Universidade do Minho

Documentos de Trabalho

Working Paper Series

"Are Central Banks following a linear or nonlinear (augmented) Taylor rule?"

Vítor Castro

NIPE WP 19 / 2008

NÚCLEO DE INVESTIGAÇÃO EM POLÍTICAS ECONÓMICAS

UNIVERSIDADE DO MINHO

"Are Central Banks following a linear or nonlinear (augmented) Taylor rule?"

Vítor Castro

NIPE* WP 19 / 2008

URL:
http://www.eeg.uminho.pt/economia/nipe

* NIPE – *Núcleo de Investigação em Políticas Económicas* – is supported by the Portuguese Foundation for Science and Technology through the *Programa Operacional Ciência, Teconologia e Inovação* (POCI 2010) of the *Quadro Comunitário de Apoio III*, which is financed by FEDER and Portuguese funds.

Are Central Banks following a linear or nonlinear (augmented) Taylor rule?

Vítor Castro*

University of Warwick, University of Coimbra and NIPE

June 2008

Abstract

The Taylor rule establishes a simple linear relation between the interest rate, inflation and output gap. However, this relation may not be so simple. To get a deeper understanding of central banks' behaviour, this paper asks whether central banks are indeed following a linear Taylor rule or, instead, a nonlinear rule. At the same time, it also analyses whether that rule can be augmented with a financial conditions index containing information from some asset prices and financial variables. A forward-looking monetary policy reaction function is employed in the estimation of the linear and nonlinear models. A smooth transition model is used to estimate the nonlinear rule.

The results indicate that the European Central Bank and the Bank of England tend to follow a nonlinear Taylor rule, but not the Federal Reserve of the United States. In particular, those two central banks tend to react to inflation only when inflation is above or outside their targets. Moreover, our evidence suggests that the European Central Bank is targeting financial conditions, contrary to the other two central banks. This lack of attention to the financial conditions might have made the United States and the United Kingdom more vulnerable to the recent credit crunch than the Eurozone.

Keywords: Taylor rule; ECB monetary policy; Financial Conditions Index; Nonlinearity; Smooth transition regression models.

JEL classification: E43, E44, E52, E58.

---

* Department of Economics, University of Warwick, Coventry CV4 7AL, UK; Departamento de Economia, Universidade de Coimbra, Av. Dias da Silva, 165, 3004-512 Coimbra, Portugal; Núcleo de Investigação em Políticas Económicas (NIPE), Departamento de Economia, Universidade do Minho, Campus de Gualtar, 4710-057 Braga, Portugal. E-mail: v.m.a.castro@warwick.ac.uk, vcastro@fe.uc.pt.
The author acknowledges helpful comments from Jennifer Smith and Natalie Chen. The author also wishes to express his gratitude for the financial support from the Portuguese Foundation for Science and Technology under Scholarship SFRH/BD/21500/2005.

1. Introduction

Since the establishment, by Taylor (1993), of the linear algebraic interest rule that specifies how the United States (US) Federal Reserve (Fed) adjusts its Federal Funds rate to inflation and the output gap, several papers have emerged to test the validity of that rule for other countries and time periods.

Some studies have recently extended the Taylor rule by considering the effect of other variables in the conduct of monetary policy. One important extension is related to the inclusion of asset prices and financial variables in the rule.[1] This issue has caused a huge discussion in the literature: while some authors consider it important that central banks target asset prices, others disagree. To contribute to this discussion, we ask whether the basic Taylor rule could instead be augmented with an alternative variable that collects and synthesises the information from the asset and financial markets, i.e. whether central banks are targeting the relevant economic information contained in a group of financial variables and not simply targeting each financial variable *per se*. Thus, the first aim of this paper is to estimate a linear Taylor rule for the Eurozone, US and United Kingdom (UK) augmented with a financial conditions index that captures the information contained in some financial variables. The main innovation is that instead of relying on particular asset prices or financial variables, like other studies do, the index built in this paper synthesises the relevant information provided by those variables in a single variable where the weight of each asset and financial variable is allowed to vary over time. In fact, the central bank may not be targeting a particular asset or financial variable all the time, but it is possible that it may target it in some occasions, i.e. when, by some reason, it acquires particular economic relevance. Thus, synthesizing the information from several assets and financial variables in a weighted index permits to extract the particular relevance of each variable at each point in time and, therefore, put together an amount of information that is more likely to be targeted by the central bank at any the time.

The results from the estimation of a linear Taylor rule indicate that the European Central Bank (ECB) targets the information contained in the financial conditions index developed in this study, but the Fed and Bank of England (BOE) are not doing so; they only take into account one or two financial variables and clearly do not target asset

[1] See, for example, Bernanke and Gertler (1999, 2001), Cecchetti *et al.* (2000), Chadha *et al.* (2004) and Driffill *et al.* (2006).

prices. This is an interesting result that might help us to understand part of the story behind the recent credit crunch.

The traditional Taylor rule is an optimal policy rule that is derived from the minimization of a symmetric quadratic central bank's loss function assuming that the aggregate supply function is linear. However, in reality, this may not be the case and the central bank can have asymmetric preferences – i.e. it might assign different weights to negative and positive inflation and output gaps in its loss function – therefore, following not a linear but a nonlinear Taylor rule. Only very recently some studies started to consider these asymmetries or nonlinearities in the analysis of monetary policy.[2] This paper extends the analysis to two areas not yet explored by those studies. First, it applies, for the first time, a nonlinear model to the study of ECB monetary policy, where the presence of asymmetries is taken into account directly in the structure of the model. This procedure will permit an answer to the following questions: Is the ECB following a nonlinear Taylor rule, or more precisely, is the ECB reacting differently to levels of inflation above and below the target? Does the ECB attempt to hit the inflation target precisely or keep inflation within a certain range? Second, this paper also extends the nonlinear specification of the Taylor rule with the financial index used in the linear estimations to check whether, after controlling for nonlinearities, the ECB and the other two central banks are still (or not) reacting to the information contained in this index.

The results of the estimation of the nonlinear smooth transition regression model used in this paper are very interesting. First, they show that the ECB follows a nonlinear (and not a linear) Taylor rule: it only reacts actively to inflation when it is above 2.5%; and it only starts to react to the business cycle when inflation is stabilised, i.e. well below 2.5%. This is an empirical result that confirms quite remarkably the principles of ECB monetary policy. Second, the results also show that the ECB – contrary to the other central banks – continues to consider the information contained in the financial index even after nonlinearities are controlled for. Third, we find weak evidence to reject the linear model for the US but not for the UK, where the BOE seems to be pursuing a target range of 1.8%-2.4% for inflation rather than the official point target of 2%.

The remainder of this paper is organized as follows: Section 2 presents a brief review of the literature on the Taylor rule. The specification used to estimate the linear Taylor rule is described in Section 3; this section also presents the data and analyses the

[2] See Martin and Milas (2004), Taylor and Davradakis (2006), Assenmacher-Wesche (2006), Surico (2007a, 2007b) and Petersen (2007).

empirical results of the estimation of that specification. The model used to estimate the nonlinear Taylor rule is presented and analysed in Section 4, as well as the results of its estimation. Section 5 emphasises the main findings of this paper and concludes.

2. A brief review of the literature on the Taylor rule

This section intends to provide a brief review of the literature on the Taylor rule, emphasizing the main contributions that motivate the analysis presented in this study.

In its original form, the Taylor rule assumes that central banks use past or current values of inflation and output gap to set up the interest rate. However, in practice, they tend to rely on all available information – concerning the expected evolution of prices – when defining the interest rate. For that reason, Clarida *et al.* (1998, 2000) suggest the use of a forward-looking version of the Taylor rule where central banks target expected inflation and output gap instead of past or actual values of these variables. That practice allows the central bank to take various relevant variables into account when forming its forecasts.[3] They prove its advantages in the analysis of the policy behaviour of the Fed and other influential central banks. Fourçans and Vranceanu (2004) and Sauer and Sturm (2007) also stress the importance of considering a forward-looking Taylor rule in the analysis of the ECB monetary policy.

Some studies extend this linear rule by considering the effect of other variables in the conduct of monetary policy. For example, Fourçans and Vranceanu (2004) present some evidence of an ECB response to the exchange rate deviations from its average. A similar result is found by Chadha *et al.* (2004) for the Fed, Bank of England and Bank of Japan and by Lubik and Schorfheide (2007) for the central banks of Canada and England. Considering the role of money supply in the ECB reaction function, Fendel and Frenkel (2006) and Surico (2007b) conclude that it does not affect the ECB's behaviour directly but it is a good instrument to predict future inflation.

The role of asset prices is an important issue considered in some studies. However, no consensus was reached about whether the central bank should or not target these kinds of financial variables. Cecchetti *et al.* (2000), Borio and Lowe (2002), Goodhart and Hofmann (2002), Chadha *et al.* (2004) and Rotondi and Vaciago (2005) consider it important that central banks target asset prices and provide strong support and evidence in that direction. On the contrary, Bernanke and Gertler (1999, 2001) and

[3] Clarida *et al.* (1998, 2000) also suggest the inclusion of an interest rate smoothing in the estimation of the Taylor rule. The reasons for its inclusion are discussed below in the description of the model.

Bullard and Schaling (2002) do not agree with an ex-ante control over asset prices. They consider that once the predictive content of asset prices for inflation has been accounted for, monetary authorities should not respond to movements in assets prices. Instead, central banks should act only if it is expected that they affect inflation forecast or after the burst of a financial bubble in order to avoid damages to the real economy.

On the other hand, Driffill *et al.* (2006) analyse the interactions between monetary policy and the futures market in the context of a linear reaction function. They find evidence supporting the inclusion of futures prices in the central bank's reaction function as a proxy for financial stability. The issue of financial stability is also investigated by Montagnoli and Napolitano (2005). They build and use a financial conditional indicator that includes the exchange rate, share prices and house prices in the estimation of a Taylor rule for some central banks. Their results reveal that this indicator can be helpful in modelling the conduct of monetary policy. Considering these developments, our first aim is simply to estimate a linear Taylor rule for the Eurozone, US and UK, where the information from some financial variables is accounted for to shed some more light on its (un)importance.

In all the studies mentioned so far, the Taylor rule is considered a simple linear interest rate rule that represents an optimal policy-rule under the condition that the central bank is minimising a symmetric quadratic loss function and that the aggregate supply function is linear. However, in reality, this may not be the case and the central bank can have asymmetric preferences and, therefore, follow a nonlinear Taylor rule. If the central bank is indeed assigning different weights to negative and positive inflation and output gaps in its loss function, then a nonlinear Taylor rule seems to be more adequate to explain the behaviour of monetary policy.[4] However, only recently the literature has started to consider nonlinear models or asymmetries in the analysis of monetary policy. Asymmetries in monetary policy can result from a nonlinear macroeconomic model (Dolado *et al.*, 2005), nonlinear central bank preferences (Dolado *et al.*, 2000, Nobay and Peel, 2003, Ruge-Murcia, 2003 and Surico, 2007a) or both (Surico, 2007b). In particular, Surico (2007b) studies the presence of nonlinearities in the ECB monetary policy for the period January 1999-December 2004 estimating a linear GMM model resulting from the derivation of a loss function with asymmetric preferences and considering a convex aggregate supply curve. He finds that output

[4] Additional reasons to consider a nonlinear reaction function are provided by Bordo and Jeanne (2002) and Chadha *et al.* (2004).

contractions imply larger monetary policy responses than output expansions of the same size, but no asymmetric response is found for inflation. With more data available and using a different model – more precisely, a nonlinear model – we expect to find evidence of an asymmetric response of the ECB to inflation as well.

The nonlinear monetary policy rule used in our paper takes into account the asymmetries in the macroeconomic model and in the central bank preferences implicitly and generalizes the Taylor rule in the tradition of Clarida *et al.* (1998, 2000). Instead of simply relying on a linear model, *à la* Surico (2007b), where the asymmetries are accounted for by using products and cross products of inflation and output gap or by a separate analysis for inflation above or below the target, this paper estimates a nonlinear model for monetary policy where the presence of asymmetries is taken into account directly in the structure of the model. Besides analysing monetary policy asymmetries, this procedure will also permit an answer to the question of whether a central bank follows a point target or a target range for inflation.

Some studies have applied Markov-switching models to the study of monetary policy asymmetries or nonlinearities (Kaufmann, 2002, Altavilla and Landolfo, 2005, Assenmacher-Wesche, 2006). All find evidence of asymmetries, especially regarding the phases of the business cycle. In other words, they find that monetary authorities tend to have a different behaviour during recessions and expansions. Only Assenmacher-Wesche (2006) presents evidence of an asymmetric behaviour of monetary authorities (Fed, Bundesbank and BOE) to inflation above or below target. However, as these models assume that the regime switches are exogenous and driven by an unobservable process, it is not able to account for the intuition behind the nonlinear central bank behaviour. Like the linear models referred to above used to capture asymmetries in the monetary policy, Markov-switching models are not able to establish whether a central bank follows a point target or a target range for inflation. Finally, it does not allow for a smooth transition between regimes, which is an important drawback and a considerable departure from reality especially when inflation-regimes are considered. In that case, regime transitions are not generally sudden but smooth.

Bec *et al.* (2000) use a smooth transition autoregressive specification to model monetary policy in the US, Germany and France allowing for monetary policy to vary between periods of booms and slumps. They find relevant evidence of a nonlinear behaviour of monetary authorities regarding the phase of the business cycle. Our study adopts a different perspective. Instead of focusing on nonlinearities from the output gap, we allow for monetary policy changes between periods of high and low inflation. Note that inflation is actually the most important variable targeted by the central banks analysed in this study, especially for the ECB and UK whose main objective is precisely to promote price stability. Furthermore, contrary to Bec *et al.* (2000), we allow for the possibility of interest rate smoothing.

To our knowledge, only Martin and Milas (2004) and Petersen (2007) have deeply focused their attention on models that allow for a smooth transition from a state of high inflation to a state of low inflation (and vice-versa) in the context of the Taylor rule. These models seem to provide a better framework to explain nonlinear policy behaviour because as they allow for endogenous regime switches – contrary to the Markov-switching model – they offer economic intuition to understand the nonlinear policy behaviour of the central bank. Furthermore, they have the advantage of being capable of explaining why and when the central bank has changed its policy rule.

Martin and Milas (2004) apply a nonlinear quadratic logistic smooth transition model to the BOE monetary policy focusing on the policy of inflation targeting set up in 1992 and find evidence of nonlinearities in the conduct of monetary policy over the period 1992-2000.[5] They show that the UK monetary authorities attempt to keep inflation within a range rather than pursuing a point target and tend to react more actively to upward than to downward deviations of inflation away from the target range. The only shortcoming of the paper is not providing a test for the adequacy of the model, i.e. the authors do not test the validity of their nonlinear model against a linear one or against other nonlinear alternatives. This is a key issue that we will cover in this study.

