Estimating Monetary Policy Preferences of the ECB

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Abstract

This paper estimates central bank policy preferences of the euro area and of the UK. We do so, by adopting the framework suggested by Cecchetti and Ehrmann (1999), which, however, we extent in two respects. First, we allow policy preferences to be asymmetric by assuming that inflation and output follow a Markov process. Second, following Bean (1998) we introduce dynamics into the supply and demand relationships. In doing so we can only estimate state-dependent policy frontiers rather than policy preferences. Empirical results from the static model show that euro area countries put more weight on inflation than the UK. Especially after 2006, in the high volatility regime, the UK has reduced the weight on inflation from 72% to 18%. Alternatively, estimates of optimal policy frontier suggest that although the UK enjoys higher anti-inflationary credibility (i.e. steeper slope), it also faces a higher trade-off between inflation and output variability than the euro area does. This is in line with evidence from the static model where the UK enjoys the advantage of its anti-inflationary credibility. This has changed substantially the policy preferences.

1 Introduction

The primary objective of the European Central Bank (ECB), stated in Article 2 of its statute, is to maintain price stability (see, also, Article 3 of the Maastricht Treaty). Svensson (2001) argues that defining price stability boils down to establishing a monetary-policy loss function. Svensson (op. cit.) also argues that maintaining price stability involves minimizing the policy maker's loss function. Three alternative policies are considered, namely, commitment to a simple instrument rule such as the Taylor rule, forecast targeting (for instance inflation-forecast targeting) and intermediate targeting. Svensson (2001), based on his earlier work (Svensson, 1997), suggests that forecast targeting is the best practice to conduct monetary policy in the real world. This is so because unlike the targeting rule, forecast targeting provides a systematic operational framework where a central bank instead of being forward looking only, once the policy rule is introduced, it needs to be continuously forward looking.

This discussion clearly shows that optimal monetary policy involves minimising the loss function of the policy maker on the basis of inflation forecasts. It is easy to show that the optimal policy under a quadratic loss function and linear dynamic of the economic state variables, is to set the rate of interest so that forecast inflation is equal to its target level. This is what Svensson (2001) calls inflation-forecast targeting.

Relevant literature in economics shows that macro-variables might follow a Markov regime switching process. If this is the case then the policy maker's loss function and the optimal policy rule that emerges from it become state dependent. Cukierman and Gerlach (2003) argue that the loss function of a central bank depends on the state that the economy is in. They use a loss function the implication of which is that the central bank is more reactive to inflation deviation from its target when the economy is in expansion rather than in contraction. Alternatively, central bank reacts more strongly to the output gap deviation from its target level in recession than in expansion. Beck et al. (2002) generalise this framework and assume a state dependent loss function. Svensson and Williams (2005) and Blake and Zambolli (2006) examine the impact of model uncertainty on optimal policy rule. Both of these studies assume a quadratic loss function subject to state variables, the dynamics of which follow a Markov process.

An important criticism of an explicit or implicit focus on inflation is that it may lead to higher output variability (see, for example, Cecchetti and Ehrmann, 1999; Cecchetti, 1998). In fact, there is a consensus in the literature that this is the case (see Svensson, 1997; Ball, 1997).[1] The aim of this paper is to test the monetary policy preferences of the EMU countries and the UK before and after the introduction of the euro. This is so because recently the consensus of optimal monetary policy has changed within a short period of time. Evidence of high inflation and low economic growth before the collapse of Lehmann Brothers raises the question of whether the ECB and the Bank of England should focus on achieving their inflation target or helping economic growth by relaxing monetary policy. However, the latter option raises questions about the credibility of the ECB and the Bank of England concerning the objective of price stability. An alternatively consideration emerges in view of the period after the collapse of Lehman Brothers, when major central banks around the world have reduced interest rates at historical low levels. The debate now has moved on to the question of whether a loose monetary policy should be coordinated with an expansionary fiscal policy. To this end we estimate the monetary policy preferences of five euro area countries and of those of the euro area as a whole as well as the UK by adopting a framework suggested by Cecchetti and Ehrmann, (1999).[2]

The contribution of this paper is towfold. First, we allow the policy preferences to be state dependent by assuming that the dynamics of state variables follow a Markov process. In doing so the loss function of policy makers becomes state dependent. Thus, policy preferences become state dependent. We estimate the policy preferences of the following euro area countries, Belgium, France, Germany, Italy and Spain; and also those of the UK. However, even if policy preferences across the euro area countries are identical, differences in their economic structure will imply different optimal policies for each country. To examine these issues we compute the slopes of the inflation-output variability trade-off for each country and for each regime; and for the UK. Second, we extent the model used by Cecchetti and Ehrmann (1999), by taking into account the dynamics of output and inflation. However, Bean (1998) shows that introducing dynamics into the demand and supply curves allows the estimation of an optimal policy frontier only. The latter trade-offs the variability of output with inflation variability rather than policy preferences explicitly.

