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Are Central Bank Monetary Policy Reactions Asymmetric? The Case of the ECB

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Abstract

A large number of central banks make decisions according to specific targets, mainly in the areas of inflation and economic growth. The question we ask ourselves is whether their reactions are as intense when deviations from those targets are positive, compared to when they are negative, or, by the contrary, the reactions are asymmetric. To respond, based on Taylor's hypotheses about the monetary policy reaction function, we analyze the possible causes of asymmetric behavior and establish a methodology to determine whether central bank decisions have been asymmetric or not. Empirically, we analyze the case of the European Central Bank (ECB), concluding that in its case, it is not possible to affirm that it reacted asymmetrically from 1999 to 2008.

JEL **Classification**: E52, E43, E58, E51.
Key words: central bank, rules, asymmetries, inflation.

Introduction

This article is part of the line of research about monetary policy strategies followed by central banks. It is important to know in the greatest detail possible the monetary policy decision-making strategy of any central bank, since the more transparent the strategy, the more effective the monetary policy will be. This is the case because the central bank's changes in interest rates will be more fully and rapidly transmitted to the different maturity rates, and inflation expectations will also be better anchored. Thus, economic agents will face their decisions in a less uncertain context.

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The analysis of a central bank's monetary policy strategy through estimating its reaction function is a fully consolidated methodology. With its application in this article, we attempt to detect the possible presence of asymmetries in monetary policy decisions made in the concrete case of the European Central Bank. That is, we attempt to determine if the reactions are more or less intense when deviations are produced —whether positive or negative— in inflation and output with regard to their targets. Given that this article is not about estimating weighting in the loss function, but detecting asymmetric behavior, it is not necessary to use a structural approach (see, for example, Aguiar and Martins [2008]).

The logical basis for this proposal implies that the central bank will change the interest rate following the principle formulated by Taylor (1993). But the additional question that occupies us here consists of discovering whether it will react with the same or different intensity (asymmetrically, in the latter case) if inflation exceeds its target, compared to a case in which inflation is lower than the target. We can also say the same with regard to the deviations of real output from its trend: that is, if it reacts in the same way given positive deviations or negative deviations. The causes of the hypothetical asymmetric behavior might be found in the central bank's preferences or in the characteristic that the inflation/output gap relationship shows in the economy in reality.

From the empirical point of view, this reasearch's main contribution regarding this supposed asymmetric behavior will be to show whether this has been the concrete case of the ECB, and the possibility of this method also being applied to other central banks. It will also contribute significantly to understanding better the monetary policy strategy followed over recent years by this central bank, which at first seems to have tried to carve out for itself an anti-inflationary reputation, which would lead one to think, *a priori*, of the existence of asymmetric behavior. The hypothetical presence of asymmetric forms of behavior would be very important for the real economy since the ECB's stabilizing activity would be more energetic the larger the deviations were. This would subject real productive activity to greater stress, with the resulting dysfunctionalities that this could bring with it for economic agents.

To carry out the analysis proposed, in the next section we debate the impact of asymmetries on monetary policy reactions, commenting on other published contributions. Then, we model the reaction function on the basis of diverse hypotheses and study the convexity of the Phillips curve. In the following

section, we continue with the empirical analysis. First, we analyze whether the Phillips curve is convex or not; then, we study the linear or asymmetric nature of the BCE's monetary policy reaction function in the first decade of its operations. And finally, we offer some conclusions.

Asymmetries in the central bank's monetary policy reaction

We will begin by pointing out that, in principle, two sources of asymmetric behavior can be considered for a central bank's monetary policy interventions: those linked to policy preferences, and those related to the slope of the trade-off between inflation and the output gap, that is the Phillips curve.

With regard to the first kind, when defining the central bank's loss function, it is often assumed that the deviations from the target inflation rate and the deviations from the level of natural output, whether they are positive or negative, are equally costly. According to Rotemberg and Woodford (1999), this is consistent with a reasonable approximation of an underlying function of well-being based on utility. However, in the short term, we can find that with the sacrifice that deflation supposes, if it is important to the central bank, it will assign greater importance to negative deviations. This could presuppose, for example, alterations in the usual loss function:

$$L(\tilde{\pi}_t, \tilde{y}_t) = \frac{1}{2}\left[(\tilde{\pi}_t)^2 + \lambda(\tilde{y}_t)^2\right] \qquad [1]$$

in which $\tilde{\pi}_t$ is the deviation of inflation from the target; $\tilde{y}_t$ is the output gap, habitually the deviation of the real gross domestic product (GDP) growth rate from its trend. The transformation suggested leads to the result that the appropriate inflation rate can be higher than the target in order to lower the employment sacrificed, even if in the long term there is no trade-off between inflation and output.