More recently, Petersen (2007) applies a simple logistic smooth transition regression model to the monetary policy of the Fed over the period 1985-2005 using a basic Taylor rule and finds the presence of nonlinearities: once inflation approaches a certain threshold, the Fed begins to respond more forcefully to inflation. However, Petersen (2007) does not take into account the degree of interest rate smoothing or the possibility of the Taylor rule being forward-looking. Therefore, a nonlinear analysis considering those aspects in the Fed behaviour is needed.[6] We will provide that analysis

---

[5] Using a simple threshold autoregressive model, i.e. without allowing a smooth transition between high and low inflation regimes, Taylor and Davradakis (2006) also find evidence of nonlinearities in the conduct of monetary policy by the Bank of England over the period 1992-2003. In particular, they find that UK monetary authorities tend to react more actively to inflation when it is above target.

[6] Qin and Enders (2008) also consider such a model among the several (linear) models that they estimate for the Fed and where they allow for interest rate smoothing and forward-looking behaviour. Their aim is simply to examine the in-sample and out-of-sample properties of linear and nonlinear Taylor rules for the

and extend the nonlinear monetary rule with other variables, like the ones that provide information on the financial conditions. Furthermore, using data for the Eurozone, this paper will be, to our knowledge, the first to apply a nonlinear model with smooth regime transition to the study of the ECB monetary policy.

3. Specification and estimation of the linear Taylor rule

A basic linear Taylor rule is specified and estimated in this section. We start by describing the rule in its contemporaneous and forward-looking versions. Then we proceed with its estimation for the Eurozone, US and UK.

3.1. The linear Taylor rule

The following rule was proposed by Taylor (1993) to characterize the monetary policy in the US over the period 1987-1992:

$$i_t^* = \bar{r} + \pi^* + \beta(\pi_t - \pi^*) + \gamma(y_t - y_t^*). \qquad \textbf{(1)}$$

This rule regards the nominal short-term interest rate (i^*) as the monetary policy instrument and assumes that it should rise if inflation (π) rises above its target (π^*) or if output (y) increases above its trend value (y^*). Therefore, β indicates the sensitivity of interest rate policy to deviations in inflation from the target and γ indicates the sensitivity of interest rate to the output gap. In equilibrium, the deviation of inflation and output from their target values is zero and, therefore, the desired interest rate (i^*) is the sum of the equilibrium real rate ($\bar{r}$) plus the target value of inflation.[7]

Taylor's (1993) original rule considers the deviation of inflation over the last four quarters from target. However, in practice, central banks do not tend to target past or actual inflation but expected inflation. For that reason, Clarida *et al.* (1998) suggest the use of a forward-looking version of the Taylor rule. That allows the central bank to take various relevant variables into account when forming its inflation forecasts. Therefore, according to Clarida *et al.* (1998, 2000), the central bank's desired target interest rate (i^*) depends on the deviation of expected inflation k periods ahead (in

---

US economy. However, unlike Petersen (2007), they did not find evidence of significant nonlinearities in the Fed's behaviour during the period 1987-2005.

[7] According to the literature, both the equilibrium real rate and the inflation target are assumed to be constant (see, for example, Clarida *et al.*, 1998, 2000).

annual rates) from its target value and the expected output gap p periods ahead, which yields the following forward-looking Taylor rule:[8]

$$i_t^* = \bar{r} + \pi^* + \beta[E_t(\pi_{t+k} \mid \Omega_t) - \pi^*] + \gamma E_t[(y_{t+p} - y_{t+p}^*) \mid \Omega_t], \tag{2}$$

where E is the expectations operator and Ω_t is a vector including all the available information for the central bank at the time it sets interest rates.

According to the 'Taylor principle', for the monetary policy to be stabilizing the coefficient on the inflation gap (β) should exceed unity and the coefficient on the output gap (γ) should be positive. A coefficient greater than unity on the inflation gap means that the central bank increases the real rate in response to higher inflation, which exerts a stabilizing effect on inflation; on the other hand, β<1 indicates an accommodative behaviour of interest rates to inflation, which may generate self-fulfilling bursts of inflation and output. A positive coefficient on output gap means that in situations in which output is below its potential a decrease in the interest rate will have a stabilizing effect on the economy.

A common procedure when estimating monetary policy reaction functions is to control for the observed autocorrelation in interest rates. This is usually done by assuming that the central bank does not adjust the interest rate immediately to its desired level but is concerned about interest rate smoothing. Several theoretical justifications are advanced in the literature for the inclusion of interest rate smoothing in the Taylor rule, like the fear of disruptions in the financial markets, the existence of transaction frictions, the existence of a zero nominal interest rate lower bound or even uncertainty about the effects of economic shocks. Thus, if the central bank adjusts interest rates gradually towards the desired level, the dynamics of adjustment of the actual level of the interest rate to its target is generically given by:

$$i_t = \left(1 - \sum_{j=1}^{n} \rho_j\right) i_t^* + \sum_{j=1}^{n} \rho_j i_{t-j} \quad \text{with} \quad 0 < \sum_{j=1}^{n} \rho_j < 1, \tag{3}$$

where the sum of ρ_j captures the degree of interest rate smoothing and j represents the number of lags. The number of lags in this equation is generally chosen on empirical grounds so that autocorrelation in the residuals is absent.

[8] Although empirically motivated, this rule can also be obtained from the central bank loss function under the assumption that the evolution of the economy is described by the New-Keynesian model. Annex A.1 shows how the monetary rule can be derived in that framework.

Defining $\alpha = \bar{r} - (\beta - 1)\pi^*$, $\tilde{y}_{t+p} = y_{t+p} - y^*_{t+p}$ and inserting equation **(3)** into **(2)** assuming that the central bank is able to control interest rates only up to an independent and identically distributed stochastic error (u) yields the following equation:

$$i_t = \left(1 - \sum_{j=1}^{n} \rho_j\right)\left[\alpha + \beta E_t(\pi_{t+k} \mid \Omega_t) + \gamma E_t(\tilde{y}_{t+p} \mid \Omega_t)\right] + \sum_{j=1}^{n} \rho_j i_{t-j} + u_t, \qquad \textbf{(4)}$$

which is the specification that is usually estimated in the literature. This rule can be easily extended to include an additional vector of other m explanatory variables ($\boldsymbol{x}$) that may potentially influence interest rate setting. To do that we just need to add $\theta' E_t(x_{t+q} \mid \Omega_t)$ to the terms in square brackets in **(4)**, where θ is a vector of coefficients associated with the additional variables.[9] Eliminating the unobserved forecast variables from this equation, the policy rule can be rewritten in terms of realized variables:

$$i_t = \left(1 - \sum_{j=1}^{n} \rho_j\right)\left[\alpha + \beta \pi_{t+k} + \gamma \tilde{y}_{t+p} + \theta' x_{t+q})\right] + \sum_{j=1}^{n} \rho_j i_{t-j} + \varepsilon_t, \qquad \textbf{(5)}$$

where the error term ε_t is a linear combination of the forecast errors of inflation, output, the vector of additional exogenous variables and the disturbance u_t.[10]

Equation **(5)** will be estimated by the generalized method of moments (GMM). According to Clarida *et al.* (1998, 2000), this method is well suited for the econometric analysis of interest rate rules when the regressions are made on variables that are not known by the central bank at the decision-making moment. To implement this method, the following set of orthogonality conditions is imposed:

$$E_t\left\{ i_t - \left(1 - \sum_{j=1}^{n} \rho_j\right)\left[\alpha + \beta \pi_{t+k} + \gamma \tilde{y}_{t+p} + \theta' x_{t+q}\right] + \sum_{i=1}^{n} \rho_j i_{t-j} \middle| v_t \right\} = 0, \qquad \textbf{(6)}$$

where $\boldsymbol{v}_t$ is a vector of (instrumental) variables within the central bank's information set at the time it chooses the interest rate and that are orthogonal with regard to ε_t. Among them we may have a set of lagged variables that helps to predict inflation, output gap and the additional exogenous variables, together with other contemporary variables that should not be correlated to the current disturbance u_t. An optimal weighting matrix that accounts for possible heteroscedasticity and serial correlation in ε_t is used in the estimation. Considering that the dimension of the instrument vector $\boldsymbol{v}_t$ exceeds the

[9] Note that q can be zero, positive or negative depending on the kind of additional variable(s) considered.
[10] For further details, see Clarida *et al.* (1998, 2000).

number of parameters being estimated, some overidentifying restrictions must be tested in order to assess the validity of the specification and the set of instruments used. In that context, Hansen's (1982) overidentification test is implemented: under the null hypothesis the set of instruments is considered valid; the rejection of orthogonality implies that the central bank does not adjust its behaviour to the information about future inflation and output contained in the instrumental variables. Since in that case some instruments are correlated with $\boldsymbol{v}_t$, the set of orthogonality conditions will be violated, which leads to the rejection of the model.

In practice, to proceed with the estimation of equation **(5)**, we consider the following reduced form:

$$i_t = \phi_0 + \phi_1 \pi_{t+k} + \phi_2 \tilde{y}_{t+p} + \varphi' x_{t+q} + \sum_{i=1}^{n} \rho_j i_{t-j} + \varepsilon_t, \qquad \textbf{(7)}$$

where the new vector of parameters is related to the former as follows: $(\phi_0, \phi_1, \phi_2, \varphi)' = \left(1 - \sum_{i=1}^{n} \rho_j\right)(\alpha, \beta, \gamma, \theta)'$. Therefore, given the estimates of the parameters obtained from **(7)**, we can recover the implied estimates of α, β, γ, and θ and the respective standard errors by using the delta method. Assuming that we can consider the observed average real interest rate over the period in analysis as the equilibrium real interest rate, we can therefore obtain an estimate of the implicit inflation target pursued by the central bank as follows: $\hat{\pi}^* = (\bar{r} - \hat{\alpha})/(\hat{\beta} - 1)$.

3.2. Data, variables and additional hypotheses to test

The data used in this paper are monthly and mostly obtained from the statistics published by the three central banks analysed here: ECB Statistics, Fred II for the Fed and BOE Statistics. Other sources are used, especially for data on the additional exogenous variables that we will consider in this study. A detailed description of all variables used in this paper and respective sources is provided in Annex (see Table A.2.1). Figures 1 to 3 show the evolution of the main variables considered in this study for the analysis of the monetary policy followed by each central bank.

[Insert Figures 1 to 3 around here]

The sample covers the following periods: January 1999-December 2007 for the Eurozone, which corresponds to the period during which the ECB has been operating;

October 1982-December 2007 for the US, a period that starts after what is considered in the literature as the 'Volcker's disinflation'; and October 1992-December 2007 for the UK, the period during which the BOE has been operating under inflation targeting.

We consider several measures of interest rate and inflation. However, in the estimations we decided to choose the ones that have been followed more closely by each central bank and that permit an easy comparison of the estimation results between the three economies. For the Eurozone we use the Euro overnight index average lending rate (*Eonia*) as the policy instrument, which is the interest rate more directly related to the key interest rate and that does not suffer from discrete oscillations observed in the later (see Figures and Tables
Figure 1). The inflation rate is the annual rate of change of the harmonized index of consumer prices (*Inflation*), which is the main reference for the ECB monetary policy. As usual, the effective Federal Reserve funds rate (*FedRate*) is used in the estimation of the Taylor rule for the US. The inflation variable is the core inflation rate (*CoreInfl*), which excludes food and energy and that is considered a definition of inflation that the Fed has been following closely (see Petersen, 2007). For the UK we use the three-month Treasury bill rate (*TreasRate*) as the nominal interest rate, which according to Martin and Milas (2004) and Figure 3 has a close relationship with the (various) official interest rate instruments used in the period analysed. The inflation rate variable is the annual rate of change of the CPI, which is the main actual reference for the BOE monetary policy. Independently of the measures used for the interest rate or inflation, Figures 1 to 3 show that both the variables have remained relatively stable and at low levels during almost all the period considered for each of the three independent monetary areas analysed in this study. In all the three cases the output gap (*OutpGap*) is constructed by calculating the percentage deviation of the (log) industrial price index from its Hodrick-Prescott trend. Figures 1 to 3 also illustrate its evolution over time.

For the estimation of the ECB monetary rule, we also consider the role of the money supply. The primary objective of the ECB is price stability or, more precisely, to keep inflation below but close 2% over the medium term. However, its mandate is also based on an analytical framework based on two pillars: economic analysis and monetary analysis. The output gap is used in our model to capture the behaviour of the economy; to control for the role of money we include in the model the growth rate of the monetary aggregate M3 (*M3*). In theory, we expect the ECB to increase the interest rate when *M3* is higher than the 4.5% target defined by this institution for the growth of money.

Whether this variable has been indeed targeted by the ECB is not entirely clear and has been a matter of huge discussion to which this analysis tries to contribute.[11]

Financial variables and asset prices represent another group of variables that have been recently considered in the specification of the Taylor rule for the analysis of the behaviour of central banks. In this paper we consider the effects of those variables not *per se* but including them in an index in which each of them will have a different weight. The weight depends on the relative economic importance of each variable at each particular moment in time. Thus, the next step is devoted to the construction of a financial conditions index (*FCI*) designed to capture misalignments in the financial markets. Some monetary and financial indices have been used in the literature as a measure of the stance of monetary policy and aggregate demand conditions. Therefore, it is expected that such indices can be able to capture current developments of the financial markets and give a good indication of future economic activity. Those indices may also contain some useful information about future inflationary pressures, which can then be taken into account by central banks in their reaction functions. Usually, the *FCI* is obtained from the weighted average of short-term real interest rate, real effective exchange rate, real share prices and real property prices.[12] The first two variables measure the effects of changes in the monetary policy stance on domestic and external demand conditions, whilst the other two collect wealth effects on aggregate demand.

