothesis $\theta_3 = \theta_4 = 0$ was applied to Model 2, and these restrictions were accepted ($p = 0.8143$). Hence these restrictions were imposed, leading to Model 3. The regression equation corresponding to Model 3 is as follows:

$$\begin{aligned} \pi_{it} - 2.0 &= \theta_1 D_t P_i + \theta_2 (1 - D_t) P_i \\ &\quad + \frac{\theta_5}{1 - \theta_9 D_t - \theta_{10} D_t P_i} \pi_{it}^{en} + \frac{\theta_8}{1 - \theta_9 D_t - \theta_{10} D_t P_i} ygap_{it} + \eta_{it}. \end{aligned} \quad (7)$$

We also assume 50 percent of agents target the null pre-crisis (represented by the parameter $\beta$), and then calculate the percentage remaining after the crisis.

In the context of (7), whose estimates appear as Model 3 in Table 2, we briefly weigh into a controversy about energy prices. We earlier claimed that energy prices are important for European inflation, but the question is how important. Following the oil price shocks in the 1970s, it has been standard to include oil or energy prices into Phillips curves worldwide (as Laubach and Williams, 2003, do in the US case). A range of justifications have been offered, as outlined by LeBlanc and Chinn (2004). An energy price shock might be inflationary via increasing input costs, or it may increase investment uncertainty, or it may reduce real money balances, or it may operate as a relative price shock leading to costly resource reallocation among sectors. All of these rely on a high degree of transmission of external shocks to the relevant CPI components. This is plausible in Europe because recent fine-grained research on disaggregated prices suggests that the CPI component of energy (around 10 per cent for Germany, Franc and Italy (OECD 2012)) is very responsive to oil price changes (Alvarez et al., 2006). Cuñado and Perez (2003) concur, finding a permanent effect on inflation of oil price changes.

Nevertheless, LeBlanc and Chinn (2004) caution that the size of the impact in Europe may have declined over recent decades. There are two special factors that in the past have been used to explain a heightened marginal impact of energy prices on European inflation. First, labour unions have historically been more powerful in Europe than in the United States, with unions more likely to extract higher wage concessions in response to rising consumer prices for energy. Second, since product market competition has been less intense, European producers may have been more likely to pass along wage costs to consumers in the form of higher prices. Many believe these special factors are no longer so important, implying a smaller energy price effect.

With regard to our preferred model (Model 3), we first note the plausibility of LeBlanc and Chinn's (2004) account of decline. Prior to the crisis, where we assume a steady state, the marginal impact of energy prices ($\theta_5$) is estimated to be around 3 per cent, which is not too far from LeBlanc and Chinn's suggested benchmark of the energy share of CPI (10 per cent), but low enough to render their account of declining union and increased product market flexibility plausible.[21]

We then estimated a Phillips curve without energy prices as a robustness test, even though this restriction would be rejected in our preferred Model 3.[22] We tested down the model to arrive at Model 4, which reassuringly gives the same broad narrative. Prior to the crisis, the countries in the periphery had underlying inflation at around one percentage point above the ECB target, and this was subsequently brought back to line after the crisis. Furthermore, agent's anchoring onto the target fell by around 79 per cent across the whole of Europe (core and periphery), which is approximately the same as the decline in the periphery in our preferred model.

Naturally, it is hard to argue for Model 4 econometrically since the restriction needed to create it is rejected by the data. Relatedly, the adjusted $R^2$, at 0.24, is less than half the adjusted $R^2$ for our preferred model (0.57).

This is fortunate because Model 3 has the additional advantage that we can test what must be assumed in Model 4. It will be recalled that the test for the operation of IE in the IE Phillips curve is that *multiple* parameters rise by the same proportion when agents abandon the null, and clearly this test needs more than one explanatory variable. Model 4 only has the output gap and therefore the IE interpretation of the Phillips curve is not falsifiable in the same way that it is for Model 3.

Another robustness test concerns the output gap. In Model 5 we repeat our analysis with the quarterly output gap based on smoothing the annual data. The results are in line with Model 3 and the adjusted $R^2$ is virtually identical. Interestingly, estimates of loss of anchoring credibility are somewhat smaller in this model. The core sees a decline in $\beta$ of 55 percent and the periphery sees a decline of 65 percent. We have a preference for Model 3, however, because a quarterly series for the output gap seems the most appropriate measure for a quarterly model. The robustness check is useful, however, both because the output gap confirms the broad shape of our own quarterly output gap and, as we have just seen, because the results are so similar.