Nevertheless, this symmetry in preferences can be questioned if the target inflation rate consists of a band of fluctuation around a central value (whose width depends positively on λ) instead of being focalized on a single point. Thus, according to Orphanides and Wieland (2000), if the central bank has set a target in the form of a band, when inflation is relatively close to the center of the band, the only concern for monetary policy is to fix the interest rate that will allow for

stabilizing output. On the other hand, if the central bank observes that inflation tends to be higher than the band width, the interest rate will be readjusted to avert that. With its numerical model, which incorporates non-quadratic preferences, a non-linear Phillips curve, and no delay in the transmission of the deviation from the output gap to prices, these authors detected that uncertainty about unexpected shocks has important effects on the width of the target band and the relative size of policy responses within and outside the band. This means that the rule of optimum policy with uncertainty does not induce a mechanical response solely when inflation is outside the band, but increases the intensity of the response progressively to make it more aggressive the higher the risk of going beyond the confines of the band.

Linked to the contribution of Orphanides and Wieland (2000), the work by Medina and Valdés (2002), with a two periods lagged monetary policy, confirms the tendency to change the interest rate even if the inflation rate is within the target band width. But they consider the asymmetry in preferences thinking that positive deviations in inflation are more costly than negative ones; that is, they give more weight to positive deviations from inflation in the loss function.

Surico (2007a) deals with the issue focusing on the asymmetric preferences, and comes to the conclusion that, in the case of the Federal Reserve, preferences were only asymmetric before 1979, and that its responses to contractions in output were comparatively greater than to expansions of output of the same magnitude. Surico (2007b) himself researches the possible existence of asymmetry in the ECB's policy rule. His main results show that deviations in inflation are followed by similar responses in the interest rate, while reactions to deviations in the output gap are associated with asymmetric preferences.

Other works of theoretical and empirical research are also in line with this: Dolado, María-Dolores, and Ruge-Murcia (2002) discovered asymmetric preferences in the Federal Reserve in Wolcker-Greenspan period; Cukierman and Muscatelli (2008) found evidence that the changes in the United Kingdom's central bank's policy rule, under an inflation-targeting regime, were due to modifications in preferences rather than alterations in the curvature of the Phillips curve —similar results were obtained for the case of the Federal Reserve; Vasicek (2011) put forward empirical strategies that made it possible to discover to what degree the asymmetries —if they exist— originate in the central bank's loss functions.

On the other hand, with regard to the trade-off slope between inflation and the output gap, according to Dupasquier and Ricketts (1998), several analyti-

cal models suggest an asymmetric relationship between both. One of those models emphasizes the role of capacity restrictions, that is, the fact that some companies may have difficulties in increasing their production capacity beyond a certain limit in the very short term. As a result, the Phillips curve will be convex: when aggregate demand increases, the impact on inflation will tend to be greater than when it is low; and, in turn, this non-linearity can imply asymmetric responses in monetary policy; changes in the interest rate will have to be bigger in the face of deviations above the target than in the opposite case. According to Schaling (2004), this means that the interest rate reaction function would be asymmetric and would in general imply a higher interest rate than the reaction function deduced by Svensson (1997).

For the case of a tight inflation target, Schaling (2004) shows that positive deviations imply greater changes in the interest rate in absolute value than do negative deviations. In addition, he shows that interest rate hikes in the face of a positive disturbance in output are greater than those that would be implemented with a linear reaction function; from this, it can be deduced that these linear reaction functions infra-estimate appropriate interest rate levels.

Later, Dolado, Maria-Dolores, and Naveira (2005) deepened this analysis and generalized Schaling's model considering the case in which the central bank's loss function also included the stabilization of output; that is, the case of loose inflation targeting. They focus on the analysis of the existence of convexity in the Phillips curve,[1] and they come to conclusions similar Schaling's in the sense that inflation's deviations above the target lead to growing increases in real interest rates, while for those below the target, the drops in the real interest rate decline in intensity. Empirically, they confirm the existence of this asymmetric behavior in the case of European central banks for different sample periods beginning in the 1980s, while the case of the U.S. Federal Reserve is an exception to this form of behavior. They use two procedures for this analysis: the first consists of estimating the Taylor rule with inflation expectations, to which they add a multiplier term (interaction term) of the expected inflation

[1] According to their analysis, this can be found in the countries that belong to the European Monetary Union, but they do not find it in the case of the United States. On the contrary, what they do detect in another paper (Dolado, Maria-Dolores, and Ruge-Murcia, 2002) is the existence in the U.S. of asymmetric preferences. This difference is supported by the presence of greater rigidities in European labor markets.

by output gap. And the second is based on a probit model that captures the discreet nature of the changes in the interest rates, which they use to model the probability that the central bank will intervene according to its perception of the state of the economy, including again a multiplier term in which inflation and the output gap interact.