In this analysis, besides computing the *FCI* we also construct a new and extended *FCI* (*EFCI*) from the weighted average of the real effective exchange rate, real share prices and real property prices plus credit spread and futures interest rate spread.[13] Following Montagnoli and Napolitano (2005), we use a Kalman Filter algorithm to determine the weight of each asset. This procedure allows those weights to change over time. Goodhart and Hoofmann (2001) propose other methodologies to compute financial indices – like the estimation of a structural VAR system or the simple estimation of a reduced-form aggregate demand equation – in which they assume that the weight associated with each variable is fixed. However, in reality, it is more likely that the economic agents' portfolios change with the business cycles. Hence, this study relaxes the assumption of fixed weights and allows for the possibility of structural changes over time. Moreover, we extend the *FCI* proposed in those two studies by

[11] On the discussion see, for example, Fendel and Frenkel (2006) and Surico (2007b).
[12] See Goodhart and Hoofmann (2001).
[13] As the real interest rate is already incorporated in the monetary rule discussed above, it is not included in the construction of our *EFCI*.

considering the two additional financial variables indicated above. From the central bank's point of view, those variables may contain further relevant information regarding markets stability and expectations. The credit spread is considered a good leading indicator of the business cycle and of financial stress; and the changes in futures interest rate spread provide an indication of the degree of volatility in economic agents' expectations that the central bank aims to reduce.[14]

To consider the importance of financial variables in the conduct of monetary policy, we extend Rudebusch and Svensson's (1999) model by adding those variables to the IS equation.[15] The result is a simple backward-looking version of the model in which the economy is defined by the following Phillips and IS curves:

$$\pi_t = a_0 + \sum_{i=1}^{m_1} a_{1,i}\pi_{t-i} + \sum_{j=1}^{m_2} a_{2,j}\tilde{y}_{t-j} + \mu_t^s, \qquad \textbf{(8)}$$

$$\tilde{y}_t = b_0 + \sum_{k=1}^{p} b_k\tilde{y}_{t-k} + \sum_{l=1}^{q} b_l rir_{t-l} + \sum_{i=1}^{5}\sum_{j=1}^{n_i} b_{ij}x_{i,t-j} + \mu_t^d, \qquad \textbf{(9)}$$

where *rir* is the de-trended real interest rate and the financial variables (*x*) are the deviation from the long run equilibrium of, respectively:[16] the real exchange rate (*REER_gap*), where the foreign currency is in the denominator; real stock price (*RStock_gap*); real house price (*RHPI_gap*); credit spread (*CredSprd*), computed as the spread between the 10-year government benchmark bond yield (*Yield10yr*) and the interest rate return on commercial corporate bonds; and the change of spread (*ΔFutSprd*) between the 3-month interest rate futures contracts in the previous quarter (*FutIR*) and the current short-term interest rate. All these variables produce valuable financial information that can be compressed in a simple indicator and then included in the central banks' monetary rule to test whether and how they react to this information when they are setting up the interest rate.[17]

Allowing for the possibility of the parameters evolving over time, this means that an unobservable change in b_{ijt} can be estimated employing the Kalman filter over the state-space form of equation **(9)**:

[14] See Driffill *et al.* (2006) for the use of these two variables in the estimation of a Taylor rule for the US.
[15] For further details see Goodhart and Hoofmann (2001) and Montagnoli and Napolitano (2005).
[16] The long run equilibrium values are computed using the Hodrick-Prescott filter.
[17] Unit root and stationarity tests reported in Annex in Table A.2.5 reveal that all these variables are stationary, as required, for all of the countries studied.

$$\tilde{y}_t = X\beta_t + \mu_t \qquad \text{(measurement equation)},$$
$$\beta_t = F\beta_{t-1} + \omega_t \qquad \text{(transition equation)}, \qquad \textbf{(10)}$$

where the error terms are assumed to be independent white noises with variance covariance matrices given by $Var(\mu_t) = Q$ and $Var(\omega_t) = R$, and with $Var(\mu_t \omega_s) = 0$, for all *t* and *s*. *X* is the matrix of the explanatory variables plus a constant; all variables are lagged one period. The state vector β_t contains all the slope coefficients that are now varying over time. As it is assumed that they follow a random walk process, the matrix *F* is equal to the identity matrix. The Kalman filter allows us to recover the dynamic of the relation between output gap and its explanatory variables. This recursive algorithm estimates the state vector β_t as follows:

$$\beta_{t|t} = F\beta_{t|t-1} + H_{t-1}X(X'H_{t-1}X + Q)^{-1}(\tilde{y}_{t-1} - X'F\beta_{t-1|t-1}), \qquad \textbf{(11)}$$

where $H_{t-1} = FP_{t-1|t-1}F' + R$, $P_{t|t} = H_{t-1} - H_{t-1}X(X'H_{t-1}X + Q)^{-1}ZH_{t-1}$ (which is the mean square error of β_t) and $\beta_{t|t-1}$ is the forecast of the state vector at period t, given the information available at the previous period (*t*-1). Using this filter we can now recover the unobservable vector that affects the output gap. For each variable, it is now possible to observe how the respective coefficients and weights change over time. The weights attached to each variable are obtained as follows: $w_{x_{i,t}} = |\beta_{x_{i,t}}| \Big/ \sum_{k=1}^{5} |\beta_{x_{k,t}}|$, where $\beta_{x_{i,t}}$ is the coefficient of variable x_i in period *t*. Hence, the extended financial conditions index at time *t* is computed as the internal product of the vector of weights and the vector of the five financial variables described above, i.e. $EFCI_t = w'_{x_t} \cdot x_t$.

The *EFCI* is then included in the monetary rule defined for each central bank. As this variable contains valuable information about the financial health of the economy, as well as information about future economic activity and future inflationary pressures, we expect a reaction of the central bank to changes in this variable. In particular, we expect an increase of interest rates when this indicator improves; on the contrary, more restrictive financial conditions would require an interest rate cut. Using such an index we are avoiding the critique formulated by some authors that central banks should not target asset prices. Central banks may not do that directly and at all the time for each asset, but this study intends to show that they can extract some additional information from the evolution of those assets, as well as from other financial variables, when setting interest rates. Finally, as the economic relevance of these variables changes over time, we are also allowing for the possibility of central banks giving different importance to them over time.[18]

A final note regarding the data goes to the kind of data used: we use ex-post revised data. Orphanides (2001) claims that estimated policy reactions based on ex-post revised data can provide misleading descriptions of the monetary policy. For that reason, he suggests the use of real-time data in the analysis of monetary policy rules, i.e. data that is available at the time the central bank takes its decision on the interest rate. However, Sauer and Sturm (2007) show that the use of real-time data for the Eurozone instead of ex-post data does not lead to substantially different results. In fact, as the quality of predictions for output and inflation has increased in the last years, it is natural that those differences are less significant and less problematic nowadays, especially in the case of the Eurozone, which represents the main object of study in this paper. For that reason we rely essentially on ex-post data in this analysis. However, in the robustness analysis we will provide some results with real-time inflation and output gap data for the Eurozone obtained from the ECB Monthly Bulletins.[19] As industrial production is the variable that is more frequently revised, we also try to overcome the revised-data problem in the three economies by including in the model an alternative variable that provides good information regarding the state of the economy but that does not suffer revisions: the economic sentiment indicator (*EcoSent*). This variable is obtained from surveys of consumers and firms designed to collect their opinion about the general economic situation (output, unemployment, prices, etc) during the next year.

3.3. Empirical results

Before proceeding with the estimation of the model it is important to consider some issues. First, the sample period must be sufficiently long to contain enough variation in inflation, output and *EFCI*, and to identify the slope coefficients. Analysing Figures 1 to 3 and the descriptive statistics provided in Annex (Tables A.2.2 to A.2.4), we conclude that the output gap presents sufficient volatility in the three economies, but the low volatility of inflation for the Eurozone and UK suggests that the interest rate response to inflation must be carefully analysed since it may only represent the ECB and BOE conduct of monetary policy in a period of relative inflation stability. The low

[18] For a picture of the evolution of the *FCI* and *EFCI* over time, see Figures 1 to 3.
[19] See Sauer and Sturm (2007) for details on the construction of real-time data for the Eurozone.

volatility of *EFCI* in the three economies analysed also requires that we consider the results for this variable with a grain of salt.

Second, it is necessary that the variables included in the estimated model are stationary. Unit root and stationarity tests for the variables considered in this study are presented in Annex in Table A.2.5. Due to the low power and poor performance of these tests in small samples, we report the results of two different unit root tests (Dickey-Fuller and Ng Perron) and the results of the KPSS stationarity test to see whether the power is an issue. For the Eurozone, the power of unit root tests seems to be an issue. Due to the small sample period, they are unable to reject the unit root in some variables. However, the KPSS test is able to provide evidence of stationarity for all variables (except *M3*) for the Eurozone. Similar results are found for the UK. For the US, there is much less evidence of stationarity for the interest rate and inflation. But if we consider a longer time period, we are able to find evidence of stationarity for these variables.[20]

The results of the estimation of the Taylor rule for the Eurozone for the period January 1999-December 2007 are reported in Table 1. The *t*-statistics are presented in parentheses and for each regression we compute the estimate of the implicit inflation target pursued by the ECB (π^*). The adjusted R^2, Durbin-Watson (DW) statistic for autocorrelation and the Schwartz Bayesian Information Criterion (SBIC) are also reported for each regression. The first column presents the results of a Taylor rule in the spirit of Taylor (1993), i.e. without allowing for both a forward-looking behaviour of the central bank and interest rate smoothing. Despite the estimates for *OutpGap* and π^* being reasonable, results indicate that this simple model is unable to capture the reaction of the ECB to inflation rate. This means that the ECB may not be following a simple Taylor rule but a monetary rule that takes into account future expectations – besides past and current information – when defining the interest rate. Therefore, we proceed with the estimation of a forward-looking Taylor rule for the Eurozone.

[Insert Table 1 around here]

A generalized method of moments (GMM) estimator is used to estimate the forward-looking Taylor rule with interest rate smoothing. One lag of the interest rate seems to be sufficient to eliminate any serial correlation in the error term (see DW statistic). The horizons of the inflation forecast and output gap were chosen to be, respectively, one year (k=12) and 3 months (p=3). These horizons were selected using

[20] See, for example, Petersen (2007).

the SBIC and they seem to represent a sensible description of the actual way the ECB operates. The set of instruments includes a constant and lags 1 to 6, 9 and 12 of *Inflation*, *OutpGap*, *Yield10yr* and *M3*.[21] To infer the validity of the instruments, we report the results from Hansen's (1982) overidentification test, i.e. the Hansen's *J*-statistic and the respective *p*-value. The validity of the instruments used is confirmed in any of the regressions presented in Table 1. Heteroscedasticity and autocorrelation-consistent standard errors are employed in all the estimations.

Results for the baseline forward-looking estimation presented in column 2 show a significant reaction of the ECB to inflation: a one percentage point (p.p.) rise in expected annual inflation induces the ECB to raise the interest rate by about 2.75 p.p. As the coefficient on the inflation is greater than unity the real rate increases as well in response to higher inflation, which exerts a stabilizing effect on inflation. Independently of its main concern about inflation, the ECB is also responding to the business cycle: a one p.p. increase in the output gap generates an interest rate increase of about 2 p.p.

We also obtain an interesting estimate of $\pi^{*}=2.39$, which indicates that the ECB target for inflation is in practice only slightly higher than the 2% announced in its definition of price stability. In fact, the data shown in Figures and Tables

Figure 1 for the evolution of inflation rate is consistent with this result: inflation is below (but close) to 2.4%-2.5% for most of the time, but generally above the 2% formal target. This means that the ECB was tough in setting the formal target for inflation to transmit the idea that it is highly concerned in controlling inflation (as the former German Bundesbank). But despite this toughness, its policy allows for some flexibility, perhaps to accommodate the differences among the economies that constitute the Eurozone.

Next we extend the baseline model considering other factors that the central bank can take into account when defining the interest rate. According to the monetary pillar, the ECB should be targeting the growth of M3. However, no significant effect is detected from the inclusion of *M3* in the model (see column 3).[22] This result confirms the evidence provided by Fendel and Frankel (2006) and Surico (2007b) that the monetary aggregate is indeed not targeted by the ECB and should be excluded from the

[21] We will see below that our results reject the hypothesis of *M3* being targeted by the ECB, but it is shown to be a good instrument for the forward-looking monetary rule for the ECB. The 10-year government benchmark bond yield (*Yield 10yr*) also contains good and useful past information about the future evolution of the interest rate.

[22] In this case we are including in the estimation the variable *M3* minus the reference value of 4.5%, which is defined as the target for *M3* by the ECB. Results did not change even when we included in the regression the difference of (log) of M3 relative to its Hodrick-Prescott trend instead of *M3*-4.5%.

equation. But as this variable traditionally provides valuable information to forecast inflation, it constitutes an important variable to be considered in the set of instruments.

The inclusion of the financial conditions indices in the ECB monetary rule provides a remarkable outcome: results indicate that the ECB is targeting not only inflation and the economic conditions but also financial conditions when defining the interest rate. The evidence provided in columns 4 and 5 of Table 1 shows that expansive financial conditions in the Eurozone are stabilized by an increase in the interest rate. For example, a unitary increase in the financial indicator developed in this study – *EFCI* – leads to an increase of about three quarters of a percentage point in the interest rate. As this extended index contains valuable information concerning the evolution of future economic activity and about future inflationary pressures, targeting financial conditions is a way of the ECB also targeting inflation indirectly and avoiding financial imbalances that can be prejudicial for economic stability. This is a striking result and represents the first analysis providing evidence that the ECB is not only trying to promote monetary stability but, in doing so, it is also trying to promote the required financial stability. This means that the ECB monetary policy can be explained by a Taylor rule augmented with information from financial conditions.

As mentioned in Section 2, there is a huge discussion in the literature about whether central banks should target financial variables and, in particular, asset prices. This paper provides some evidence favouring the inclusion of the information contained in those variables in the monetary rule.[23] In general, papers deal with this issue by including each single asset price or financial variable independently in the model without taking into account the relative importance of each one at each particular moment in time. With the index used in this study, we overcome that problem and concentrate the information provided by those variables in a single indicator. This also avoids possible multicollinearity problems that may result from the inclusion of all those variables at a time in a single regression. Nevertheless, to permit a direct comparison with other studies, column 6 provides the results of a regression that includes the components of *EFCI*. With the exception of the *CredSprd*, they all present

[23] This conclusion is in line with other works in the field, like Cecchetti *et al.* (2000), Borio and Lowe (2002), Goodhart and Hofmann (2002), Chadha *et al.* (2004), Rotondi and Vaciago (2005) and Driffill *et al.* (2006), that consider it important that central banks target asset prices and other indicators of financial market stress.

a coefficient with the expected sign and are statistically significant.[24] However, the implicit target for inflation is very high and not significant, which can be the consequence of a multicollinearity problem.

Another interesting issue raised by this study is whether, besides the ECB reacting to the Eurozone economic cycle, it is also responding to international economic conditions. To capture this effect, the US output gap is used as a proxy for the world economic cycle. Results indicate that the ECB takes into consideration the current state of the global economy when deciding on interest rates. In an open global economy, fears of imported inflation (or recession) resulting from a higher (lower) global economic growth above (below) the trend are counteracted by a higher (lower) interest rate in the Eurozone.

The next group of regressions was devised to analyse the robustness of the results presented so far. The first robustness test is related to the definition of interest rate. We have been considering the *Eonia* interest rate as the policy instrument, but the main results are not substantially affected when we use the three months Euribor instead (see column 8). Only the implicit inflation target is higher than the expected, which confirms the use of *Eonia* as a sensible choice.

As industrial production is a variable that usually suffers revisions, we include an alternative variable in the model to capture the reaction of the ECB to *expected* economic conditions (*EcoSent_gap*).[25] This variable is not affectted by revisions and provides good information regarding the expectations of economic agents about the state of economy at the time the central bank takes its decision on the interest rate. Results are presented in column 9 of Table 1 and show that the coefficient on the lag of this variable is positive and highly significant, as expected, and the other results are not substantially affected. Moreover, no major differences are obtained even when we assume that the central bank is considering the economic information from both the *OutpGap* and *EcoSent_gap* simultaneously (see column 10). Results show that information from these two variables can be easily combined in taking policy actions.