A very useful feature of our specification is that information about inflation expectations is implicitly obtained using a single equation with observed inflation on the left hand side. This was made possible by our reliance on the model of Carroll (2003) who, using household survey data, showed that expectations are best summarized as infrequent rational expectations. This in turn made an inflation equation a natural home for inferential expectations (Menzies and Zizzo, 2009) which allowed us to build the IE Phillips curve. Thus, we did not need to include survey data or uncover inflation expectations from financial data, for example by deconstructing yield curves or comparing inflation-indexed bonds to non-indexed bonds. This opens up a host of possibilities when such data is not readily available or of poor quality.

[21] It would be unreasonable in our framework to discount their suggestion on the basis of the higher post-crisis parameter, since we have interpreted the rise as resulting from diminished anchoring.

[22] We are grateful to an anonymous referee for suggesting this.

## 5.2 Measuring Credibility

We are now in possession of our estimates for official targeting credibility and anchoring credibility, and we will use Model 3 to assess credibility in the Euro area following the crisis. With regards to the official target, the core countries never move significantly away from 2 percent, the officially announced target. The peripheral countries get closer, starting one percentage point above and ending up half a percentage point below the official target. Both results appear in the top row of Table 3.

*(Insert Table 3 here)*

With regard to anchoring credibility, the core countries saw a decline in the anchoring coefficient of nearly 70 per cent, and the peripheral countries saw a decline of nearly 80 per cent. Assuming $\beta$ starts out at 50 per cent, as a steady-state value, the estimates translate to a decline of 50 to 16 percent in the former case (the core) and 50 to 11 percent in the latter case (the periphery).

Finally, with regards to coherence credibility, we calculated the cross-country standard deviation of inflation for the core and periphery countries on a quarterly basis, creating a time series over the full sample. The change is insignificant over the crisis for core (dashed) countries, but significant for peripheral countries ($p = 0.0645$ and $p = 0.0071$). In the periphery, it steps from 0.7678 to 1.1801, but in the core the standard deviation is 0.6541, with no significant change estimated over the sample.

*(Insert Figure 5 here)*

Our main results are summarized in two credibility cubes below, where the axes are defined in the same way as they were introduced. The standout result of policy relevance is that there is a lowering of anchoring credibility by well over one half in both the core and periphery.

*(Insert Figure 6 here)*

# 6 Discussion and Conclusion

We have shown the usefulness of considering credibility along three dimensions: official target credibility, cohesion credibility and anchoring credibility.

The IE-based Phillips curve provides a plausible mechanism why some explanators in regressions can seem to be unimportant most of the time, but then, as if suddenly, they become a major driver of a crisis. That is, equations like (2) have the property that whenever agents become detached from a null belief (the status quo), they attach more importance to other sources of information. Our IE model delivers an endogenous and accentuated marginal impact, relying on the insight that regression variables are not just causal factors—they are also, by virtue of this fact, sources of information for those who must form expectations about the LHS variable. If the explanators in question are normally small, and undetectable by econometric means, they can become significant in a crisis, as agents turn away from trusting the central bank, or some other source of a status quo, towards their own (or experts') analysis of information. In this way our model departs significantly from other models that combine rational expectations with naïve expectations, and turns towards what Vines and Wills (2018) sense is a realistic property for macroeconomic models during crises. It is an innovation that ought to prove useful in many other applications and contexts.

Our analysis of the Euro area has shown that, as a result of the Great Recession and the sovereign debt crisis, there is no evidence for an erosion of official target credibility in the Euro area: the ECB's official target of (just below) 2 percent is still credible in the sense that $H_0$ agents believe the central bank will achieve this.

However, despite these positives, we have found evidence of an erosion of anchoring credibility, not only in the periphery of the Euro area. The estimation of anchoring credibility, using only a single reduced-form equation, was made possible by incorporating IE into a standard macroeconomic model of aggregate supply. In our preferred Model 3 the loss is 70 per cent in the core, and in our next most preferred Model 5 it is 55 per cent.