From a theoretical point of view, other works can also be examined that justify the possible existence of asymmetries. This includes the work of Kahneman and Tversky (1979), Persson and Tabellini (1999), Erosa and Ventura (2002), Nobay and Pell (2003), and Galí and Gertler (2007). More empirically, aside from those mentioned above, other work that can be reviewed is that of Cukierman and Muscatelli (2002); Martin and Milas (2004); Ruge-Murcia (2003); Cukierman and Gerlach (2003); Altavilla and Landolfo (2005); Kim, Osborn, and Sensier (2005); and Klose (2011).

Modeling the asymmetries in the monetary policy reaction function

As we already stated, the aim of this article is to study whether a central bank has exhibited asymmetric behavior in making decisions about interest rates. Our starting point is that its fundamental aim is price stability, which may be concretized in an inflation target. In addition, economic activity will also influence monetary policy decisions, even if only due to its relation to prices. In other work, as can be seen in García-Iglesias, Pateiro and Salcines (2011), the basic theoretical model used is intertemporal and is part of the interest-rate rules stream. More concretely, it is part of Clarida, Gali, and Gertler's contribution (1998):

$$i_t^* = \bar{\iota} + a\left[E_t(\pi_{t+k}|\Omega_t) - \pi^*\right] + b\left[E_t(y_{t+j}|\Omega_t) - y_{t+j}^*\right] + cE_t\left[z_{t+g}|\Omega_t\right] \qquad [2]$$

where i^* is the nominal, short-term interest rate set by the central bank; $\bar{\iota}$, the nominal equilibrium interest rate, which is equivalent to $\bar{i} = \bar{r} + \pi^*$, when $\bar{r}$ is the real equilibrium interest rate and π^* the inflation target; y_t is an indicator of real economic activity, usually the real GDP growth rate, and y_t^* is its trend; E_t is the expectations operator, and Ω_t is a vector that includes information the central bank has during the time period t; and z_t is a vector containing other

hypothetically explanatory variables of the monetary policy followed. The temporal sub-indices k, j, g can be positive or negative, meaning that the model can be forward-looking or backward-looking. At the same time, this model could be broadened out by incorporating the smoothing hypothesis in the central bank's interest-rate modifications.[2] Nevertheless, another option is to do without the partial adjustment term, supposing that $\rho = 0$ in some of our estimates.

We suppress the unobserved variables so that:

$$i_t^* = \bar{\iota} + a\left[\pi_{t+k} - \pi^*\right] + b\left[y_{t+j} - y_{t+j}^*\right] + cz_{t+g} + \varepsilon_t \qquad [3]$$

in which:

$$\begin{aligned}\varepsilon_t = v_t - a\left[\pi_{t+k} - E_t(\pi_{t+k}|\Omega_t)\right] + b\left[y_{t+j} - E_t(y_{t+j}|\Omega_t)\right] \\ + c\left[z_{t+g} - E_t(z_{t+g}|\Omega_t)\right]\end{aligned} \qquad [4]$$

Taking as a given that when the central bank decides interest rates, it behaves rationally in pursuing its targets, the previous specification formally corresponds to a proposal of minimization of a loss function; that is, intertemporally, the central bank's problem in the case in which it is focusing on achieving its inflation target is, then,

$$\underset{i_t}{Min}\, E_t \sum_{s=0}^{\infty} \delta^s L\left(\pi_{t+s} - \pi^*\right)$$

where $\delta \in [0,1)$ is a discount factor.

If the partial adjustment of the interest rate is taken into account, the monetary policy reaction function will definitely be:

$$\begin{aligned}i_t = (1-\rho)(\bar{\iota} - a\pi^*) + (1-\rho)a\pi_{t+k} + (1-\rho)[b(y_{t+j} - y_{t+j)}^*)] \\ + (1-\rho)cz_{t+g} + \rho i_{t-h} + \varepsilon_t^{'}\end{aligned} \qquad [5]$$

[2] With that, we would have $i_t = (1-\rho)i_t^* + \rho i_{t-h} + v_t$, where v_t is a random disturbance and ρ indicates the degree of smoothing.