Finally, in columns 11 and 12 we use real-time data for inflation and output gap instead of ex-post revised data. However, as already shown by Sauer and Sturm (2007),

[24] Note that a depreciation of the Euro above its trend, an increase in the share and house prices above their trends and a higher departure of the futures interest rate from the actual interest rate all contribute to a significant reaction of the ECB to the increase in the interest rate.

[25] The variable *EcoSent_gap* is computed from the *EcoSent* in the same way as we compute the output gap from the industrial production. While *EcoSent* has a unit root, *EcoSent_gap* is stationary, as required.

the use of real-time data for the Eurozone, instead of ex-post data, does not lead to substantially different results.

In the next table (Table 2) we reproduce some of the main results obtained for the other two economies (US and UK). The sequence in which the results are presented is quite similar to the one used for the Eurozone. The estimates in columns US1 and UK1 were obtained from a simple Taylor rule. Such a rule produces quite good results for the US but not so impressive for the UK. While the coefficient on inflation is higher than 1 for the US, as expected, it is lower than 1 for the UK. However, note that both regressions suffer from a problem of autocorrelation (see DW). Moreover, it is expected that these central banks tend to rely on all available information, which requires a GMM estimation of a forward-looking Taylor rule with interest rate smoothing.

[Insert Table 2 around here]

The results presented in Table 2 show that two lags of the interest rate are required to eliminate any serial correlation in the error term for the US and UK regressions (see DW). The horizons of the inflation and output gap forecasts for the US were chosen to be the same as the ones used for the Eurozone; for the UK, we have the contemporaneous value of the output gap and lead 6 of inflation. These horizons were selected using the SBIC. The set of instruments for the US includes a constant and lags 1 to 6, 9 and 12 of *CoreInfl*, *OutpGap* and *Yield10yr*; For the UK, it includes a constant and lags 1 to 6, 9 and 12 of *RPI_Infl*, *OutpGap*, *Yield10yr* and *FCI*. The validity of these instruments is confirmed by the Hansen's *J*-test in any of the GMM estimations.

Results are consistent with the Taylor rule for both countries: the coefficients on inflation are consistently higher than unity and statistically significant, as required; and the coefficients on the output gap are positive and statistically significant, as expected. Results also indicate that the Fed has been following an average target for inflation of about 3.5% from October 1982 to December 2007, while the BOE has been following an inflation target of about 2% in the period October 1992-December 2007, which is in line with the current target defined by this central bank for its monetary policy.

Contrary to the ECB, these two central banks are not targeting financial conditions, as is revealed by the insignificant coefficients on *FCI* and *EFCI* in both cases. However, some components of the extended index seem to be considered by those central banks. As pointed out by Driffill *et al.* (2006), this work confirms that the Fed reacts to the expected future evolution of interest rates. On one hand, when the long-term government bond yield rate is above the corporate bond yield rate – which means an expected improvement of the economic conditions and consequent inflationary pressures in the future – the central bank increases the interest rate. On the other hand, the Fed also aims to reduce the volatility of the spread between the futures and actual interest rates, which induces it to follow the pace of the futures market. The first effect is also found for the BOE, but not the second. Moreover, we found no evidence that these two central banks are targeting the evolution of the exchange rate or asset prices, a result that is in line with the arguments advanced by Bernanke and Gertler (1999, 2001) and Bullard and Schaling (2002) on this matter.

These results bring about an important conclusion of this study: while the ECB is targeting financial conditions in general to avoid imbalances in the asset and financial markets and, in the limit, in the monetary market, the Fed and BOE are not so worried about the financial conditions and let the financial markets, in particular the asset markets, act free from any direct control. The result of this different behaviour seems to be well evident in the recent credit crunch that arose in the US housing market and that quickly spread to the UK. Due to the integration of global markets, indirect repercussions are also felt in the Eurozone, but its asset markets (and the economy, in general) remain more solid and stable than their counterparts in the US and even in the UK. Thus, targeting financial conditions might be a solution to avoid imbalances in the financial and asset markets and, consequently, to avoid a sharp economic slowdown.

Results from column UK6 indicate that, as in the Eurozone, the international economic conditions (proxied by the US output gap) seem to be taken into account in the monetary rule for the BOE as well. However, in this case the statistical evidence is much weaker. We also include the *EcoSent_gap* instead of *OutpGap* in the regressions US6 and UK7, to avoid the data revision problems that affect the output gap. The main results do not change, but the coefficient on the lag of *EcoSent_gap* for the US regression is not significant, which can mean that the Fed is not relying on consumers' and firms' economic sentiment as it relies on real output forecasts.

Finally, to compare the monetary policy of the three central banks analysed here in the same time period, we estimate a regression for the US and UK using data for the period January 1999-December 2007 (see columns US7 and UK8). The estimated targets for inflation are now lower than in the periods previously considered. They are 2.60% for the US and 1.34% for the UK, which indicates a stronger concern by the respective central banks in keeping inflation low. In general, the results for the US are quite similar to the ones obtained for the Eurozone, but the estimated model for the UK is not able to capture any significant effect from the inflation rate. One reason might be the fact that the inflation rate has remained below the inflation target defined by the BOE for most of the time during this period (see Figure 3), which makes it difficult to extract any significant reaction of the BOE to this variable.

In sum, after analysing the results from the linear estimation of the Taylor rule for the ECB, Fed and BOE, we conclude that these central banks follow a forward-looking Taylor rule, which in the case of the Eurozone is clearly augmented by a composite indicator of financial variables. However, an important question remains: Are these central banks indeed following a linear Taylor rule or is their behaviour characterized instead by a nonlinear rule? The next section is devoted to answering this question.

4. Specification and estimation of the nonlinear Taylor rule

A forward-looking nonlinear Taylor rule is specified and estimated in this section. We start by presenting the nonlinear model and a test to detect the presence of nonlinearities. For cases in which the nonlinearity is not rejected, we proceed with the estimation of the respective nonlinear specifications.

4.1. The nonlinear Taylor rule

The Taylor rule presented and estimated above is a simple linear interest rate rule that represents an optimal policy-rule under the condition that the central bank is minimising a symmetric quadratic loss function and that the aggregate supply function is linear. However, in reality, this may not be the case and the central bank can be responding differently to deviations of aggregates from their targets. If the central bank is indeed assigning different weights to negative and positive inflation and output gaps in its loss function, then a nonlinear Taylor rule seems to be more adequate to explain the behaviour of monetary policy.[26] Moreover, inflation and the output gap tend to reveal an asymmetric adjustment to the business cycle. It is well known that output exhibits short and sharp recessions over the business cycle, but long and smooth recoveries. Inflation also increases more rapidly over the business cycle than it

[26] See Nobay and Peel (2003), Ruge-Murcia (2003), Dolado *et al.* (2005) and Surico (2007a, 2007b).

decreases.[27] Under these circumstances it is natural that the central bank has to respond differently to levels of inflation and output above, below or around the required targets. These arguments emphasize the importance of considering a nonlinear Taylor rule in the analysis of the central bank's behaviour.

To explain this non-linear behaviour, we have to consider non-linear time series models. The main options to consider are the Markov-switching model and the smooth transition regression (STR) model. Some studies in this field have employed the first model (see Section 2 for details), but as this assumes that the regime switches are exogenous and driven by an unobservable process, it is not able to account for the intuition behind the nonlinear central bank behaviour. On the other hand, as the STR model allows the regression coefficients to change smoothly from one regime to another, it provides a better structural framework to explain nonlinear policy behaviour. Allowing for endogenous regime switches – contrary to the Markov-switching models – it also provides economic intuition for the nonlinear policy behaviour of the central bank and it is able to explain why and when the central bank changes its policy rule.

Although three versions of this model have been applied to the study of the behaviour of some relevant central banks by Bec *et al.* (2000), Martin and Milas (2004) and Petersen (2007), no study has yet applied such a model to the analysis of the behaviour of the ECB.[28] This paper intends to do so providing, at the same time, a comparative analysis between the monetary policy of the ECB and the monetary policy of the Fed and the BOE. Additionally, this paper extends the existing studies on nonlinear Taylor rules by controlling for financial conditions.

A standard STR model for a nonlinear Taylor rule can be defined as follows:[29]

$$i_t = \psi' z_t + \omega' z_t G(\eta, c, s_t) + \varepsilon_t, \qquad t = 1,...,T \tag{12}$$

where $z_t = (1, i_{t-1},..., i_{t-n}; \pi_t, \tilde{y}_t; x_{1,t},..., x_{m,t})'$ is the vector of the explanatory variables, with h=n+2+m. The parameters $\psi = (\psi_0, \psi_1,..., \psi_h)'$ and $\omega = (\omega_0, \omega_1,..., \omega_h)'$ represent ((h+1)×1) parameter vectors in the linear and nonlinear parts of the model, respectively.[30] The disturbance term is assumed to be independent and identically

[27] See, for example, Hamilton (1989) and Neftçi (2001).

[28] The presence of nonlinearities in the ECB monetary policy is also studied by Surico (2007b), but without estimating a nonlinear model.

[29] For further details on the STR model, see Granger and Teräsvirta (1993), Teräsvirta (1998) and van Dijk *et al.* (2002).

[30] Some of these parameters may be zero a priori.

distributed with zero mean and constant variance, $\varepsilon_t \sim iid(0,\sigma^2)$. The transition function $G(\eta,c,s_t)$ is assumed to be continuous and bounded between zero and one in the transition variable s_t. As $s_t \rightarrow -\infty$, $G(\eta,c,s_t) \rightarrow 0$ and as $s_t \rightarrow +\infty$, $G(\eta,c,s_t) \rightarrow 1$. The transition variable, s_t, can be an element or a linear combination of z_t or even a deterministic trend.

A few definitions have been suggested for the transition function in the literature. This paper starts by considering $G(\eta,c,s_t)$ as a logistic function of order one:

$$G(\eta,c,s_t) = [1+\exp\{-\eta(s_t - c)\}]^{-1}, \qquad \eta > 0. \tag{13}$$

This kind of STR model is called a logistic STR model or an LSTR1 model. This transition function is a monotonically increasing function of s_t, where the slope parameter η indicates the smoothness of the transition from one regime to another, i.e. how rapid the transition from zero to unity is, as a function of s_t. Finally, the location parameter c determines where the transition occurs.

Considering this framework, the LSTR1 model can describe relationships that change according to the level of the threshold variable. Assuming that the transition variable is the level of inflation ($s_t=\pi_t$), then the LSTR1 model is able to describe an asymmetric reaction of the central bank to a high and to a low inflation regime. Given the important weight that the central banks analysed in this study put on inflation, we expect to find significant differences in the behaviour of these banks when (expected) inflation is deviating considerably from a certain threshold.

The STR model is equivalent to a linear model with stochastically time-varying coefficients and, as so, it can be rewritten as:

$$i_t = [\psi' + \omega' G(\eta,c,s_t)]z_t + \varepsilon_t \Leftrightarrow i_t = \zeta' z_t + \varepsilon_t, \qquad t = 1,\ldots,T. \tag{14}$$

Given that $G(\eta,c,s_t)$ is continuous and bounded between zero and one, the combined parameters, ζ, will fluctuate between ψ and $\psi+\omega$ and change monotonically as a function of s_t. The more the transition variable moves beyond the threshold, the closer $G(\eta,c,s_t)$ will be to one, and closer the parameters ζ will be to $\psi+\omega$; similarly, the further s_t approaches the threshold, c, the closer the transition function will be to zero and closer the parameters ζ will be to ψ.[31]

As, in practice, a monotonic transition may not be a satisfactory alternative, this study will also consider (and test for) the presence of a non-monotonic transition

[31] Note that when $\eta \rightarrow 0$, the logistic transition function converges to 0.5 and the model is linear; when $\eta \rightarrow \infty$, the LSTR1 model becomes a two regime switching regression model.

function, in line with the work of Martin and Milas (2004). In fact, central banks may consider not a simple numeric and rigid target for inflation but a band or an inner inflation regime, where inflation is considered under control and, consequently, the reaction of the monetary authorities will be different from a situation where inflation is outside that regime.

The non-monotonic alternative function to consider is the following logistic function of order two:

$$G(\eta, c, s_t) = [1 + \exp\{-\eta(s_t - c_1)(s_t - c_2)\}]^{-1}, \qquad \textbf{(15)}$$

where $\eta>0$, $c=\{c_1,c_2\}$ and $c_1 \geq c_2$. This transition function is symmetric about $(c_1+c_2)/2$ and asymmetric otherwise, and the model becomes linear when $\eta \to 0$. If $\eta \to \infty$ and $c_1 \neq c_2$, $G(\eta,c,s_t)$ becomes equal to zero for $c_1 \leq s_t \leq c_2$ and equal to 1 for other values; and when $s_t \to \pm\infty$, $G(\eta,c,s_t) \to 1$. To distinguish this STR model from the one specified above, we call this the quadratic logistic STR model or LSTR2 model.[32] Considering inflation as a transition variable, this model allows us to estimate separate lower and upper bands for the inflation instead of a simple target value (which in practice may not be easy to reach every time).

4.2. Linearity versus nonlinearity

Before proceeding with the estimation of the nonlinear model, it is important to test whether the behaviour of monetary policy in a particular country can be really described by a nonlinear Taylor rule. This implies testing linearity against the STR model.[33] The null hypothesis of linearity is H_0: $\eta=0$ against H_1: $\eta>0$. However, neither the LSTR1 model nor the LSTR2 model are defined under this null hypothesis; they are only defined under the alternative. Teräsvirta (1998) and van Dijk *et al.* (2002) show that this identification problem can be solved by approximating the transition function with a third-order Taylor-series expansion around the null hypothesis. This approximation yields, after some simplifications and re-parameterisations, the following auxiliary regression:

$$i_t = \beta_0' z_t + \beta_1' \tilde{z}_t s_t + \beta_2' \tilde{z}_t s_t^2 + \beta_3' \tilde{z}_t s_t^3 + \varepsilon_t^*, \qquad t = 1,\dots,T. \qquad \textbf{(16)}$$

[32] When $c_1=c_2$, the transition function is symmetric and the model is called exponential STR (ESTR).
[33] These tests require that the errors are uncorrelated with z_t and s_t, and that all the variables are stationary. Stationarity tests are provided in Annex in Table A.2.5.

where $\varepsilon_t^* = \varepsilon_t + \omega' z_t R_3(\eta, c, s_t)$, with the remainder $R_3(\eta,c,s_t)$, and $z_t = (1, \tilde{z}_t')'$ where $\tilde{z}_t$ is a (h×1) vector of explanatory variables. Moreover, $\beta_j = \gamma\tilde{\beta}_j$, where $\tilde{\beta}_j$ is a function of ω and c. The null hypothesis of linearity becomes H_{01}: $\beta_1=\beta_2=\beta_3=0$, against the alternative H_{11}: "at least one $\beta_j \neq 0$, j=1,2,3". An LM-test can be used to investigate this hypothesis because under the null, $u_t^* = u_t$. The resulting asymptotic distribution is χ^2 with 3h degrees of freedom under the null.[34] If linearity is rejected, we can proceed with the estimation of the nonlinear model. But, which transition function should be employed? The decision between an LSTR1 and an LSTR2 model can be made from the following sequence of null hypotheses based on the auxiliary regression **(16)**: H_{02}:β_3=0; H_{03}:$\beta_2=0|\beta_3=0$; and H_{04}:$\beta_1=0|\beta_3=\beta_2=0$. Granger and Teräsvirta (1993) show that the decision rule works as follows: if the p-value from the rejection of H_{03} is the lowest one, choose an LSTR2 model; otherwise, select an LSTR1.