Our result is consistent with Natoli and Sigalotti (2017) who, after constructing a new indicator of inflation expectations anchoring, argue that the risk of de-anchoring in the Euro area rose significantly after the GFC, and remains high and volatile to this day, while inflation expectations in the US and the UK remain firmly anchored.[23] But the firmest backing comes from Dovern and Kenny (2017) who, studying individual density forecasts from the ECB Survey of Professional Forecasters, state that:

> "the level of long-term inflation expectations remains aligned with the ECB's quantitative definition of price stability. However, the shifts in higher moments indicate a change in the degree to which inflation expectations are anchored, i.e. in how tightly they are anchored at that level."

Similar findings were presented by Scharnagl and Stapf (2011), using a different methodology and data set, as well as van der Cruijsen and Demertzis (2011) who find that, on average, expectations of national inflation rates appear to have become less anchored than expectations of Euro area average inflation. Buono and Formai (2018), too, found that Euro area inflation expectations became less anchored post-GFC.

A theoretical model, broadly consistent with the above results, is presented by Busetti et al. (2017). They analyze how a prolonged period of subdued price developments may induce de-anchoring of inflation expectations from the central bank's inflation target. In their small-scale New Keynesian model agents form expectations

[23] Mehrotra and Yetman (2018a,b) study long-run inflation expectations using forecast behaviour since 1990. In Mehrotra and Yetman (2018a) it is argued that 'inflation expectations have become more tightly anchored over time', yet 'the level of the anchor has fallen'. In Mehrotra and Yetman (2018b) the authors find that, 'the estimated anchor of inflation forecasts is close to the announced inflation target' and 'any deviations between the estimated anchor and the target tend to be short lived.' While interesting, their results and ours cannot be readily compared because we are comparing behaviour of inflation expectations in Europe since the Great Recession in 2008, whereas they are generalizing about worldwide [TIMO CHECK] inflation targeting since 1990.

using adaptive learning in which a sequence of deflationary shocks elicits two responses, a reduction in agents' perception of the inflation target as well as in the share of agents selecting a naïve, backward-looking forecasting model.

We thus conclude that beliefs about the European Central Bank's inflation target have increasingly converged to the official 2 percent target as the actual target. This was always accepted (in our sample) in the core, but prior to the crisis agents in the periphery believed the ECB acquiesced to something more than 2 percent, and after the crisis they believed the ECB would acquiesce to something a little less. However, while it is widely believed that the ECB targets (close to) 2 percent, attachment to this target has weakened, particularly in countries which have been or are under financial and fiscal stress. Nowhere has this been more apparent than in Greece, but our results are applicable to the periphery countries more generally.[24] We leave to future research the task of detailing mechanisms that connect financial and fiscal stress to the loss in anchoring credibility, a problem of increasing importance for the periphery countries, especially Italy. Attachment to the ECB's policies, especially its inflation target, plausibly depends on the prospect of each country remaining in the European Monetary Union. So, while the retention of official target and cohesion credibility will be welcomed by proponents of the Euro project, the loss of anchoring credibility in the financially weaker countries still generates some uncertainty for the continued existence of the common currency.

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**Table 1: Matrix of Model Parameters**

| | $P=0$ Core | | $P=1$ Periphery | |
|---|---|---|---|---|
| | $D=0$ Pre | $D=1$ Post | $D=0$ Pre | $D=1$ Post |
| Predicted inflation when $\pi^{en}=ygap=0$ | $\theta_4$ | $\theta_3$ | $\theta_2$ | $\theta_1$ |
| Impact of energy price inflation on inflation | $\theta_5$ | $\theta_5/(1-\theta_6)$ | $\theta_5$ | $\theta_5/(1-\theta_6-\theta_7)$ |
| Impact of output gap on inflation | $\theta_8$ | $\theta_{8/(1-\theta_9)}$ | $\theta_8$ | $\theta_8/(1-\theta_9-\theta_{10})$ |