On the other hand, if we eliminate the partial adjustment and z and suppose that the trend growth rate is constant, separating the variables from the target values, the monetary policy reaction function to be estimated would be the following:

$$i_t = (\bar{\iota} - a\pi^* - by^*) + a\pi_{t+k} + by_{t+j} + \varepsilon_t \qquad [6]$$

For the entire proposition we have just presented, linear behavior is the underlying hypothesis, since, as we have deduced, the monetary policy reaction function is linear, giving rise to symmetric decisions about the interest rate, regardless of whether the deviations from inflation and output targets are positive or negative.

But, as indicated above, a central bank's reaction function can be asymmetric, whether because it has asymmetric preferences or because of the existence of a non-linear Phillips curve. Our empirical work centers on contrasting the possible existence of asymmetries in ECB decisions that are rooted in a non-linear relationship between variations in inflation and output, that is, the possible existence of a non-linear Phillips curve, along the lines of the work by Dolado, Maria-Dolores, and Naveira (2005).

So, we will use a quadratic loss function as in equation [1]:

$$L(\tilde{\pi}_t, \tilde{y}_t) = \frac{1}{2}\left(\tilde{\pi}_t^2 + \lambda\tilde{y}_t^2\right)$$

where, as we said, $\tilde{\pi}$ and $\tilde{y}$ are, respectively, the deviations of inflation and the output gap, and $\lambda > 0$ is a measure of the weighting the central bank gives to economic activity. The evolution of the economy is characterized by a convex relationship between variations in inflation and the output gap described by the Phillips curve (or the curve of aggregate supply):

$$\Delta\pi_t = \alpha\tilde{y}_{t-1} + \alpha\theta\tilde{y}_{t-1}^2, \tilde{y}_t > -\frac{1}{2\theta} \qquad [7]$$

and by an IS curve that describes a slow adjustment in the output gap according to the equation:

$$\tilde{y}_{t+1} = \beta\tilde{y}_t + \mu x_t - \xi r_t + u_{\tilde{y},t+1} \qquad [8]$$

where r is the real interest rate: $r_t = i_t - E_t \pi_{t+1}$. For its part, x_t captures other variables that determine the interest rate, like, for example, the exchange rate, the budget balance, etc.

Just like in Svensson (1997), interest-rate variations affect output with a one-period time lag, and the latter affects inflation with another period time lag. The transmission process, which can be described as $\Delta i_t \rightarrow \Delta y_{t+1} \rightarrow \Delta \pi_{t+2}$, has to be highlighted to obtain the Euler equation as a result of minimizing the present value subtracted from the losses, period by period of function [1], that is, making the following a minimum

$$E_t \sum_{s=0}^{\infty} \delta^s L(\tilde{\pi}_{t+s}, \tilde{y}_{t+s}) \qquad [9]$$

As shown in Appendix, the interest rate rule takes the form:

$$i_t = c_1 E_{t-1}\tilde{\pi}_{t+1} + c_2 E_{t-1}\tilde{y}_t + c_3 E_{t-1} x_t + c_4 E_{t-1}(\tilde{\pi}_{t+1}\tilde{y}_t) \qquad [10]$$

where the coefficients c_i are a function of the structural parameters (δ, α, λ, μ, θ, ξ, and β), as explained in Appendix. If we replace the expectations about inflation and the output gap with effective values, it gives us the optimum rule for the interest rate, which we will contrast in this article with the generalized method of moments (GMM):

$$i_t = c_0 + c_1\tilde{\pi}_{t+1} + c_2\tilde{y}_t + c_3 x_t + c_4(\tilde{\pi}_{t+1}\tilde{y}_t) + v_t \qquad [11]$$

Equation [11] is a modified Taylor rule. Just as with the Taylor rule in equation [6], the reaction function [11] is linear with regard to the inflation, output gap, and x variables. But, in addition, it presents the term of interaction or rectangular component between the expected deviation from inflation and the output gap [$c_4(\tilde{\pi}_{t+1}\tilde{y}_t)$]. If the Phillips curve is convex ($\theta > 0$; $c_4 > 0$),[3] the central bank will react more sharply than if it is concave ($\theta < 0$; $c_4 < 0$), given the future inflationary pressure caused by the larger output gap —we should remember that, like in Svensson (1997), $\Delta i_t \rightarrow \Delta y_{t+1} \rightarrow \Delta \pi_{t+2}$.[4] If the Phillips

[3] See Appendix.