4.3. Empirical results

The empirical work provided in this section shows evidence that two of the three central banks considered in this study are clearly following a nonlinear Taylor rule instead of a linear one: the ECB and the BOE. The results of the linearity tests provided in the bottom of Table 3 (see line H_{01}) – where (expected) inflation is the threshold variable – show that we can reject the linearity hypothesis at a level of significance of 5% (but only at 10% for the preferred model for the US). Inflation is chosen to be the threshold variable because of the important weight central banks put on this variable and also because this variable has provided the lowest p-value for the rejection of the linear model.[35] The tests for the choice of the transition function are also presented in the bottom of Table 3 (see lines H_{02}, H_{03} and H_{04}) and indicate that an LSTR1 fits better to the Eurozone, while an LSTR2 model is more adequate for the UK (and the US). This means that the ECB is pursuing a point target, while the BOE (and perhaps the Fed) are attempting to keep inflation within a certain range.

[Insert Table 3 around here]

[34] See Teräsvirta (1998).

[35] Teräsvirta (1998) argues that if there is no reason to choose one variable over any other to be threshold variable and if nonlinearity is rejected for more that one transition variable, the variable presenting the lowest p-value for the rejection of linearity should be chosen to be the transition variable.

The first results presented in Table 3 (EZ1, US1 and UK1) were obtained from the nonlinear least squares estimation of a simple nonlinear Taylor rule without allowing for a forward-looking behaviour or interest rate smoothing (see notes in Table 3). The best fitting model is found by sequentially eliminating insignificant regressors by using the SBIC measure of fit. The results indicate that the ECB is reacting to inflation (according to the Taylor principle, $\omega_{\pi}>1$) only when it reaches values above 2%, which remarkably coincides with the ECB's target for inflation and with the implicit target for inflation estimated in the linear version. When inflation is well below 2%, the ECB does not react to inflation directly, but reacts to the inflationary pressures that may arise through the economic cycle. The ECB's reaction to the output gap seems to become stronger when inflation grows above the 2% target. Instead of pursuing a point target (of 2%) for inflation like the ECB, the Fed and BOE try to keep inflation within, respectively, the 2.04%-3.67% and 1.61%-1.99% ranges, according to this basic nonlinear Taylor rule. When inflation is inside these ranges, these two central banks only react to the output; they only react to inflation when it is outside these ranges. However, the reaction of the BOE does not accord with the Taylor principle.

In general the results seem quite reasonable, but the autocorrelation problems presented by these estimations and the fact that central banks are taking into account not only present and past information but also future inflation expectations suggest we should proceed with the estimation of a forward-looking version of these nonlinear models, where the nonlinear Taylor rule allows for interest rate smoothing. A nonlinear instrumental variables (IV) estimator is used to estimate these models, where the horizons of the inflation and output gap forecasts and the set of instruments are the same as we considered in the estimation of the linear model. The validity of the instruments is confirmed by the Hansen's *J*-test in any of the IV estimations. Heteroscedasticity and autocorrelation- consistent standard errors are used in all the estimations.

Considering the Eurozone first, we start by estimating a more general version of the model where inflation and output gap are included in the linear and nonlinear parts of the model. Given the relevance demonstrated by the *EFCI* variable in the linear model, we extend the forward-looking nonlinear model with the lag of this variable. The results are presented in columns EZ2 and EZ3 and confirm the significant nonlinear reaction of the ECB to expected inflation: the ECB only starts to react actively to inflation when it is above 2.5%, a value that is very close to the implicit inflation target estimated in the linear model and not very far from the target announced by the ECB;

moreover, they only react to the output gap when expected inflation is well below 2.5% ($\psi_y + \omega_y$ is not significant). This is a very important result: first, it confirms the main aim of the ECB of keeping inflation low; second, once this objective is achieved, this study also supports the expressed ECB's intention of promoting a sustainable growth.[36] This means that the nonlinear Taylor rule completely embodies the monetary policy sustained by the ECB for the Eurozone. Moreover, the nonlinear model also shows some evidence that the ECB is considering the information contained in some financial variables in its decisions on the interest rate.[37] Therefore, this study concludes that this augmented nonlinear Taylor rule is the policy rule that best represents the ECB's behaviour.[38]

The forward-looking Taylor rule with interest rate smoothing estimated for the US (see column US2) does not present significant differences in comparison with the results presented in column US1. Nevertheless, it is important to emphasize that the forward-looking linear model for the US is only rejected at a level of significance of 10%, which means that the Fed monetary behaviour can be well explained by a forward-looking linear Taylor rule. Therefore, this paper shows that the evidence found by Petersen (2007) that the Fed follows a nonlinear Taylor rule is only valid when we consider a basic nonlinear Taylor rule. As soon as we depart from this assumption and consider a more complete framework – where the forward-looking behaviour of the Fed and interest rate smoothing are controlled for – the conclusion may not be the same.[39] In fact, additional linearity tests (not presented here) revealed that linearity is not rejected when two relevant variables such as *CredSprd* and Δ*FutSprd* are included in the nonlinear model. The same result was obtained when we tried to include *EFCI*.

Finally, the results obtained for the UK are quite similar to the ones obtained for the Eurozone (see columns UK2 and UK3) and update the evidence provided by Martin and Milas (2004) that the BOE follows a nonlinear Taylor rule and tries to keep inflation within a range – of 1.8%-2.4% according to our evidence – rather than pursuing the actual official point target of 2%. Results indicate a strong reaction of the

[36] Note that according to the ECB: "The contribution of monetary policy consists in maintaining price stability and establishing confidence in the continuation of its efforts, thereby creating the conditions necessary for the sustained, non-inflationary growth of output and employment." Cf. ECB (1999, p.10).

[37] Despite *US_OutpGap* proving significant in the linear model, it is not included in the nonlinear regressions because due to the complexity of the model it was not possible to achieve convergence after trying several combinations of initial values.

[38] The results of a nonlinear Taylor rule without *EFCI* are presented in column EZ4 to permit a direct comparison with the main results obtained for the other economies.

[39] The recent evidence provided by Qin and Enders (2008) for the Fed also points into that direction.

BOE to inflation when expected inflation is outside the 1.8%-2.4% range. As soon as inflation is in this range, it only reacts to the business cycle and, to a lesser degree, to the additional economic information contained in the *CredSprd* variable.[40]

5. Conclusions

This paper discusses two important issues. First, it asks whether central banks, besides targeting inflation and the output gap, are also targeting the information contained in the asset prices and financial variables. Second, it analyses whether central banks are following a linear or nonlinear Taylor rule. Related to this second point, this study also considers whether they are pursuing a point target or a range target for inflation. The central banks considered in this analysis are the ECB, Fed and BOE.

To answer the first question we built a financial conditions index from the weighted average of a group of asset prices and financial variables and included it, first, in the linear Taylor rule. The results indicate that while the ECB is targeting the information contained in this index in order to avoid inflationary pressures from imbalances in the asset and financial markets, the Fed and BOE leave those markets free from any direct control. In our opinion, this different behaviour might be one of the causes for the credit crunch that arose recently in the US housing market and that affected the real economy, with important repercussions in the UK, but to which the Eurozone remained less exposed. Thus, the first main conclusion of this study is that targeting financial conditions might be a solution to avoid imbalances in the financial and asset markets and, consequently, to help to avoid sharp economic slowdowns.

The results mentioned above were obtained using a linear Taylor rule but, considering that the central banks might be responding differently to deviations of inflation above or below from their targets, we decided to test for the presence of nonlinearities in the rule and estimate a nonlinear model in case they are present. The linearity tests indicate that the ECB and the BOE are clearly following a nonlinear Taylor rule instead of a linear one, but the evidence is not enough to clearly reject the linear Taylor rule for the Fed.

The estimation of the nonlinear Taylor rule using a smooth transition regression model provides interesting results. First, they show that the ECB pursuits a point target of 2.5% for inflation. Second, the ECB only reacts actively to inflation when it is above

[40] Like in the linear model, no other significant results were obtained with the inclusion of other variables.

that target and it only starts to react to the business cycle when inflation is stabilised well below 2.5%. Thus, another important conclusion of this study is that the nonlinear Taylor rule estimated in this paper encompasses quite remarkably the principles of the ECB monetary policy: i) promoting price stability above everything; ii) when that is achieved, promote conditions for a sustainable growth. The fact that the estimated inflation threshold is slightly higher than the 2% reference value announced by the ECB may mean that the ECB is in reality allowing for some monetary flexibility, perhaps to accommodate the differences among the economies that constitute the Eurozone.

Even after the nonlinearities are controlled for, the ECB continues to consider the information contained in financial variables, which reinforces the first main conclusion of this study and allows us to say that the nonlinear Taylor rule augmented with the financial conditions index developed in this paper is the policy rule that best represents the ECB’s behaviour.

Finally, the nonlinear Taylor rule estimated for the BOE indicates that this central bank is pursuing a target range of 1.8%-2.4% for inflation rather than the official point target of 2%. The BOE reacts actively to inflation when it is outside that range, but, once inside, it only reacts to the business cycle and to the credit spread variable.

Besides extending this study to other central banks, another important extension would be to understand whether and how financial sector regulation and commercial banks’ off-balance sheet entities are taken into account in the central banks’ reaction function. We believe that such analysis could contribute a little more to the understanding of the reasons for the recent credit crunch. Our intention is to proceed with that analysis in a future work, as soon as more data are available.

References

Altavilla, Carlo and Luigi Landolfo (2005). Do central banks act asymmetrically? Empirical evidence from the ECB and the Bank of England. *Applied Economics*, 37, 507-519.

Assenmacher-Wesche, Katrin (2006). Estimating Central Banks' preferences from a time-varying empirical reaction function. *European Economic Review*, 50, 1951-1974.

Bec, F., M. Salem, F. Collard (2000). Nonlinear economic policies: Pitfalls in the Lucas critique empirical counterpart. *Mimeo*. University de Cergy-Pontoise.

Bernanke, Ben and Mark Gertler (1999). Monetary policy and asset prices volatility. *Federal Reserve Bank of Kansas City Economic Review*, 84(4), 17-51.

Bernanke, Ben and Mark Gertler (2001). Should Central Banks respond to movements in asset prices? *American Economic Review*, 91(2), 253-257.

Bordo, Michael and Olivier Jeanne (2002). Monetary policy and asset prices: Does 'benign neglect' make sense? *International Finance*, 5(2), 139-164.

Borio, Claudio and Philip Lowe (2002). Asset prices, financial and monetary stability: Exploring the nexus. *Bank for International Settlements Working Papers*, 114.

Bullard, James and Eric Schaling (2002). Why the Fed should ignore the stock market. *The Federal Reserve Bank of St. Louis,* March-April 2002, 35-41.

Cecchetti, S., H. Genberg, J. Lipsky and S. Wadhwani (2000). *Asset Prices and Central Bank Policy*. CEPR, London.

Chadha, J., L. Sarno and G. Valente (2004). Monetary policy rules, asset prices, and Exchange rates. *IMF Staff Papers*, 51(3), 529-552.

Clarida, R., J. Gali and M. Gertler (1998). Monetary policy rules in practice: Some international evidence. *European Economic Review*, 42, 1003-1067.

Clarida, R., J. Gali and M. Gertler (1999). The science of monetary policy: A new Keynesian perspective. *Journal of Economic Literature*, 37(4), 1661-1707.

Clarida, R., J. Gali and M. Gertler (2000). Monetary policy rules and macroeconomic stability: Evidence and some theory. *Quarterly Journal of Economics*, 115(1), 147-180.

Dolado, J., R. Dolores and M. Naveira (2000). Asymmetries in monetary policy: Evidence for four central banks. *CEPR Discussion Paper Series,* Discussion Paper 2441.

Dolado, J., R. Dolores and M. Naveira (2005). Are monetary policy reaction functions asymmetric? The role of nonlinearity in the Phillips curve. *European Economic Review*, 49, 485-503.

Driffill, J., Z. Rotondi, P. Savona and C. Zazzara (2006). Monetary policy and financial stability: What role for futures market? *Journal of Financial Stability,* 2, 95-112.

European Central Bank (1999). *Monthly Bulletin*, January.

Fendel, Ralf and Michael Frenkel (2006). Five years of single European monetary policy in practice: Is the ECB rule-based? *Contemporary Economic Policy*, 24(1), 106-115.

Fourçans, André and Radu Vranceanu (2004). The ECB interest rate rule under the Duisenberg presidency. *European Journal of Political Economy*, 20, 579-595.

Goodhart, Charles and Boris Hofmann (2001). Asset prices, financial conditions, and the transmission of monetary policy. Paper presented at the conference on *Asset Prices, Exchange Rates and Monetary Policy,* Stanford University, March 2-3, 2001.

Goodhart, Charles and Boris Hofmann (2002). Asset prices and the conduct of monetary policy. *Mimeo*. London School of Economics.

Granger, Clive and Timo Teräsvirta (1993). *Modelling Nonlinear Economic Relationships*. Oxford University Press, Oxford.

Hamilton, James (1989). A new approach to the economic analysis of non-stationary time series and the business cycle. *Econometrica*, 57, 357-384.

Hansen, Lars. (1982). Large sample properties of generalized method of moments estimators. *Econometrica*, 50, 1029-1054.

Kaufmann, Sylvia (2002). Is there an asymmetric effect of monetary policy over time? A Bayesian analysis using Austrian data. *Empirical Economics*, 27, 277-297.

Lubik, Thomas and Frank Schorfheide (2007). Do central banks respond to exchange rate movements? A structural investigation. *Journal of Monetary Economics*, 54, 1069-1087.

Martin, Christopher and Costas Milas (2005). Modelling monetary policy: Inflation targeting in practice. *Economica*, 71, 209-221.

Montagnoli, Alberto and Oreste Napolitano (2005). Financial Condition Index and interest rate settings: a comparative analysis. *Istituto di Studi Economici Working Paper* 8.2005. Università degli studi di Napoli "Parthenope".

Neftçi, Salih (2001). Are economic time series asymmetric over the business cycle? *Journal of Political Economy*, 92, 307-328.

Nobay, Robert and David Peel (2003). Optimal discretionary monetary policy in a model of asymmetric central bank preferences. *Economic Journal*, 113(July), 657-665.

Orphanides, Athanasios (2001). Monetary policy rules based on real-time data. *American Economic Review*, 91(4), 964-985.

Petersen, Kenneth (2007). Does the Federal Reserve follow a non-linear Taylor rule? *Department of Economics Working Paper Series*, Working Paper 2007-37. University of Connecticut.