**Table 2: Nonlinear Least Squares Estimates of 5 Models**

| | MODEL 1 | MODEL 2 | MODEL 3 | MODEL 4 | MODEL 5 |
|---|---|---|---|---|---|
| Dependentvariable | $\pi$ | $\pi-2.0$ | $\pi-2.0$ | $\pi-2.0$ | $\pi-2.0$ |
| Output gap | ols resid. | ols resid. | ols resid. | ols resid. | OECD |
| | | | | | |
| $\theta_1$ | 1.541*** | -0.464** | -0.463** | | |
| | (0.215) | (0.206) | (0.205) | | |
| $\theta_2$ | 3.080*** | 1.071*** | 1.076*** | 1.024*** | 1.029*** |
| | (0.253) | (0.232) | (0.230) | (0.234) | (0.208) |
| $\theta_3$ | 1.939*** | -0.044 | | | |
| | (0.117) | (0.127) | | | |
| $\theta_4$ | 1.937*** | -0.066 | | | |
| | (0.110) | (0.102) | | | |
| $\theta_5$ | 0.034** | 0.034*** | 0.032*** | 0 imposed | 0.049*** |
| | (0.013) | (0.010) | (0.010) | | (0.009) |
| $\theta_6$ | 0.671*** | | | | |
| | (0.120) | | | | |
| $\theta_7$ | 0.090** | | | | |
| | (0.037) | | | | |
| $\theta_8$ | 0.021 | 0.023*** | 0.022** | 0.033* | 0.052*** |
| | (0.020) | (0.007) | (0.007) | (0.016) | (0.008) |
| $\theta_9$ | 0.595 | 0.668*** | 0.687*** | 0.785*** | 0.552*** |
| | (0.431) | (0.086) | (0.085) | (0.083) | (0.075) |
| $\theta_{10}$ | 0.196 | 0.099** | 0.091** | | 0.105* |
| | (0.267) | (0.034) | (0.032) | | (0.057) |
| | | | | | |
| $n$ | 672 | 672 | 672 | 672 | 672 |
| $R^2$ | 0.8760 | 0.6042 | 0.6033 | 0.3032 | 0.6320 |
| Adjusted $R^2$ | 0.8748 | 0.5682 | 0.5672 | 0.2398 | 0.5985 |

Notes: Non-linaear least squares estimates of five models. Standard errors clustered by country. *** strongly significant (p<0.01); ** significant (p<0.05); * marginally significant (p<0.10). $R^2$ in MODEL 1 not comparable to that from others models because dependent variable is different.

**Table 3: Numerical Estimates of Parameters Listed in Table 1**

| | $P = 0$ Core | | $P = 1$ Periphery | |
|---|---|---|---|---|
| | $D = 0$ Pre | $D = 1$ Post | $D = 0$ Pre | $D = 1$ Post |
| Predicted inflation when $\pi^{en} = ygap = 0$ | 2 | 2 | 3.07<br>(0.23) | 1.53<br>(0.21) |
| Impact of energy price inflation | 0.03<br>(0.009) | 0.10<br>(0.007) | 0.03<br>(0.009) | 0.14<br>(0.02) |
| Impact of output gap | 0.02<br>(0.007) | 0.07<br>(0.017) | 0.02<br>(0.007) | 0.10<br>(0.017) |
| Anchor onto null | $\beta = 0.50$ | $\beta\,(1 - \theta_6) = 0.16$<br>(0.04) | $\beta = 0.50$ | $\beta\,(1 - \theta_6 - \theta_7) = 0.11$<br>(0.03) |

Standard errors in parantheses (obtained using the delta method).