[4] For a fuller explanation, see Dolado, Maria-Dolores, and Naveira (2005).

curve is linear ($\theta = 0$), then $c_4 = 0$, and the reaction function of equation [11] will be a linear Taylor rule. In this way, the term of interaction in the Euler equation allows us to determine the existence of asymmetry in the central bank reaction function.

The empirical work

As indicated above, asymmetry in a central bank's behavior can stem from the existence of a convex Phillips curve or from asymmetrical preferences. Our empirical work in this article consists of contrasting first of all the possible convexity of the Phillips curve in equation [7] for the period 1999:1 to 2007:4,[5] and secondly, the existence of asymmetry in ECB decisions about the interest rate. The presence of this potential asymmetry will be analyzed using equation [11], but without the exogenous x_t variable and incorporating smoothed interest rate behavior, that is, as shown in equation [12]. As will be explained, we adopt four-quarters forward-looking behavior for the inflation deviation and one-quarter backward-looking behavior for the output gap. Therefore, the concrete equation to estimate through the GMM is:

$$i_t = cte + c_1\tilde{\pi}_{t+4} + c_2\tilde{y}_{t-1} + c_3(\tilde{\pi}_{t+4}\tilde{y}_{t-1}) + \rho i_{t-1} + v_t \qquad [12]$$

Is the Phillips curve convex?

Following a similar proposal to that of Dolado, Maria-Dolores, and Naveira (2005), we have contrasted by using ordinary least squares (OLS) the possible convexity of the Phillips curve for the euro zone in the periods from 1999:1 to 2007:4 and 1999:1 to 2008:4.[6] The output is the GDP, and the natural level of the output is the Hodrick-Prescott (HP) filter, with a coefficient of 1:600. The product gap is calculated as the difference between the GDP logarithm and its HP trend. For prices, we used the euro zone GDP deflator. All the series of data are seasonally adjusted.

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[5] In the period from the end of 2008 to 2011, the ECB made extraordinary decisions about the system's liquidity and the interest rate that are very far from a systematic strategy oriented toward price stability or stabilizing production; this is why including it in this work would notably disturb the results

[6] Extending the period to 2008:4 has the intention of detecting if the ECB's "non-rule" behavior in the face of the financial and economic crisis could have modified the results, as actually happened.

The equation to be estimated is equation [7]: $\Delta\pi = \alpha\tilde{y}_{t-1} + \alpha\theta\tilde{y}_{t-1}^2 + \varepsilon_{\pi,t}$. When $\alpha > 0$, the Phillips curve will be convex if $\theta > 0$,[7] and concave in the opposite case. The linearity of the Phillips curve is recovered if $\theta = 0$.

In the period from 1999:1 to 2007:4, $\theta = -0.25$ is negative and not significant ($p = 0.265$). The Phillips curve in this period would approximate more a concave than a convex form. Nevertheless, since the concave form is not significant, we rather consider a linear relationship between inflation and output.[8] The results for the period from 1997:1 to 2008:4 do not undergo significant modifications.

If we replace the quarterly GDP data with monthly figures for the industrial production index (IPI) for output,[9] and with underlying inflation figures in the case of prices, the results for the period from 1999:1 to 2007:12 allow us to again reject the convexity of the Phillips curve in the euro zone for the period. As in the previous case, θ takes on negative values and is not significant ($p = 0.35$). Similar results are obtained for the period that includes 2008.

Is the ECB reaction function asymmetric?

To contrast equation [12], we use quarterly data for our periods of analysis, ranging from the first quarter of 1999 to the fourth of 2007, and from the first of 1999 to the fourth of 2008. The sources are Eurostat and the ECB, with data adapted to the successive incorporation of countries into the euro area.

For the interest rate variable, we used the ECB's official, or base interest rate, equivalent to the minimum main refinancing operations rate (MRO), as the fundamental indicator of its monetary policy, taking into account the last quarterly data observed.

For the inflation rate we used the core inflation rate, that is, the rate that excludes the prices of energy and unprocessed foods from the Harmonized Index of Consumer Prices (HICP), obtained from Eurostat. We will use this se-

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[7] In effect, with $\alpha > 0$, $\frac{\partial^2 \Delta\pi_t}{\partial y_{t-1}^2} = 2\alpha\theta > 0 \Leftrightarrow \theta > 0$.