Qin, Ting and Walter Enders (2008). In-sample and out-of-sample properties of linear and nonlinear Taylor rules. *Journal of Macroeconomics*, 30, 428-443.

Rotondi, Zeno and Giacomo Vaciago (2005). The Fed's reaction to asset prices. *Rivista di Politica Economica*, 3-4, 221-243.

Rudebusch, Glenn and Lars Svensson (1999). Policy rules for inflation targeting. In J. B. Taylor Eds. *Monetary Policy Rules*. University of Chicago Press for NBER.

Ruge-Murcia, Francisco (2003). Inflation target under asymmetric preferences. *Journal of Money, Credit and Banking*, 35(5), 763-785.

Sauer, Stephan and Jan-Egbert Sturm (2007). Using Taylor rules to understand the ECB monetary policy. *German Economic Review*, 8(3), 375-398.

Surico, Paolo (2007a). The Fed's monetary policy rule and US inflation: the case of asymmetric preferences. *Journal of Economic Dynamics and Control*, 31, 305-324.

Surico, Paolo (2007b). The monetary policy of the European Central Bank. *Scandinavian Journal of Economics*, 109(1), 115-135.

Svensson, Lars (1997). Inflation forecast targeting: Implementing and monitoring inflation targets. *European Economic Review*, 41, 1111-1146.

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

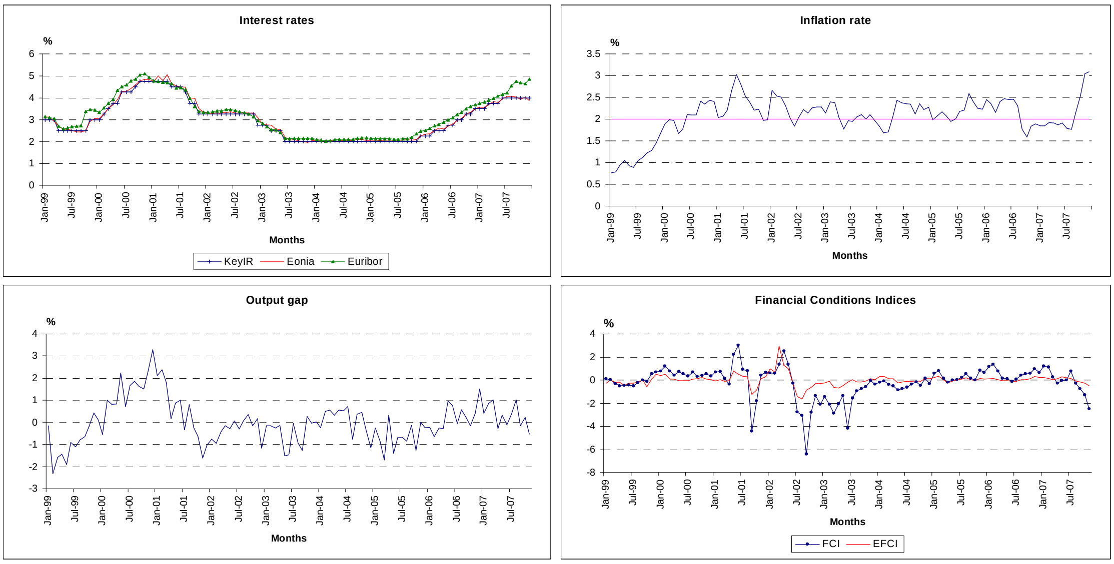
Taylor, Mark and Emmanuel Davradakis (2006). Interest rate setting and inflation targeting: Evidence of a nonlinear Taylor rule for the United Kingdom. *Studies in Nonlinear Dynamics and Econometrics*, 10(4), Article 1.

Teräsvirta, Timo (1998). Modeling economic relationships with smooth transition regressions. In U. Aman and D. Giles (Eds.), *Handbook of Applied Economic Statistics*, Ch. 15, 507-552. Dekker, New York.

van Dijk, D., T. Terävirta and P. Franses (2002). Smooth transition autoregressive models: A survey of recent developments. *Econometric Reviews*, 21(1), 1-47.

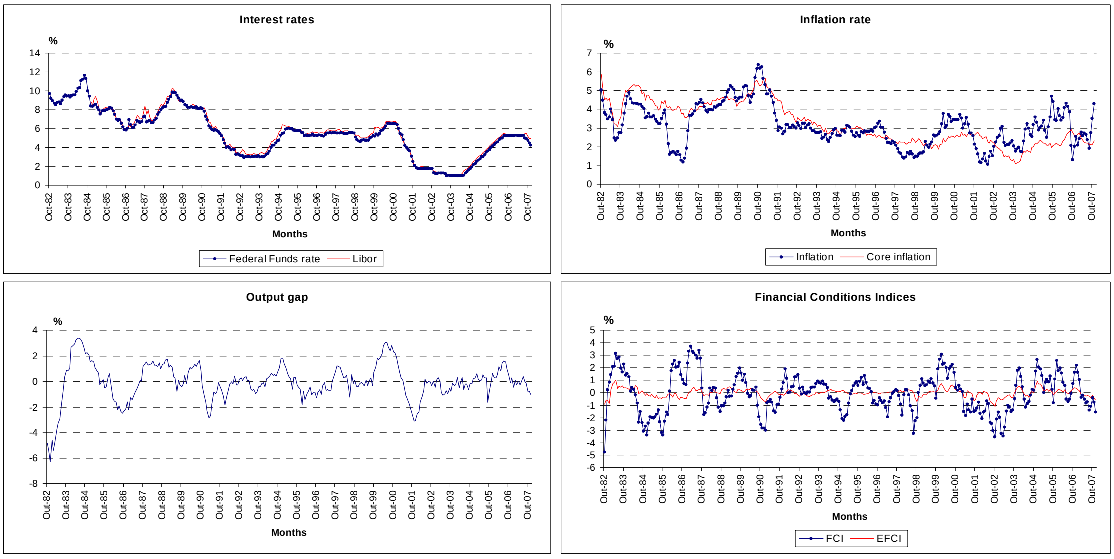
Figures and Tables

Figure 1. Evolution of the main variables: Eurozone



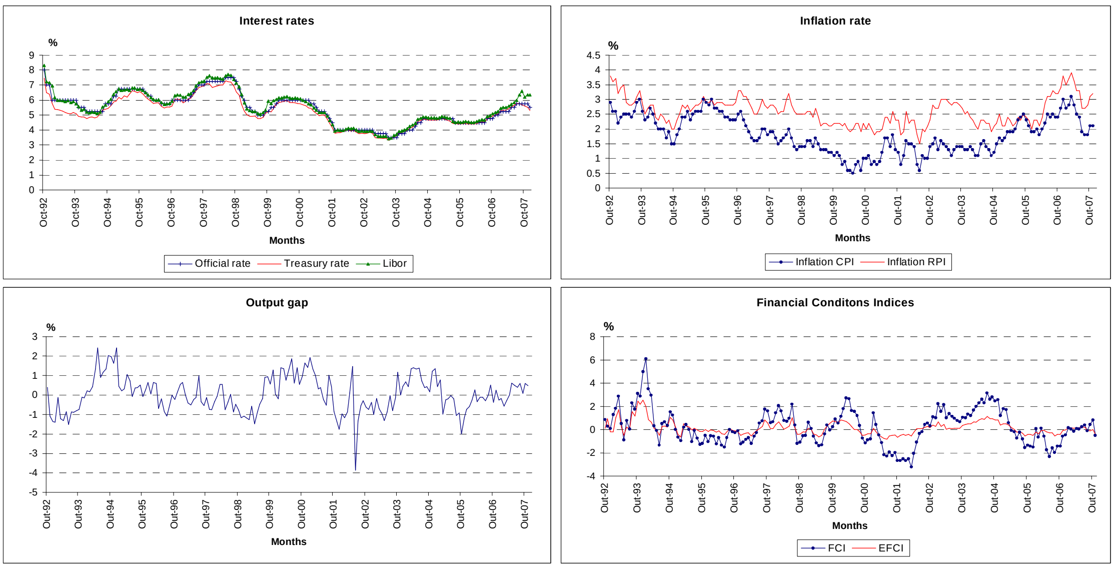
Sources: See Table A.2.1

Figure 2. Evolution of the main variables: US



Sources: See Table A.2.1.

Figure 3. Evolution of the main variables: UK



Sources: See Table A.2.1.

Table 1. Estimation results from the linear model: Eurozone (January 1999-December 2007)

	Main estimation results							Robustness analysis				
	1	2	3	4	5	6	7	8	9	10	11	12
Inflation	-0.045	2.774***	2.624***	2.322***	2.430***	1.179***	2.598***	1.337***	3.281***	1.651***		
	(-0.19)	(2.85)	(2.76)	(3.37)	(3.37)	(4.58)	(3.89)	(2.92)	(3.64)	(3.45)		
OutpGap	0.541***	1.991***	1.860***	1.717***	1.798***	1.153***	1.074***	1.099***		1.507***		
	(6.03)	(5.84)	(5.32)	(6.92)	(7.34)	(9.01)	(3.78)	(8.79)		(8.21)		
Eonia(-1)		0.948***	0.944***	0.947***	0.939***	0.953***	0.958***		0.953***	0.938***	0.950***	0.958***
		(101.3)	(87.7)	(125.0)	(101.6)	(175.5)	(141.6)		(93.2)	(108.7)	(84.3)	(127.1)
Euribor3m(-1)								0.947***				
								(116.5)				
M3			-0.083									
			(-0.93)									
FCI				0.534***								
				(3.73)								
EFCI					0.706**		1.561***	1.222***	0.911***	0.634***		1.758***
					(2.44)		(4.55)	(5.44)	(3.87)	(4.30)		(4.31)
REER_gap						0.122***						
						(3.37)						
RStock_gap						0.041***						
						(3.88)						
RHPI_gap						1.096***						
						(4.86)						
CredSprd						-0.271						
						(-1.27)						
ΔFutSprd						3.186***						
						(4.15)						
US_OutpGap							1.161***	0.648***				1.230***
							(4.59)	(3.67)				(4.14)
EcoSent_gap									0.347***	0.096***		
									(5.04)	(4.00)		
RT_Inflation											3.005***	2.018***
											(3.17)	(4.64)
RT_OutpGap											1.319***	0.632***
											(5.82)	(3.34)
π^*	1.92***	2.39***	2.31***	2.42***	2.52***	5.17	2.53***	3.09**	2.33***	2.86***	2.42***	2.75***
	(16.8)	(18.0)	(16.9)	(15.8)	(14.5)	(1.19)	(14.9)	(2.49)	(31.0)	(5.88)	(21.9)	(9.99)
Hansen *J*-stat.		17.5[0.953]	17.6[0.935]	16.5[0.985]	18.2[0.956]	22.1[0.999]	19.6[0.983]	19.8[0.987]	18.4[0.934]	19.1[0.981]	17.7[0.951]	20.3[0.978]
Adj. R^2	0.347	0.977	0.977	0.979	0.978	0.981	0.983	0.985	0.979	0.980	0.977	0.982
DW	0.37	2.21	2.20	2.34	2.32	2.51	2.57	1.50	1.96	2.40	2.10	2.51
SBIC	447.8	70.54	74.8	68.2	69.0	70.9	49.4	33.7	62.8	64.5	70.4	52.3

Notes: See Table A.2.1 for sources. Column 1 presents the least square estimates of the following basic Taylor rule: $Eonia_t=\alpha+\beta*Inflation_{t-1}+\gamma*OutpGap_{t-1}+u_t$. A GMM estimator is used in the other regressions, where the horizons of the inflation and output gap forecasts are, respectively, 12 and 3 months (even when real time data is used); the other variables (except US_OutpGap) are all lagged one period to avoid simultaneously problems, i.e. $Eonia_t=(1-\rho)*[\alpha+\beta*Inflation_{t+12}+\gamma*OutpGap_{t+3}+\boldsymbol{\theta}'\mathbf{x}_{t-1}]+\rho*Eonia_{t-1}+\varepsilon_t$, where α, β, γ, and the vector $\boldsymbol{\theta}$ represent the estimated parameters; the respective standard errors are recovered from the estimated reduced form using the delta method. The set of instruments includes always a constant, 1-6, 9, 12 lagged values of the *Inflation*, *OutpGap*, *Yield10yr* and *M3*; some lags of the other exogenous variables are also used when those variables are added to the equation. Robust standard errors (heteroscedasticity and autocorrelation-consistent) with Newey-West/Bartlett window and 3 lags were computed and the respective *t*-statistics are presented in parentheses; significance level at which the null hypothesis is rejected: ***, 1%; **, 5%; and *, 10%. The estimate of $\pi^*(=(r-\alpha)/(\beta-1))$ assumes that the long-run equilibrium real interest rate is equal to its sample average (*r*). The *p*-value of the Hansen's overidentification test is reported in square brackets. The Schwartz Bayesian Information Criterion is computed as follows: SBIC=N*ln(RSS)+k*ln(N), where k is the number of regressors, N is the number of observations and RSS is the residual sum of squares. DW represents the Durbin-Watson statistic.