This paper proceeds as follows. Section 2 presents a general theoretical framework of optimal monetary policy. The subsequent section describes the construction of state dependent optimal-policy frontiers.

[1] Ball (1997) and Svensson (1997) show that concerns about output-gap stability translates into a more gradualist policy.

[2] The same approach has been used by Cecchetti et al. (2006). For alternative methods of estimating policy preferences see Dennis (2006), Favero and Rovelli (2003) and Salemi (1995).

Section 4 explains the econometric methodology used to estimate monetary policy preferences. Section 5 discusses the data utilised and the empirical results of the study. Section 6 summarises and concludes.

2 Estimation of Monetary Policy Preferences

This section describes how a theoretical model concerning monetary policy preferences can be brought to data. We follow Cecchetti (1998) and derive the trade-off between inflation and output gap variability by assuming that a central bank is faced with a quadratic loss function (QLF), which is subject to linear dynamics of output and prices. We begin by minimizing the loss function as in (1):

$$L = E[\lambda(\pi - \pi^*)^2 + (1 - \lambda)(y - y^*)^2] \tag{1}$$

subject to (2) and (3):

$$y_t = \gamma(r_t - d_t) + s_t, \ \gamma < 0 \tag{2}$$

$$\pi_t = -(r_t - d_t) - \theta s_t \tag{3}$$

where λ is the weight that the central bank attaches to inflation relative to output stabilization, γ is the inverse slope of the supply curve and θ is the slope of the aggregate demand; d_t and s_t stand for the demand and the supply shocks respectively. The combination of the quadratic loss function and the linear constrains yields a linear reaction function:

$$r_t = ad_t + bs_t \tag{4}$$

Substituting this optimal policy into (2) and (3) we obtain the respective variances σ_y^2 and σ_π^2.

$$\sigma_y^2 = (a - 1)^2\gamma^2 + (1 + \gamma b)^2\sigma_s^2 \tag{5}$$

$$\sigma_\pi^2 = (1 - a)^2 + (\theta + b)^2\sigma_s^2 \tag{6}$$

Substituting (5) and (6) into (1) we arrive at the following loss function:

$$L = \lambda\sigma_\pi^2 + (1 - \lambda)\sigma_y^2 \tag{7}$$

which, when minimised, yields

$$a = 1 \tag{8}$$

and

$$b = \frac{\lambda(\gamma - \theta) - \gamma}{\lambda(1 - \gamma^2) + \gamma^2} \tag{9}$$

The main implication of (8) and (9) is that policy makers completely offset demand shocks on both output and inflation. This is so because demand shocks move output and inflation in the same direction. A trade-off between output and inflation is caused by supply shocks. We substitute (8) and (9) into (5) and (6) and in turn substitute these expressions into (7). This will give a loss function in terms of the policy preference parameter (λ) and in terms of the inverse slope of the supply curve (γ). Substituting (8) and (9) into (5) and (6), it is easy to show that the ratio σ_y^2/σ_π^2 is a function of policy preferences λ and of the inverse of the slope of the supply curve γ, as in (10):

$$\frac{\sigma_y^2}{\sigma_\pi^2} = [\frac{\lambda}{\gamma(1-\lambda)}]^2 \tag{10}$$

Using the actual values of σ_π^2 and σ_y^2 and the estimated value of γ, we can infer the policy preference parameter λ. Equation (10) has the property that for $\lambda = 0$ (the central bank only cares about output gap variability), $\sigma_y^2/\sigma_\pi^2 = 0$. Likewise, for $\lambda = 1$ (the central bank only cares about inflation variability), $\sigma_y^2/\sigma_\pi^2 = \infty$.[3] Cecchetti (1998) shows that central banks that care about the aggregate price path lose little by putting some weight on the output gap (i.e. $\lambda < 1$). Alternatively, central banks that care about output gap variability are faced with a substantially worse position if they decide to target the path of the price level.