**Figure 1: $\chi^2$ Distribution**

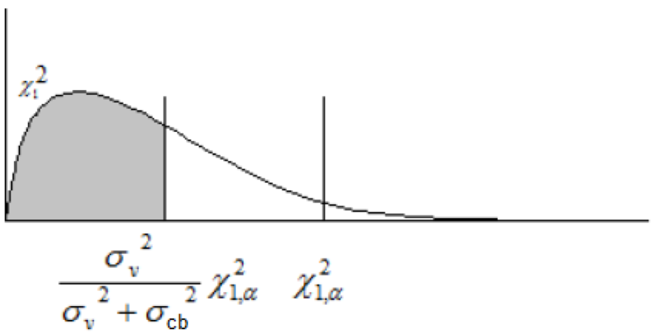


**Figure 2: The Credibility Cube**

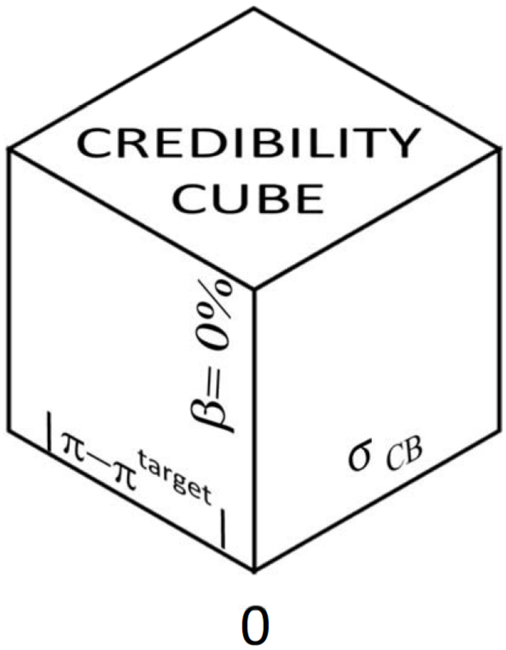

**Figure 3: Four-Quarter-Ended Inflation (in percent)**

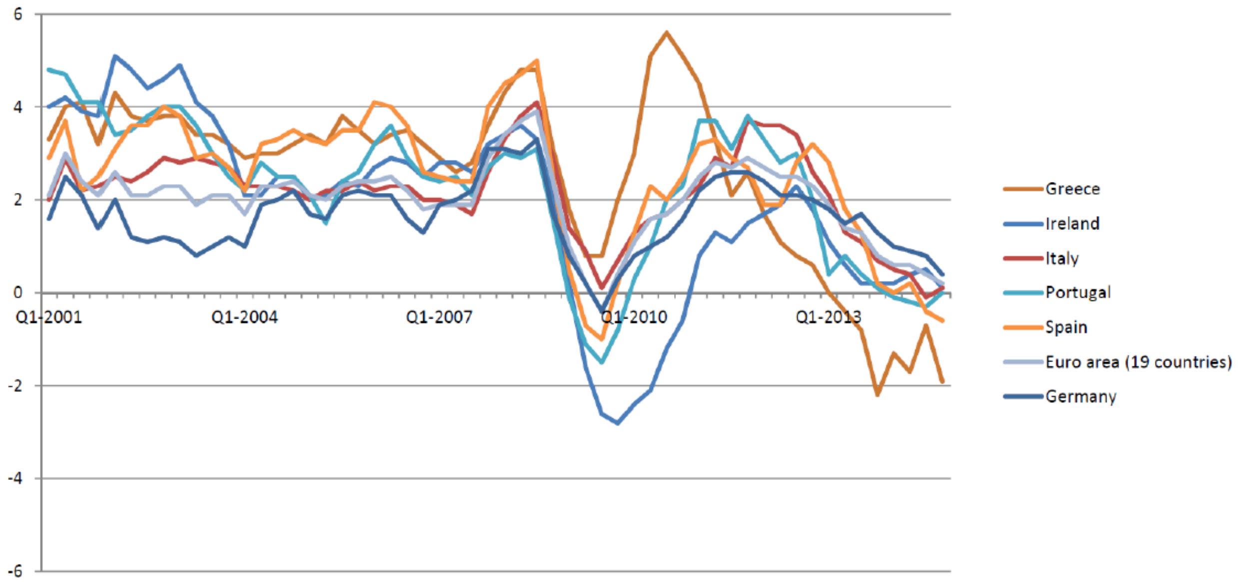