Table 2. Estimation Results from the linear model: US and UK

	United States (October 1982-December 2007)							United Kingdom (October 1992-December 2007)							
	US1	**US2**	**US3**	**US4**	**US5**	**US6**	**US7**	**UK1**	**UK2**	**UK3**	**UK4**	**UK5**	**UK6**	**UK7**	**UK8**
Inflation								0.532***	1.872***	1.971***	1.791***	1.377***	1.563***	1.809***	0.610
								(3.27)	(4.89)	(4.59)	(4.02)	(3.60)	(6.62)	(5.81)	(1.43)
CoreInfl	1.632***	1.530***	1.462***	1.542***	1.556***	1.369**	2.759***								
	(11.5)	(5.18)	(4.71)	(5.53)	(5.80)	(2.12)	(3.00)								
OutpGap	0.356***	1.404***	1.314***	1.039***	1.203***		0.967**	0.264***	0.912***	0.839**	0.882**	0.865***	0.648***		0.725***
	(2.59)	(2.77)	(2.61)	(2.71)	(2.96)		(2.15)	(2.85)	(2.80)	(2.43)	(2.10)	(2.94)	(3.01)		(3.02)
FedRate(-1)		1.430***	1.448***	1.471***	1.291***	1.739***	1.755***								
		(14.2)	(14.9)	(13.4)	(13.1)	(15.3)	(21.7)								
FedRate(-2)		-0.467***	-0.484***	-0.508***	-0.325***	-0.756***	-0.776***								
		(-4.73)	(-5.09)	(-4.73)	(-3.37)	(-6.85)	(-10.1)								
TreasRate(-1)									1.388***	1.396***	1.447***	1.456***	1.377***	1.318***	1.577***
									(13.9)	(13.3)	(15.5)	(19.5)	(19.4)	(9.74)	(36.4)
TreasRate(-2)									-0.433***	-0.440***	-0.484***	-0.492***	-0.433***	-0.403***	-0.605***
									(-4.78)	(-4.69)	(-5.75)	(-6.96)	(-6.95)	(-3.29)	(-15.3)
FCI			0.125							0.089					
			(0.56)							(0.63)					
EFCI				1.658							0.160				
				(1.29)							(0.39)				
CredSprd					1.242**							1.878***			
					(2.56)							(3.57)			
Δ*FutSprd*					4.734**										
					(2.14)										
US_OutpGap													0.135*		
													(1.82)		
EcoSent_gap						0.272								0.448***	
						(0.79)								(2.80)	
π^*	3.23***	3.52***	3.54***	3.56***	-1.36	3.54**	2.60***	1.80***	1.93***	1.93***	1.97***	-2.69	1.99***	1.74***	1.34***
	(11.9)	(6.18)	(5.29)	(6.26)	(-0.44)	(2.27)	(7.23)	(6.48)	(7.80)	(8.17)	(6.31)	(-0.64)	(8.82)	(10.1)	(3.35)
Hansen *J*-stat.		20.3	21.6	21.9	24.9	16.2	13.2		22.2	21.6	22.4	26.5	32.2	17.8	18.6
		[0.441]	[0.485]	[0.407]	[0.635]	[0.299]	[0.868]		[0.771]	[0.710]	[0.664]	[0.739]	[0.951]	[0.852]	[0.910]
Adj. R^2	0.603	0.993	0.993	0.993	0.993	0.992	0.995	0.142	0.979	0.979	0.980	0.982	0.979	0.974	0.978
DW	0.06	2.18	2.22	2.29	2.18	2.57	2.48	0.10	1.73	1.73	1.91	2.11	1.68	1.17	2.31
SBIC	2010.5	754.0	759.2	745.9	753.7	808.3	66.6	927.4	234.7	238.9	228.2	213.0	241.4	275.4	28.8

Notes: See Table A.2.1 for sources. Columns US1 and UK1 present the least square estimates of a basic Taylor rule identical to the one estimated for the Eurozone. A GMM estimator is used in the other regressions; the horizons of the inflation and output gap forecasts for the US (UK) are, respectively, 12 (6) and 3 (0) months (these leads were chosen according to the SBIC); the other variables (except US_OutpGap) are all lagged one period to avoid simultaneously problems. The set of instruments for the US includes a constant, 1-6, 9, 12 lagged values of the *CoreInfl*, *OutpGap* and *Yield10yr*; the set of instruments for the UK includes a constant, 1-6, 9, 12 lagged values of the *RPI_Infl*, *OutpGap*, *Yield10yr* and *FCI*; some lags of the other exogenous variables are also used when those variables are added to the equation. In these two cases, a second-order partial adjustment model fits the data better than the first-order model used for the Eurozone. Robust standard errors (heteroscedasticity and autocorrelation-consistent) with Newey-West/Bartlett window and 3 lags were computed and the respective *t*-statistics are presented in parentheses; significance level at which the null hypothesis is rejected: ***, 1%; **, 5%; and *, 10%. The *p*-value of the Hansen's overidentification test is reported in square brackets. Regressions in columns US7 and UK8 were estimated just over the period January 1999-December 2007.For further details see Table 1.

Table 3. Estimation results from the nonlinear model

	Eurozone				United States		United Kingdom		
	EZ1	**EZ2**	**EZ3**	**EZ4**	**US1**	**US2**	**UK1**	**UK2**	**UK3**
ψ_0	3.156***	-0.397	2.636***	2.820***	4.806***	-1.712**	5.536***	2.063*	3.357***
	(19.9)	(-0.12)	(14.9)	(12.4)	(14.9)	(-2.03)	(11.0)	(1.71)	(2.92)
ψ_π		1.353							
		(0.87)							
ψ_y	0.347***	2.091***	1.979***	3.091***	0.303**	0.555*	0.257***	1.301**	1.136***
	(3.56)	(4.36)	(4.67)	(3.63)	(2.24)	(1.77)	(2.62)	(2.30)	(3.59)
ψ_{efci}		0.092**	0.537*						
		(2.34)	(1.71)						
ψ_{cs}									1.031*
									(1.72)
ρ		0.963***	0.960***	0.974***					
		(112.6)	(110.8)	(130.9)					
ρ_1						1.500***		1.258***	1.267***
						(11.6)		(11.6)	(14.4)
ρ_2						-0.561***		-0.295***	-0.289***
						(-4.37)		(-2.80)	(-3.54)
ω_0	-2.784***				-6.117***		-1.388**		
	(-3.08)				(-9.51)		(-2.28)		
ω_π	1.139***	1.164*	1.190**	1.169***	1.974***	2.537***	0.541**	2.356**	2.415***
	(2.88)	(1.83)	(2.38)	(2.59)	(13.5)	(7.52)	(3.28)	(2.52)	(2.82)
ω_y	0.321**	-2.483*	-1.639						
	(2.45)	(-1.82)	(-1.47)						
η	21.19	95.04	98.60	15.9	7.22	8.55	64.33	5.61	2.79
	{29.26}	{651.3}	{353.0}	{23.47}	{7.00}	{7.01}	{1490.1}	{6.64}	{3.13}
c	1.99***	2.47***	2.47***	2.41***					
	(45.0)	(190.3)	(197.7)	[72.4]					
c_1					2.04***	3.10***	1.61***	1.79***	1.75***
					(20.0)	(13.3)	(9.96)	(9.67)	(5.53)
c_2					3.67***	3.68***	1.99***	2.35***	2.37***
					(10.0)	(12.2)	(9.87)	(22.4)	(21.4)
$\psi_\pi+\omega_\pi$		2.517*							
		(1.78)							
$\psi_y+\omega_y$	0.668***	-0.392	0.340						
	(7.30)	(-0.31)	(0.33)						
Hansen		16.4	16.3	17.5		18.9		18.8	24.3
J-stat.		[0.927]	[0.947]	[0.983]		[0.331]		[0.804]	[0.912]
Adj. R^2	0.407	0.978	0.978	0.978	0.632	0.992	0.145	0.977	0.980
DW	0.54	2.27	2.36	2.30	0.09	1.98	0.15	1.50	1.60
SBIC	452.0	83.7	77.3	72.6	2006.2	817.0	942.5	262.0	247.0
H_{01}	0.000	0.037	0.037	0.000	0.000	0.092	0.001	0.075	0.023
H_{02}	0.053	0.004	0.004	0.003	0.274	0.646	0.187	0.224	0.016
H_{03}	0.045	0.300	0.300	0.121	0.061	0.054	0.055	0.095	0.005
H_{04}	0.014	0.180	0.180	0.019	0.117	0.042	0.562	0.424	0.017

Notes: See Table A.2.1 for sources. Column EZ1, US1 and UK1 present the (Gauss-Newton) nonlinear Least Square (LS) estimates of the following basic nonlinear Taylor rule: $IR_t=\psi_0+\psi_\pi*Inflation_{t-1}+\psi_y*OutpGap_{t-1}+(\omega_0+\omega_\pi*Inflation_{t-1}+\omega_y*OutpGap_{t-1})*G(\eta,c,Inflation_{t-1})+u_t$, where *IR* is the respective interest rate considered for each country and $G(\eta,c,Inflation_{t-1})=[1+\exp(-\gamma\,(Inflation_{t-1}-c))]^{-1}$, when the LSTR1 is chosen model, or $G(\eta,c,Inflation_{t-1})=[1+\exp(-\gamma(Inflation_{t-1}-c_1)*\,(Inflation_{t-1}-c_2))]^{-1}$, when an LSTR2 is preferred instead. H_{02} to H_{04} report the *p*-value of the tests used to choose the preferred model; H_{01} reports the *p*-value of the linearity test. A nonlinear Instrumental Variables (IV) estimator is used in the other regressions, where the horizons of the inflation and output gap forecasts are, respectively, 12 and 3 months for the Eurozone and the US, and 6 and 0 months for the UK. Considering the case of the Eurozone, the equation can be written generically as follows: $Eonia_t=(1-\rho)*(\psi_0+\psi_\pi*Inflation_{t+12}+\psi_y*OutpGap_{t+3}+\psi_{efci}*EFCI_{t-1})+\rho*Eonia_{t-1}+(1-\rho)*(\omega_0+\omega_\pi*Inflation_{t+12}+\omega_y*OutpGap_{t+3}+\omega_{efci}*EFCI_{t-1})*G(\eta,c,Inflation_{t+12})+\varepsilon_t$. A similar equation is considered for the US and UK, however, in these cases, a second-order partial adjustment model fits the data better than the first-order model used for the Eurozone; moreover, *EFCI* is replaced by *CredSprd* in regression 3 for the UK3; both variables are lagged one period to avoid simultaneously problems. The best fitting model is found by sequentially eliminating insignificant regressors by using the SBIC measure of fit. The set of instruments includes: a constant, 1-6, 9, 12 lagged values of the *Inflation*, *OutpGap*, *Yield10yr* and *M3*, and the second and third lags of *EFCI* for the Eurozone; a constant, 1-6, 9, 12 lagged values of the *CoreInfl*, *OutpGap* and *Yield10yr* for the US; and a constant, 1-6, 9, 12 lagged values of the *RPI_Infl*, *OutpGap*, *Yield10yr* and *FCI* for the UK. Following Granger and Teräsvirta (1993) and Teräsvirta (1998), η is made dimension free by dividing it by the standard deviation (LSTR1) or variance (LSTR2) of the inflation variable; since η is not defined at zero, the respective standard error is reported (in brackets) instead of the *t*-statistic; η presents high standard deviations because relative few observations are located around the threshold. Robust standard errors (heteroscedasticity and autocorrelation-consistent) with Newey-West/Bartlett window and 3 lags were computed and the respective *t*-statistics are presented in parentheses; significance level at which the null hypothesis is rejected: ***, 1%; **, 5%; and *, 10%. The delta method is used to compute the standard errors of $\psi_\pi+\omega_\pi$ and $\psi_y+\omega_y$. The *p*-value of the Hansen's overidentification test is reported in square brackets. The time periods considered for each country are the same as the linear estimations. For further details see Table 1 and Table 2.

Annex

A.1 Derivation of the linear forward-looking Taylor rule

According to the New-Keynesian model,[41] the evolution of the economy can be described by the following equations:

$$\pi_{t+k} = a_1 \pi_{t+k-1} + a_2 (y_{t+p} - y^*_{t+p}) + \mu^s_{t+k}, \tag{A.1.1}$$

$$(y_{t+p} - y^*_{t+p}) = b_1 (y_{t+p-1} - y^*_{t+p-1}) - b_2 (i_t - \pi_{t+k-1}) + \mu^d_{t+p}. \tag{A.1.2}$$

Equation **(A.1.1)** can be interpreted in terms of a Phillips curve (or AS curve) where inflation is sluggish and depends on the cyclical component of output, whilst equation **(A.1.2)** can be considered as an aggregate demand curve where output gap depends on its lagged value and on the real interest rate. Supply and demand disturbances are captured by μ^s and μ^d, respectively.

Assuming that the central bank uses a policy rule to control monetary policy, the problem faced by this authority is to choose the interest rate in period *t* conditional upon the information available at that time. Therefore, at time *t* the central bank commits to a state contingent sequence of short-term interest rates in order to minimize the following inter-temporal loss function:

$$E_t \sum_{\tau=0}^{\infty} \delta^\tau \left[\lambda_1 (\pi_{t+\tau} - \pi^*)^2 + \lambda_2 (y_{t+\tau} - y^*_{t+\tau})^2 + \lambda_3 (i_{t+\tau} - \bar{i})^2 \right] \tag{A.1.3}$$

subject to **(A.1.1)** and **(A.1.2)**. The parameter δ represents the inter-temporal discount factor (0< δ <1) and $\bar{i}$ is the long-run equilibrium nominal interest rate ($\bar{i} = \bar{r} + \pi^*$). Svensson (1997) shows that since i_t does not affect y_t and π_t contemporaneously, minimizing **(A.1.3)** is equivalent to the period-by-period static minimization of:

$$\min_{i_t} E_t \left[\lambda_1 (\pi_{t+k} - \pi^*)^2 + \lambda_2 (y_{t+p} - y^*_{t+p})^2 + \lambda_3 (i_t - \bar{i})^2 \right]. \tag{A.1.4}$$

Therefore, after some calculations and simplifications, the first-order necessary conditions for policy reaction function are given as follows:

$$i^*_t = \bar{i} + \beta E_t (\pi_{t+k} - \pi^*) + \gamma E_t (y_{t+p} - y^*_{t+p}), \tag{A.1.5}$$

which can be rewritten as equation **(2)**, considering that the central bank relies on all available information in beginning period *t* to choose the interest rate for that period.

[41] For more details on the derivation of the forward-looking Taylor rule derived in this section, see Svensson (1997) and Clarida *et al.* (1999).

This model can be easily extended to include additional equations (and variables). In general, the vector $x_{t+q} = f(\pi_{t+k}, y_{t+p} - y^*_{t+p}, i_{t-j}, x_{1,t+q-l}, ..., x_{m,t+q-l})$ of *j=1,…,m* linear equations (and variables) – where *l*=0,1,2,… and $x_1, \ldots, x_m$ are elements of the vector ***x*** – can be added to the system as a way of providing additional explanations for the evolution of the economy. Similarly, the central bank can also take those variables into account in its minimization problem, which means that the term $\sum_{j=1}^{m} \lambda_{j+3} x^2_{j,t+q}$ can be added to the loss function. In this case, the result of the minimization problem will resemble equation **(5)** after controlling for interest rate smoothing.

A.2 Description of the variables, descriptive statistics and unit root tests

A complete description of the variables used in this paper is presented in this part of the Annex – for the Eurozone, United States and United Kingdom – as well as some descriptive statistics and unit root and stationarity tests.