To make the analysis more realistic we could follow Ball (1997) and Svensson (1997) and introduce dynamics both in the demand and supply functions. However, by adopting the dynamic structure of Svensson (1997), Bean (1998) shows that we can estimate an optimal policy frontier but not policy preferences explicitly. We provide further details on this point in the section on inflation forecast targeting where we extent the work of Bean (op. cit.) by computing state dependent policy frontiers.

2.1 State Dependent Policy Preferences

The linear policy rule in (4) is based on the assumption that a central bank minimizes a QLF subject to linear constraints. However, recent research has challenged both the assumption of QLF and of linear restrictions.[4] Cukierman and Gerlach (2003) show that a central bank responds strongly to inflation when the economy is in expansion and to

[3] We can trace out the entire output-inflation variability frontier by allowing λ to vary between 0 and 1.

[4] Linear restrictions concern the data generating process (DGP) of state variables such as prices and output gap.

output gap when the economy is in contraction. Nobay and Peel (1998) and Rurge-Murcia (2000) assume that central banks have a linex loss function. If the asymmetry parameter of the linex loss is positive, then positive deviations of inflation and/or output gap from their targets is more costly than negative deviations.

Alternatively, Dolado et al. (2005) relax the assumption of a linear Phillips curve and allow both inflation and the loss function to be convex functions of output gap. Minimizing a quadratic loss function subject to a nonlinear Phillips curve leads to a nonlinear policy rule where the central bank is more averse to positive than to negative deviation of inflation from its target level. Dolado et al. (2004) adopt the linex loss in inflation deviation as the loss function, namely, $L(\pi-\pi^*) = [\exp(\phi(\pi_t - \pi^*)) - \phi(\pi_t - \pi^*) - 1]/\phi^2$, where ϕ is a nonzero parameter.[5] This function permits different weights for positive and negative deviation of π_t from π^*. It implies that not only is the size important but also the sign of deviation and it also relaxes certainty equivalence. If $\phi > 0$, then the exponential component dominates the linear component. Therefore, positive deviations are more costly than negative deviations. The reverse is true if $\phi < 0$. Minimizing a linex loss function subject to a nonlinear Philips curve, the optimal policy rule that is derived is a nonlinear function of inflation and output gap including also inflation variability. The effect of inflation variability is to introduce prudence in the loss function of the central bank with values above targets weighted more heavily than below.

Evidence that macroeconomic series follow a Markov process led monetary economists to develop quadratic control problems with regime shifts. Svensson and Williams (2005) have developed a general form of model uncertainty that remains tractable, using a so-called Markov-jump-linear-quadratic (MJLQ) model. In this set up, model uncertainty takes the form of different modes that follow a Markov process. It can be thought of as a model encompassing a number of possible representations of the world. MJLQ models have been widely used in control theory but only for the special case when there are no forward-looking variables. Zambolli (2006) used MJLQ to study monetary policy under regime shifts without including forward-looking variables. Although conceptually, we could use this framework to estimate a state dependent policy preferences in view of the model used by Cecchetti and Ehrmann (1999) being static, policy preferences would not be a state dependent

[5] For analytical tractability Dolado et al. (2002) assume that the central bank's loss function includes only inflation stabilisation. They show that including both output gap and inflation in a convex loss function the optimazition problem can be solved numerically only by a dynamic programing method.

version of (10). To obtain a state dependent version of (10) we adopt the framework of passive learning used by Ellison and Valla (2001).[6]

Passive learning fails to take into account that current actions of the central bank have an impact on expected future losses. Since in this set up learning and updated beliefs is the only source of dynamics, the problem of passive learning is reduced to that of minimizing the expected one-period loss function each period, subject to the supply curve. Under such circumstances the optimization problem can be solved with Langrange multiplier techniques. We adopt the framework used by Ellison and Valla (2001) and we assume that central banks minimize a loss function subject to state dependent supply and demand curves:

$$E_t[L_t|S_t,\Omega_t] = p_t L_e + (1-p_t)L_R \tag{11}$$
$$E_t[L_t|S_t,\Omega_t] = p_t[\lambda\pi^2 + (1-\lambda){y_t}^2] + (1-p_t)[\lambda\pi^2 + (1-\lambda){y_t}^2] \tag{12}$$

subject to (13) and (14):

$$y_t = \gamma_{S_t}(r_t - d_t) + s_t \tag{13}$$
$$\pi_t = -(r_t - d_t) - \theta s_t \tag{14}$$