[8] As will be seen in tables 1 and 2, this result is compatible with the lack of significance of the coefficient c_3 in equation [12].

[9] In this case, the evolution of output is measured by the IPI, adjusted seasonally: the output gap is the difference between the IPI logarithm and its HP trend (coefficient 14.400).

ries because, as shown in García-Iglesias (2007) and García-Iglesias and Pateiro (2009), it adequately explains ECB decisions. Just as in the previous case, we use a quarterly frequency, taking into account the last data. For the output gap, we utilize the same definition that we presented in the previous section.

In terms of the method used to estimate the parameters of the monetary policy reaction function, since we are making an intertemporal analysis, we must focus on the GMM, in it there is an underlying element of a rational, intertemporal optimizing behavior approach, which is what we suppose the central bank follows when it decides on the interest rate, controlling inflation with regard to a target value and also trying to help achieve economic stability. As is well-known,[10] once the relations among the variables are deduced, with this method, we obtain the "deep" parameters that describe the central bank's monetary policy reaction function preferences, fulfilling the conditions of orthogonality among the adjustment residuals and the information available to it when it decides the interest rate.

As instrumental variables, we use a constant and the variables involved in the reaction function lagged by –1 to –3 quarters, that is, the interest rate, the inflation rate, and the output gap, according to the behavior observed throughout the preceding year.

With regard to the degree of stationarity of the series, as has been argued elsewhere,[11] in the case of short samples like this one, the usual tests are biased against the alternative hypothesis of stationarity at their level. For this reason, taking into account the context of stability in which our analysis is situated, we suppose that the conditions required for making the estimates through the GMM exist. To contrast the validity of the instruments used, we will take into account the *p*-value of the J statistic with Sargan's test. The J statistic reported by Eviews 4.1 is divided among the number of observations, so that to be able to calculate J's *p*-value, that is the probability of making a type-I error by rejecting the hypothesis of the validity of the instruments, we must multiply it by the number of observations.

By making these adjustments, taking into account the results obtained in the works cited by García-Iglesias (2007), García-Iglesias and Pateiro (2009), and García-Iglesias, Pateiro, and Salcines (2011), we adopt the criteria that when

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[10] See, for example, García-Iglesias (2007).

[11] See, for example, García-Iglesias, Pateiro, and Salcines (2011).

the ECB decides on the interest rate, it takes into account inflation four quarters in advance and GDP growth delayed one quarter; that is, it acts in a forward-looking manner with regard to core inflation and a backward-looking manner with regard to growth in output.

On the other hand, taking as a given that the ECB follows a smoothing strategy as we have commented above,[12] initially, in the adjustments presented in table 1, we do the estimations without the partial adjustment term in order to better detect the degree of influence of the two variables we are taking into account in the ECB monetary policy reaction function: inflation, as seen through core inflation, and the output gap. Given that our research attempts to detect asymmetric behavior when the ECB changes the short-term interest rate, we estimate equation [12] to be able to contrast whether the c_3 coefficient corresponding to the rectangular term $(\tilde{\pi}_{t+4}\tilde{y}_{t-1})$ is significantly different from zero.

Table 1
Reaction function without partial adjustment, with rectangular term, 1999-2007 and 1999-2008

$$i_t = cte + c_1\tilde{\pi}_{t+4} + c_2\tilde{y}_{t-1} + c_3(\tilde{\pi}_{t+4}\tilde{y}_{t-1}) + v_t$$

	Constant	c_1	c_2	c_3	*Adjusted* R^2	*J Statistic*	*p-value*
1999-2007	–2.07* (1.03)	2.09** (0.59)	0.85** (0.39)	–0.15 (0.22)	0.73	0.13	0.65
1999-2008	–0.97 (0.91)	1.43 (0.72)	0.38 (0.76)	0.1 (0.43)	0.12	0.1	0.72

Notes: the standard errors are in parentheses. The superscripts ** and * denote the rejection of the hypothesis that the true coefficient is zero at a level of significance 5 and 10 per cent, respectively.

From table 1, we can deduce that for the period analyzed, the c_3 coefficient is not significantly different from zero. If we broaden the analysis until the end of 2008, again the values of the reaction coefficients tend to remain the same, but now they stop being significant, and the coefficient of determination is reduced to 0.12, in line with what we pointed out above about the fact that the ECB stopped displaying behavior according to the rule in the context of the profound financial crisis of 2008.