**Figure 4: Output Gaps, OLS and OECD Measures**

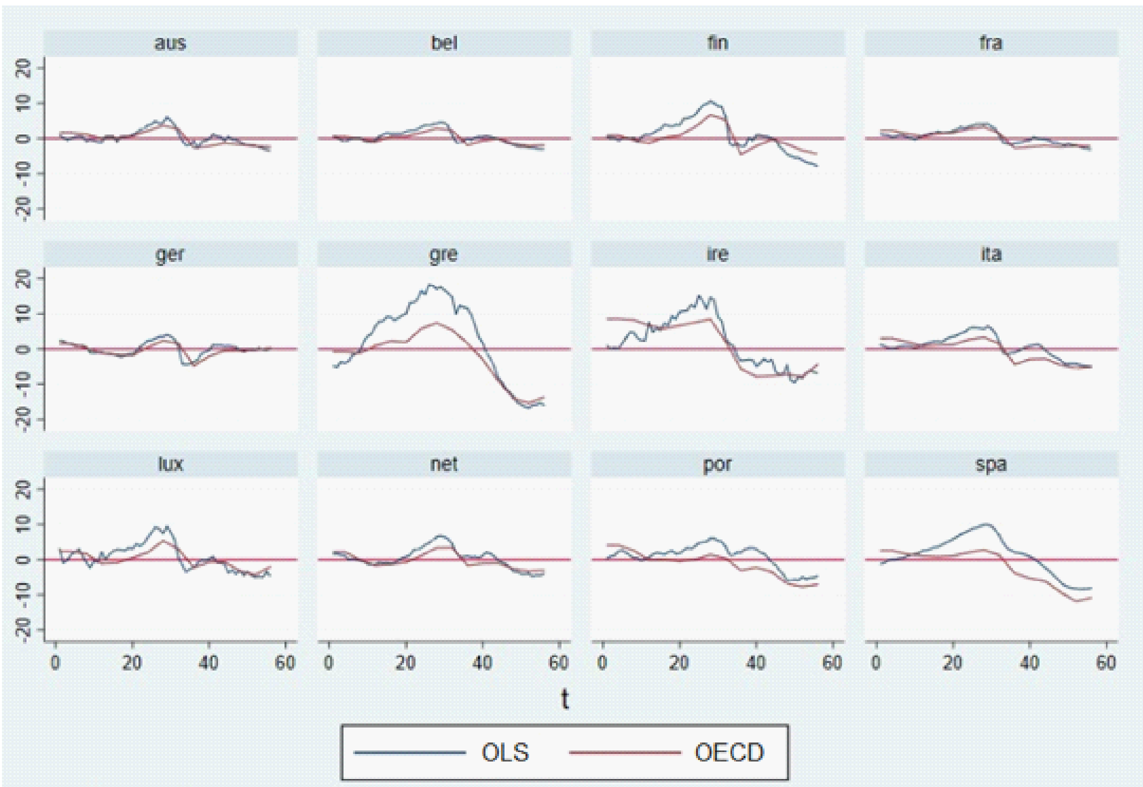

**Figure 5: Cross-Country Standard Deviations of Inflation**

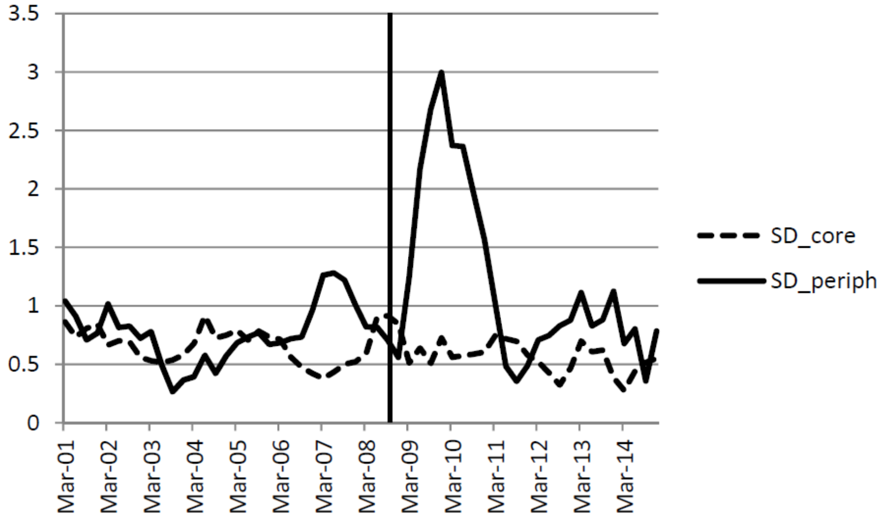


**Figure 6: Changes in Credibility Mapped Into the Credibility Cube**