where, Ω_t is the information set available at time t, S_t is an unobserved state variable at time t, p_t indicates the probability for given Ω_t, S_t is in expansion (i.e. $P(S = e|\Omega_t)$, the subscript e and R indicate that the relevant variables are in expansion and recession respectively. Substituting (13) and (14) into (11) and then minimizing with respect to the nominal interest rate we obtain a state dependent reaction function:

$$r_t = ad_t + b(S_t)s_t \tag{15}$$

where

$$a = 1$$
$$b(S_t) = \frac{p_t[(\gamma_e - \theta)\lambda - \gamma_e] + (1-p_t)[(\gamma_R - \theta)\lambda - \gamma_R]}{p_t[(\gamma_e^2 + \lambda(1-\gamma_e)] + (1-p_t)[\gamma_R^2 + \lambda(1-\gamma_R)]}$$

Substituting (15) into (13) and (14) and taking the variances of these expressions we obtain:

$$\sigma_y^2(S_t) = \gamma_{S_t}^2(a-1)^2[\gamma_{S_t}b(S_t)+1]^2\sigma_s^2 \tag{16}$$

[6] Ellison and Valla (2001) in a standard model of monetary policy with uncertainty, learning and strategic interaction, analyse the impact of passive and active learning on wellfare.

$$\sigma_\pi^2(S_t) = (a-1)^2 + [b(S_t) + \theta]^2\sigma_s^2 \tag{17}$$

Taking now the first order conditions with respect to a and $b(S_t)$ that minimize the loss function (11):

$$L = \lambda\sigma_\pi^2(S_t) + (1-\lambda)\sigma_\pi^2(S_t) \tag{18}$$

which yields

$$L_a = \lambda(a-1) + (1-\lambda)\gamma_{S_t}^2(a-1) \tag{19}$$

$$L_{b(S_t)} = b(S_t)[\lambda(1-\gamma_{S_t}^2) + \gamma_{S_t}^2] + [\lambda(\theta - \gamma_{S_t}) + \gamma_{S_t}] \tag{20}$$

Setting (19) and (20) equal to zero yields,

$$a = 1 \tag{21}$$

$$b(S_t) = \frac{\lambda(\gamma_{S_t} - \theta) - \gamma_{S_t}}{\lambda(1-\gamma_{S_t}^2) + \gamma_{S_t}^2} \tag{22}$$

Given (21) and (22), we estimate policy preferences from the following ratio of output to inflation variability

$$\begin{aligned}
\frac{\sigma_y^2(S_t)}{\sigma_\pi^2(S_t)} &= \left[\frac{1+\gamma_{S_t}b(S_t)}{\theta + b(S_t)}\right]^2 \Rightarrow \\
\frac{\sigma_y^2(S_t)}{\sigma_\pi^2(S_t)} &= \left[\frac{\lambda(1-\gamma_{S_t}\theta)}{\gamma_{S_t}(a-1)}\right]^2 \Longrightarrow \\
\frac{\sigma_y^2(S_t)}{\sigma_\pi^2(S_t)} &= \left[\frac{\lambda}{\gamma_{S_t}(\lambda-1)}\right]^2
\end{aligned} \tag{23}$$

3 Inflation Forecast Targeting and Optimal Policy Frontier

This section shows that if we introduce the dynamics in the static model as in Cecchetti and Ehrmann (1999), we can only estimate an optimal policy frontier but not policy preferences explicitly. We do so, by following Bean (1998), who uses Svensson's (1997) inflation forecast targeting model, to derive an optimal policy frontier for the UK. We also extent the work of Bean (1998) by obtaining a state dependent policy frontier using a framework suggested by Blake and Zampolli (2006) and Svensson and Williams (2005).

3.1 Optimal Policy Frontier: The Linear Case

Inflation targeting has some general advantages and some potential problems. Svensson (1997) shows that although inflation targeting can be used as a commitment mechanism to enhance the credibility of monetary policy there are some serious problems with respect to both its implementation and monitoring. First, implementation may be difficult because central banks have imperfect control over inflation. Long and variable lags in the impact of monetary policy make decisions on current policy instrument very difficult. A central bank can argue that deviation of realized inflation from inflation target might be due to factors outside its control; and that it should not be held accountable for the deviation as in the case of supply shocks, for example.