[12] And as can be seen in the work just cited.

As can be observed, the intertemporality adopted appropriately reflects the ECB behavior, and through the J statistic, we have proven that we should not reject the hypothesis of the validity of the instruments utilized in the adjustments.

As we have said, the objective of this research project is to detect the possible existence of asymmetric decisions through the degree of significance of the c_3 coefficient, and, as can be seen, we cannot reject the hypothesis of insignificance of that coefficient. This, in turn, leads us to think that there is not sufficient evidence of asymmetric behavior by the ECB. These results are compatible with the non-existence of a convex Phillips curve (or a curve of aggregate demand) in the euro zone in the period analyzed, as set forth above.

Table 2 summarizes the results of contrasting equation [12] in this case with interest-rate smoothing and the interaction term.

Table 2
Reaction function with partial adjustment and the rectangular term

$$i_t = cte + c_1\tilde{\pi}_{t+4} + c_2\tilde{y}_{t-1} + c_3(\tilde{\pi}_{t+4}\tilde{y}_{t-1}) + \rho i_{t-1} + v_t$$

	Constant	c_1	c_2	c_3	*P*	*Adjusted* R^2	*J Statistic*	*p-value*
1999-2007	–0.46 (0.84)	0.47 (0.52)	0.36 (0.29)	–0.02 (0.16)	0.64** (0.06)	0.94	0.04	0.93
1999-2008	–0.79 (0.75)	0.54 (0.42)	0.54** (0.26)	–0.14 (0.15)	0.74** (0.07)	0.9	0.06	0.81

Notes: the standard errors are in parentheses. The superscripts ** and * denote the rejection of the hypothesis that the true coefficient is zero at a level of significance of 5% and 10%, respectively.

The result is less satisfactory regarding the significance of the reaction coefficients c_1 and c_2, a fact linked to the highly smoothed nature of the ECB decisions, and that implies a high degree of involvement of the coefficient of the partial adjustment term ρ. Regarding the c_3 rectangular term coefficient, which, as we mentioned, must reflect the possible existence of asymmetric behavior in ECB decisions, once again, we cannot reject the hypothesis that it is different from zero.

Conclusions

Asymmetry in monetary policy rules must be sought in the existence of an asymmetric preference function of the central bank and in the potential convexity

of the relationship between output and inflation. Central banks do not make explicit the preferences function, this is why the existence of an asymmetric loss function must be detected through the decisions taken on the monetary policy instrument over sufficiently long periods. In addition, these preferences can change when the governing teams of the monetary institution itself change and due to the evolution of the economy. In this sense, a central bank's preferences are institutionally dependent, even if the central bank's objective is well defined. On the other hand, the existence of a convex Phillips curve has its origin in the structural model of the economy, which is beyond the scope of the central bank's action and monetary policy.

Throughout this article, we have reviewed how the presence of asymmetries in central bank preferences or the Phillips curve can lead to asymmetric behavior in the central bank's monetary policy decision-making. Such asymmetric behavior would consist of some type of over- or under-reaction upon changing the interest rate in the presence of deviations of deviations from the inflation target or from the output trend, depending on whether the deviations are positive or negative. This asymmetry, if it exists, must be reflected in the monetary policy reaction function which summarizes the decision strategy followed. Thus, the function must incorporate a non-linear term, in this case ($\tilde{\pi}_{t+4}\tilde{y}_{t-1}$), whose coefficient is significantly different from zero.

It could be supposed that in the case of the ECB, a relatively young central bank desirous of gaining anti-inflationary credibility, in principle it would have developed asymmetric behavior, reacting more intensely against positive deviations of the inflation rate from its target than against negative deviations. However, after carrying out the corresponding estimates, we came to the conclusion that, in the first ten years of its monetary policy, ECB reactions have not been asymmetric. Greater accuracy in the estimated linear reaction functions was observed —the results have not been incorporated into this article—, both with a partial adjustment term and without it, compared to the non-linear functions that incorporated the rectangular term. In addition, it has been proven that the coefficient that corresponds to the latter term is not significantly different from zero.

The explanation for this result cannot lie with the compensation of asymmetries, in the sense that the possible asymmetries in the presence of inflation deviations were compensated for by possible asymmetries of the opposite sign in the face of deviations in output, because, given the ECB's priority on price

stability, we believe this compensating effect must not have had much influence. On the other hand, as has been shown above, in the estimation of the Phillips curve for this period, the hypothesis of linearity over the convexity prevails, which means it is possible to discard this cause of asymmetric behavior.