Table A.2.1. Description of the variables and respective sources

	Eurozone (January 1999-December 2007)	United States (October 1982-December 2007)	United Kingdom (October 1992-December 2007)
Eonia	Euro Overnight Index Average (EONIA) lending interest rate on the Eurozone money market.		
Euribor3m	3-month Euro Interbank Offered Rate (Euribor).		
KeyIR	Key ECB interest rate of the main refinancing operations; minimun bid rate (end of the month).		
FedRate		Effective Federal Reserve funds interest rate (monthly average).	
Libor3m		3-month Interbank US Dollar lending rate (Libor)	3-month Interbank Sterling lending rate (Libor).
TreasRate			3-month Treasury bill discount rate (monthly average).
OfficRate			Official Central Bank interest rate (end of the month).
Inflation	Inflation rate computed as the annual rate of change of the harmonized index of consumer prices (HICP, base year: 2005=100), seasonally adjusted.	Inflation rate computed as the annual rate of change of the consumer prices index (CPI, base year: 1982-84=100) for all urban consumers and all items, seasonally adjusted.	Inflation rate computed as the annual rate of change of the CPI (base year: 2005=100), seasonally adjusted. *Note*: The official CPI starts in 1996 but historical estimates back to 1988 were calculated by the UK Office for National Statistics based on archived RPI data.
CoreInfl		Core inflation rate computed as the annual rate of change of the consumer price index (CPI, base year 1982-84=100) for all urban consumers and all items less food and energy, seasonally adjusted.	
RPI_Infl			Retail price index (RPI) inflation rate computed as the annual change of the RPI all items (January 1987=100).
OutpGap	Output gap computed as the percentage deviation of the (log) industrial production index (total industry, seasonally adjusted) from its Hodrick-Prescott trend.	Output gap computed as the percentage deviation of the (log) industrial production index (total industry, seasonally adjusted) from its Hodrick-Prescott trend.	Output gap computed as the percentage deviation of the (log) industrial production index (total industry, seasonally adjusted) from its Hodrick-Prescott trend.
M3	Annual growth rate of the monetary aggregate M3 (seasonally adjusted, 3-month moving average).		
FCI	Financial conditions index computed as the weighted average of the real effective exchange rate, real share prices and real property prices.	Financial conditions index computed as the weighted average of the real effective exchange rate, real share prices and real property prices.	Financial conditions index computed as the weighted average of the real effective exchange rate, real share prices and real property prices.
EFCI	Extended financial conditions index computed from the weighted average of the real effective exchange rate, real share prices and real property prices plus credit spread and futures interest rate spread.	Extended financial conditions index computed from the weighted average of the real effective exchange rate, real share prices and real property prices plus credit spread and futures interest rate spread.	Extended financial conditions index computed from the weighted average of the real effective exchange rate, real share prices and real property prices plus credit spread and futures interest rate spread.
REER	Real effective exchange rate of the Euro against a group of 24 currencies (CPI deflated); a depreciation of the Euro corresponds to an increase in *REER*.	Real effective exchange rate of the US Dollar against the currencies of a group of 26 major US trading partners (CPI deflated); a depreciation of the US Dollar corresponds to an increase in *REER*.	Real effective exchange rate of the UK Pound against the currencies of the major UK trading partners (CPI deflated); a depreciation of the UK Pound corresponds to and increase in *REER*.

(To be continued on the next page…)

(… Continued from the previous page.)

RStock	Real share price index computed as the monthly average of the Dow Jones Euro STOXX price index (HICP deflated).	Real share price index computed as the monthly average of the Dow Jones Wilshire 5000 composite share price index (CPI deflated).	Real share price index computed as the monthly average of the FTSE 100 share price index (CPI deflated).
RHPI	Real house price index obtained by linear interpolation of half yearly data for the Eurozone residential property price index (period 1995-07; 2004=100; HICP deflated).	Real house price index obtained from the linear interpolation of the quarterly data for the US residential property price index (1980Q1=100; CPI deflated).	Real house price index obtained from the Nationwide monthly house price index (1993Q1=100; CPI deflated and seasonally adjusted).
Yield10yr	10-year Eurozone government benchmark bond yield (monthly average).	10-Year US Treasury benchmark bond yield (government constant maturity rate, monthly average).	10-year monthly average yield from British Government Securities.
CorpBond	Eurozone Corporate Bond Yield, i.e. interest rate returns on commercial corporate bonds (monthly average).		UK Corporate Bond Yield, i.e. interest rate returns on commercial corporate bonds (monthly average).
BAAYield		Moody's Seasoned BAA Corporate Bond Yield.	
FutIR	3-month Euribor interest rate futures contracts (monthly average).	3-month Eurodollar interest rate futures contracts (monthly average).	3-month Sterling interest rate futures contracts (monthly average).
CredSprd	Difference between *Yield10yr* and *CorpBond*.	Difference between *Yield10yr* and *BAAYield*.	Difference between *Yield10yr* and *CorpBond*.
Δ*FutSprd*	Monthly change of the difference between *FutIR* in the previous quarter and the current *Euribor3m*.	Monthly change of the difference between *FutIR* in the previous quarter and the current *FedRate*.	Monthly change of the difference between *FutIR* in the previous quarter and the current *TreasRate*.
EcoSent	Economic sentiment indicator developed by the European Commission and based on surveys of firms and consumers at national level (seasonally adjusted).	Economic sentiment indicator computed as the simple average of the consumer sentiment and manufacturing industrial confidence indicators (seasonally adjusted).	Economic sentiment indicator computed as the simple average of the consumer and industrial confidence indicators (seasonally adjusted).
RT_Inflation	Real time inflation rate obtained from the inflation estimates reported in the Euro Area Statistics of the ECB Monthly Bulletins for each month.		
RT_OutpGap	Real time output gap computed as the ex-post *OutpGap*, but from the most recent values for the industrial production published in each ECB Monthly Bulletin.		
Sources:	European Central Bank Statistics and Monthly Bulletins (http://www.ecb.int/stats/html/index.en.html); Datastream for *CorpBond* and *FutIR*.	Federal Reserve Bank of St. Louis Economic Data – FredII (http://research.stlouisfed.org/fred2/); ECB Statistics for *Libor3m*; Datastream for *REER*, *RStock* and *FutIR*. Office of Federal Housing Enterprise Oversight (http://www.ofheo.gov/hpi_download.aspx) for *RHPI*.	Bank of England Statistics (http://www.bankofengland.co.uk/statistics/index.htm); UK Office for National Statistics (http://www.statistics.gov.uk/); OECD, Main Economic Indicators for *REER*, *RStock* and *EcoSent*; Nationwide Building Society for *RHPI* (http://www.nationwide.co.uk/hpi/historical.htm); Datastream for *CorpBond* and *FutIR*.

Table A.2.2. Descriptive Statistics: Eurozone (January 1999 – December 2007)

Variable	No. Obs.	Mean	Std. Dev.	Min.	Max.
Eonia	108	3.077	0.900	1.97	5.06
Euribor3m	108	3.213	0.939	2.03	5.09
KeyIR	108	3.014	0.891	2.00	4.75
Inflation	108	2.057	0.451	0.76	3.09
OutpGap	107	0.021	0.995	-2.33	3.30
M3	107	7.101	1.941	3.80	12.30
FCI	107	-0.161	1.347	-6.39	3.02
EFCI	107	0.007	0.502	-1.62	2.95
REER	108	102.605	8.895	89.38	121.18
RStock	108	334.188	78.552	191.24	506.99
RHPI	108	96.853	10.965	80.94	114.53
Yield10yr	108	4.442	0.653	3.16	5.70
CorpBond	108	4.706	0.847	3.35	6.18
FutIR	108	3.228	0.938	1.94	5.20
EcoSent	108	102.548	7.713	87.30	117.40
RT_Inflation	108	2.117	0.483	0.80	3.40
RT_OutpGap	107	-0.033	1.225	-2.58	4.05

Sources: See Table A.2.1.

Table A.2.3. Descriptive Statistics: United States (October 1982 – December 2007)

Variable	No. Obs.	Mean	Std. Dev.	Min.	Max.
FedRate	303	5.501	2.458	0.98	11.64
Libor3m	277	5.362	2.203	1.11	10.30
CoreInfl	303	3.227	1.114	1.09	5.86
Inflation	303	3.124	1.070	1.07	6.38
OutpGap	303	-0.035	1.469	-6.29	3.38
FCI	303	-0.035	1.543	-4.74	3.72
EFCI	303	0.004	0.317	-1.10	1.01
REER	303	105.350	11.081	78.59	123.50
RStock	303	4174.309	1998.298	1258.44	8233.81
RHPI	303	138.922	23.750	113.39	201.41
Yield10yr	303	6.913	2.284	3.33	13.56
BAAYield	303	8.999	2.256	5.82	15.15
FutIR	303	5.841	2.574	1.03	12.98
EcoSent	303	95.568	5.104	79.68	106.77

Sources: See Table A.2.1.

Table A.2.4. Descriptive Statistics: United Kingdom (October 1992 – December 2007)

Variable	No. Obs.	Mean	Std. Dev.	Min.	Max.
TreasRate	183	5.223	0.972	3.31	7.47
Libor3m	183	5.535	1.094	3.42	8.32
OfficRate	183	5.440	1.048	3.50	8.00
Inflation	183	1.817	0.621	0.50	3.10
RPI_Infl	183	2.709	0.855	0.70	4.80
OutpGap	182	0.026	0.930	-3.85	2.43
FCI	182	0.208	1.505	-3.21	6.10
EFCI	182	0.129	0.569	-0.81	2.51
REER	183	108.309	8.648	97.35	127.21
RStock	183	80.367	17.296	50.32	113.43
RHPI	183	201.461	81.685	117.01	352.54
Yield10yr	183	5.895	1.461	4.08	8.90
CorpBond	183	6.817	1.486	5.10	10.49
FutIR	183	5.597	1.089	3.44	7.84
EcoSent	182	100.446	1.714	94.36	103.56

Sources: See Table A.2.1.

Table A.2.5. Unit root and stationarity tests

	Eurozone			United States			United Kingdom		
	DF	**NP**	**KPSS**	**DF**	**NP**	**KPSS**	**DF**	**NP**	**KPSS**
Eonia	-0.604	-1.425	0.321+						
Euribor3m	0.215	-0.868	0.295+						
FedRate				-1.887	-0.547	1.450			
TreasRate							-4.425*	-0.864	0.730+
Inflation	-2.723*	0.117	0.432+				-2.718*	-1.246	0.482+
CoreInfl				-2.277	-0.250	1.990			
OutpGap	-4.881*	-3.869*	0.095+	-3.599*	-1.141	0.035+	-6.210*	-5.136*	0.044+
M3	1.593	0.529	0.927						
FCI	-4.236*	-3.512*	0.160+	-4.711*	-1.640*	0.043+	-4.430*	-3.346*	0.109+
EFCI	-4.754*	-2.700*	0.048+	-5.346*	-1.876*	0.033+	-4.923*	-4.141*	0.214+
REER_gap	-2.901*	-1.439	0.142+	-4.509*	-2.429*	0.032+	-3.579*	-2.006*	0.156+
RStock_gap	-2.219	-2.457*	0.156+	-4.791*	-2.460*	0.038+	-3.989*	-3.305*	0.071+
RHPI_gap	-2.368	-1.992*	0.087+	-2.822*	-1.877*	0.031+	-2.959*	-2.441*	0.050+
CredSprd	-1.452	-1.175	0.157+	-2.808*	-0.800	0.187+	-1.227	-1.204	0.169+
ΔFutSprd	-7.352*	-4.707*	0.229+	-14.22*	-1.159	0.165+	-9.625*	-0.812	0.195+
EcoSent_gap	-1.678	-2.236*	0.067+	-5.605*	-3.337*	0.062+	-2.705*	-1.750*	0.027+
RT_Inflation	-2.647*	-0.264	0.208+						
RT_OutpGap	-3.951*	-2.475*	0.076+						
1% crit.value	-3.507	-2.580	0.739	-3.456	-2.580	0.739	-3.482	-2.580	0.739
5% crit.value	-2.889	-1.980	0.463	-2.878	-1.980	0.463	-2.884	-1.980	0.463
10%crit.value	-2.579	-1.620	0.347	-2.570	-1.620	0.347	-2.574	-1.620	0.347

Sources: See Table A.2.1.

Notes: DF=Dickey-Fuller (1979) unit root test; NP=Ng-Perron (2001) unit root MZt test (the MZa, MSB and MPT tests yield similar results); KPSS=Kwiatkowski-Phillips-Schmidt-Shin (1992) stationarity test. The automatic Newey-West bandwidth selection procedure is used in the NP and KPSS tests and, in both cases, the autocovariances are weighted by the Bartlett kernel.

* unit root is rejected at a significance level of 10% => stationarity.

+ stationarity is not rejected at a significance level of 10%.

Most Recent Working Papers

NIPE WP 19/2008	**Castro, Vítor,** “Are Central Banks following a linear or nonlinear (augmented) Taylor rule?”, 2008
NIPE WP 18/2008	**Castro, Vítor,** “The duration of economic expansions and recessions: More than duration dependence”, 2008
NIPE WP 17/2008	**Holmås, Tor Helge, Egil Kjerstad, Hilde Lurås and Odd Rune Straume,** “Does monetary punishment crowd out pro-social motivation? The case of hospital bed-blocking”, 2008.
NIPE WP 16/2008	**Alexandre, Fernando, Miguel Portela and Carla Sá,** “Admission conditions and graduates’ employability”, 2008.
NIPE WP 15/2008	**Alexandre, Fernando, Pedro Bação and Vasco Gabriel,** “Taylor-type rules versus optimal policy in a Markov-switching economy”, 2008.
NIPE WP 14/2008	**Bastos, Paulo, Natália P. Monteiro and Odd Rune Straume**, “Firm heterogeneity and wages in unionised labour markets: Theory and evidence”, 2008.
NIPE WP 13/2008	**Esteves, Rosa Branca**, “Price Discrimination with Private and Imperfect Information”, 2008.
NIPE WP 12/2008	**Esteves, Rosa Branca,** “Price Discrimination with Partial Information: Does it pay off?”, 2008.
NIPE WP 11/2008	**Ribeiro, José Cadima and José Freitas Santos,** “Portuguese quality wine and the region-of-origin effect: consumers’ and retailers’ perceptions”, 2008.
NIPE WP 10/2008	**Lommerud, Kjell Erik, Frode Meland and Odd Rune Straume,** “Mergers and capital flight in unionised oligopolies: Is there scope for a ‘national champion’ policy?”, 2008.
NIPE WP 9/2008	**Gabriel, Vasco J., Paul Levine and Christopher Spencer,** "How forward-looking is the Fed? Direct estimates from a ‘Calvo-type’ rule", 2008.
NIPE WP 8/2008	**Brekke, Kurt R., Roberto Cellini, Luigi Siciliani and Odd Rune Straume,** "Competition and quality in regulated markets: a differential-game approach", 2008.
NIPE WP 7/2008	**Neto, Delfim Gomes, and Francisco José Veiga**, “Financial globalization, convergence and growth”, 2008.
NIPE WP 6/2008	**Brekke, Kurt R., Luigi Siciliani and Odd Rune Straume,** "Hospital competition and quality with regulated prices", 2008.
NIPE WP 5/2008	**Aguiar-Conraria, Luís, and Pedro C. Magalhães,** "Referendum Design, Quorum Rules and Turnout", 2008.
NIPE WP 4/2008	**Silva, João Cerejeira,** “Young Employment, Job-Skill Composition and Minimum Wages: Evidence from a ‘Natural Experiment’ ”, 2008.
NIPE WP 3/2008	**Amado, Cristina, and Timo Teräsvirta**, "Modelling Conditional and Unconditional Heteroskedasticity with Smoothly Time-Varying Structure", 2008.
NIPE WP 2/2008	**Buhai, Sebastian, Miguel Portela, Coen Teulings and Aico van Vuuren**, "Returns to Tenure or Seniority?", 2008.
NIPE WP 1/2008	**Brekke, Kurt R., Tor Helge Holmås and Odd Rune Straume**, "Regulation, generic competition and pharmaceutical prices: Theory and evidence from a natural experiment", 2008.