Svensson (1997) proposes an inflation *forecast* targeting policy as a solution to the problem concerning the implementation and monitoring of inflation targeting. In an inflation forecast targeting regime the optimal monetary policy requires to set the policy instrument so that expected inflation is equal to target:

$$E_t \pi_{\tau+s} = \pi^* \tag{24}$$

where $\pi_{\tau+s}$ is future inflation at time $t+s$ and π^* is the inflation target. Svensson (1997) also shows that once the central bank put some weight on output stabilization, the optimal policy is to adjust inflation forecast gradually to inflation target:

$$E_t \pi_{\tau+s} = \pi^* - f(\lambda) y_{t+s|t} \tag{25}$$

That is, inflation forecast should be adjusted to the inflation target only if the forecasted output gap is equal to zero. The intuition for this is that strict inflation targeting will lead to more output gap variability.[7]

Bean (1998) adopted Svensson's (1997) framework to derive the optimal policy frontier for the UK. He considers the problem of

$$\min_{r_t} L(\pi, y) = \frac{1}{2}(\pi_t^2 + \lambda y_t^2) \tag{26}$$

subject to

$$\pi_{t+1} = \pi_t + \alpha_1 y_t + s_{t+1} \tag{27}$$

$$y_{t+1} = \beta_1 y_t - \beta_2 r_t + d_{t+1} \tag{28}$$

Svensson (1997) formulated this problem as

$$v(\pi_{t+1|t}) = \min_{y_{t+1|t}} \left\{ \frac{1}{2}(\pi_{t+1|t}^2 + \lambda y_{t+1|t}^2) + E_t v(\pi_{t+2|t+1}) \right\}$$

[7]Strict inflation targeting requires an immediate adjustment of inflation forecast to the set inflation target.

subject to

$$\pi_{t+2|t+1} = \pi_{t+1|t} + \alpha_1 y_{t+1|t} + (s_{t+1} + \alpha_1 d_{t+1}) \tag{29}$$

where $y_{t+1|t}$ is considered as the control variable. Assuming that the indirect loss function is quadratic

$$v(\pi_{t+1|t}) = k_0 + \frac{1}{2}k\pi^2_{t+1|t} \tag{30}$$

the first order condition is

$$\pi_{t+2|t} + \frac{\lambda}{\alpha_1 k} y_{t+1|t} = 0 \Rightarrow \tag{31}$$

$$y_{t+1|t} = -\frac{\alpha_1 k}{\lambda + \alpha_1^2 k}\pi_{t+1|t} \tag{32}$$

$$y_{t+1|t} = -\rho\pi_{t+1|t} \tag{33}$$

where

$$\rho = \frac{\alpha_1 k}{\lambda + \alpha_1^2 k}$$

using the envelope theorem we can show that

$$k = \frac{1}{2}\left(1 - \sqrt{1 + \frac{4\lambda}{\alpha_1^2}}\right) \tag{34}$$

the optimal reaction function can be inferred from (28)[8]

$$r_t = \frac{\alpha_1\rho + \beta_1}{\beta_2} y_t + \frac{\rho}{\beta_2}\pi_t \tag{35}$$

Substituting (35) into (27) and (28) and lagging the resulting equations by one period we can write the evolution of y and π as

$$\begin{bmatrix} y_t \\ \pi_t \end{bmatrix} = \begin{bmatrix} -\alpha_1\rho & -\rho \\ -\alpha_1 & 1 \end{bmatrix} \begin{bmatrix} y_{t-1} \\ \pi_{t-1} \end{bmatrix} + \begin{bmatrix} d_t \\ s_t \end{bmatrix} \tag{36}$$

We compute the unconditional variances of output gap and inflation as[9]

$$\begin{bmatrix} Var(y_t) \\ Var(\pi_t) \end{bmatrix} = \frac{1}{2 - \alpha_1\rho} \begin{bmatrix} 2 & \frac{\rho}{\alpha_1} \\ \alpha_1\rho & \frac{1}{\alpha_1\rho} - \alpha_1\rho + 2 \end{bmatrix} \begin{bmatrix} \sigma^2_{d_t} \\ \sigma^2_{s_t} \end{bmatrix} \tag{37}$$

[8] Bean (1998) derived the same optimal reaction function as (35).

[9] To obtain (37) we have applied the property that if $Y_t = FY_{t-1} + E$, where Y is a random vector, F is a matrix of coefficients, and E is a vector of a white noise process, then: $Vec[Var(Y)] = [I - (F \otimes F)]^{-1} Vec[Var(E)]$.