Lastly, it is possible that the smoothing in the interest-rate decisions diluted the asymmetric behavior, making it more difficult to detect. Nevertheless, we consider that we have eliminated this risk by using quarterly data. In addition, we have also taken the smoothing into account by making adjustments, including the partial adjustment term, proving again the non-significance of the c_3 coefficient. As a complementary conclusion, we can add that accepting the linearity hypothesis is equivalent to the ECB opting for simplicity in order to preserve transparency, in the face of other, more complex, decision strategies.

Appendix

$$E_t \sum_{s=0}^{\infty} \delta^s L\left(\tilde{\pi}_{t+s}, \tilde{y}_{t+s}\right) = E_t[L(\tilde{\pi}_t, \tilde{y}_t) + \delta L(\tilde{\pi}_{t+1}, \tilde{y}_{t+1}) + \delta^2 L(\tilde{\pi}_{t+2}, \tilde{y}_{t+2}) + \cdots + \delta^s L(\tilde{\pi}_{t+s}, \tilde{y}_{t+s})]$$

with i_t implicit in $\tilde{y}_{t+1}$, $\tilde{\pi}_{t+2}$, and $\tilde{y}_{t+2}$. Using the chain rule, we obtain the first order condition:

$$\frac{\partial L}{\partial i_t} = \frac{\partial L}{\partial \tilde{\pi}_{t+2}} \cdot \frac{\partial \tilde{\pi}_{t+2}}{\partial \tilde{y}_{t+1}} \cdot \frac{\partial \tilde{y}_{t+1}}{\partial r_t} \cdot \frac{\partial r_t}{\partial i_t} + \frac{\partial L}{\partial \tilde{y}_{t+2}} \cdot \frac{\partial \tilde{y}_{t+2}}{\partial \tilde{y}_{t+1}} \cdot \frac{\partial \tilde{y}_{t+1}}{\partial r_t} \cdot \frac{\partial r_t}{\partial i_t} + \frac{\partial L}{\partial \tilde{y}_{t+1}} \cdot \frac{\partial \tilde{y}_{t+1}}{\partial r_t} \cdot \frac{\partial r_t}{\partial i_t} = 0$$

by operating:

$$\frac{\partial L}{\partial i_t} = \delta^2 \tilde{\pi}_{t+2} \alpha (1 + 2\theta \tilde{y}_{t+1})(-\xi)(1) + \lambda \delta^2 \tilde{y}_{t+2} \beta (-\xi)(1) + \delta \lambda_{t+1}(-\xi)(1) = 0$$

we obtain the following Euler equation:

$$\lambda E_t \tilde{y}_{t+1} + \lambda \beta \delta E_t \tilde{y}_{t+2} + \alpha \delta E_t \tilde{\pi}_{t+2}(1 + 2\theta \tilde{y}_{t+1}) = 0$$

Using equation [8] to replace $E_t\tilde{y}_{t+2}$ in terms of $E_t\tilde{y}_{t+1}$, $E_t x_{t+1}$ y $E_t r_{t+1}$, and solving for i_t, we obtain the Taylor rule:

$$\lambda E_t\tilde{y}_{t+1} + \delta\lambda\beta E_t\tilde{y}_{t+2} + \alpha\delta E_t\tilde{\pi}_{t+2}(1+2\theta\tilde{y}_{t+1}) = 0$$

$$\begin{aligned}&\lambda E_{t-1}\tilde{y}_t + \delta\lambda\beta^2 E_{t-1}\tilde{y}_t + \delta\lambda\beta\eta E_{t-1}x_t - \delta\lambda\beta\xi i_t \\ &+ \delta\lambda\beta\xi E_{t-1}\tilde{\pi}_{t+1} + \delta\alpha E_{t-1}\tilde{\pi}_{t+1}(1+2\theta\tilde{y}_t) = 0\end{aligned}$$

$$i_t = c_1 E_{t-1}\tilde{\pi}_{t+1} + c_2 E_{t-1}\tilde{y}_t + c_3 E_{t-1}x_t + c_4 E_{t-1}(\tilde{\pi}_{t+1}\tilde{y}_t)$$

where $c_1 = 1 + \dfrac{\alpha}{\lambda\xi\beta}; c_2 = \dfrac{1+\delta\beta^2}{\delta\xi\beta}; c_3 = \dfrac{\eta}{\xi}; c_4 = \dfrac{2\theta\alpha}{\lambda\xi\beta}$.

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