Following Bean (1998) we minimize $Var(\pi_t) + \lambda Var(y_t)$ with respect to optimal feedback coefficient ρ. Bean (1998) shows that the solution to this is

$$\rho = \frac{-\alpha_1 + \sqrt{\alpha_1^2 + 4\lambda}}{2\lambda} \tag{38}$$

(38) indicates that we can only estimate policy as an efficient policy frontier but not the policy preferences λ. By varying λ we can trace out an optimal efficient frontier that trade-offs inflation variability against output gap variability.

3.2 A state dependent Optimal Policy Frontier

We extent the work of Bean (1998) and estimate state dependent optimal policy frontiers by adopting the MJLQ model suggested by Zampolli (2006) and Blake and Zampolli (2006).[10] Policy makers minimize an intertemporal loss function:

$$\sum_{t=0}^{\infty} \beta^t L(x_t) = x_t' R x_t \tag{39}$$

where $0 < \beta \leq 1$ is the discount factor, $x_t = [y_t \ \pi_t]'$ is a vector of state variables and R is given by

$$R = \begin{bmatrix} \lambda \, 0 \\ 0 \, 1 \end{bmatrix}$$

The minimization problem is subject to a reduced form state dependent linear dynamic of the economy

$$x_{t+1} = A(S_{t+1})x_t + B(S_{t+1})u_t + \epsilon_{t+1} \tag{40}$$

$$\epsilon \tilde{} N(0, \Sigma_\epsilon) \tag{41}$$

where

$$A(S_{t+1}) = \begin{bmatrix} \beta_1(S_{t+1}) & 0 \\ \alpha_1(S_{t+1}) & 1 \end{bmatrix}, \ B(S_{t+1}) = \begin{bmatrix} -\beta_2 \\ 0 \end{bmatrix} \text{ and } \epsilon_{t+1} = \begin{bmatrix} d_{t+1} \\ s_{t+1} \end{bmatrix} \tag{42}$$

The matrices A and B depend on the value of the unobserved-state vector S_j, $j \in \{1, 2, ..N\}$. S_t follows a Markov process with transition probability$\{p\}_{ij}$. Solving the problem requires jointly solving the follow-

[10]Zambolli (2006) used MJLQ to study monetary policy under regime shifts without including forward-looking variables.

ing set of Belman equations

$$v(x)\widehat{\boldsymbol{\xi}}_{t|t} = \max_{r_t}\{L(x_t,)\widehat{\boldsymbol{\xi}}_{t|t} + \beta E[v(x_{t+1})\widehat{\boldsymbol{\xi}}_{t+1|t}]\} \tag{43}$$

$$v(x)\widehat{\boldsymbol{\xi}}_{t|t} = \max_{r_t}\{L(x_t,)\widehat{\boldsymbol{\xi}}_{t|t} + \beta E[v(x_{t+1})P\widehat{\boldsymbol{\xi}}_{t|t}]\} \tag{44}$$

$$v(x_t, i) = \max_{r_t}\{L(x_t,) + \beta \sum_{j=1}^{N} p_{ij} E[v(x_{t+1})]\},\ i = 1, 2, ...N \tag{45}$$

where $v(x)$ is the continuation value of the dynamic programing problem, $\widehat{\boldsymbol{\xi}}_{t|t}$ is a $N \times 1$ vector whose i element is the conditional expectation that the unobserved state of the world is $S_t = j$, given the information at time t and $S_{t-1} = i$ and $P = \{p_{ij}\}$. Given the linear quadratic nature of the problem and assuming further that the value function is quadratic, i.e. $v(x_t, i) = x'V_i x + d$, the first order conditions will give a set of decision rules of the following form

$$u(x, i) = -F_i x_t \tag{46}$$

where by substituting (46) into (43) and equating the terms in the quadratic form we obtain a set of Riccati equations

$$\begin{aligned} V_i &= R + \beta G[A'VA|S = i] \\ &-\beta^2 G[A'VA|s = i](\beta[B'VB|S = i])^{-1} G[B'VA|S = i] \end{aligned} \tag{47}$$

where $i = 1, ..., N$, and $G()$ is a conditional operator defined as follows

$$G[X'PY|s = i] = [P\widehat{\boldsymbol{\xi}}_{t|t} \otimes (X'VY)] = \sum_{j=1}^{N} X'_j(p_{ij}P_j)Y_j$$

where $X = A, B$; $Y = A, B$. Having found V_i from the solution of (47) we can estimate the matrices

$$F_i = (\beta + G[B'VB|S = i]^{-1}\beta G[B'VA|S = i) \tag{48}$$

Assuming $\beta = 1$ and substituting (48) and (42) into (46) we obtain a state dependent version of the policy reaction function given by (35). After legnthy matrix algebra we can also derive a state dependent version of the optimal feedback coefficient ρ :

$$\rho(S_{t+1}) = \frac{-\alpha_1(S_{t+1}) + \sqrt{\alpha_1^2(S_{t+1}) + 4\lambda}}{2\lambda} \tag{49}$$

Substituting $\rho(S_{t+1})$ into (36) we obtain the regime-dependent unconditional variance of output and inflation:

$$\begin{bmatrix} Var(y_{St}) \\ Var(\pi_{St}) \end{bmatrix} = \frac{1}{2 - \alpha_1\rho(S_{t+1})} \begin{bmatrix} 2 & \frac{\rho(S_{t+1})}{\alpha_1} \\ \alpha_1\rho & \frac{1}{\alpha_1\rho(S_{t+1})} - \alpha_1\rho(S_{t+1}) + 2 \end{bmatrix} \begin{bmatrix} \sigma(S_{t+1})^2_{d_t} \\ \sigma(S_{t+1})^2_{s_t} \end{bmatrix} \tag{50}$$

4 Econometric Methodology

The next task is to identify the impact of monetary policy on output and inflation. We need to identify and estimate the impulse response functions of output and inflation to a monetary shock. Cecchetti and Ehrmann (1999) use the structural VAR approach suggested by King, Ploser, Stock and Watson (KPSW) (1991) to identify the monetary transmission mechanism. The KPSW identification scheme is based on cointegrating relationships in a n-variable system. Complete identification of the n-variable system requires $[n(n-1)/2]$ restrictions.[11]

Checchetti (1998) argues that the VAR model used to estimate the responses of output and prices to interest rate changes presumes that these responses remain constant over the sample used in the estimation. Thus, the estimates of policy preferences by Checchetti and Ehrmann (1999) are based on the assumption that VAR parameters remain constant over a significant historical period. However, in the case of the EMS monetary policy, it went through different regimes. This implies that we need to adopt a statistical model which accounts for regime changes. Here, we estimate (14) by employing a structural Markov regime-switching VAR (SMRS VAR) suggested by Ehrmann et al. (2003). As another check for the use of SMRS VAR model, following Hamilton and Lin (1996), we test for parameter stability using a test suggested by Andrews (1993). We also apply various tests for structural breaks.[12] Evidence of structural breaks indicates that variables went through different states rather than having a stochastic trends. Table A1 in the appendix presents results from tests of parameter stability and structural breaks. We have used the Andrews (1993) and Andrews and Ploberger (1994) methods to test for the presence of a break in the stochastic process of our macro-variables. The above tests can also be used to identify multiple breaks in a series by incorporating them in an iterative scheme (algorithm) and apply them to sub-samples of the series. In this paper, we have employed the algorithm proposed by Karoglou (2009), which is more robust than the basic binary division algorithm to the presence of transitional peri-

[11] If among the n-variable system there are r cointegrating vectors there will be k common stochastic trends, where $k = (n - r)$. To identify the k stochastic trends KPSW (1991) impose $[k(k-1)/2]$ restriction in the long-run matrix. Alternatively, to identify the r transitory shocks KSPW (op.cit.) impose $[r(r-1)/2]$ restrictions on the short-run matrix.

[12] We could test for the number of states using the Hansen (1992) test. However, this test is computationally demanding and has low power when dynamics are included in the data generation process. Mitchell and Mouratidis (2004) have tested for regime switches in nine European monetary union countries. Evidence from Hansen (1992) test shows that the growth rate of industrial production of nine EMU countries were subject to regime switching.

ods. Appendix 1 explains this algorithm.

In a standard SVAR the underlying structural model is identified by imposing restrictions on the moving average representation of an unrestricted VAR. A SMRS VAR is a two-step procedure combining two important developments of VAR analysis: Markov regime-switching and identification. In the first step we estimate an MRS VAR model, where we allow all estimated parameters to be state dependent:

$$X_t = \begin{pmatrix} y_t \\ \pi_t \\ i_t \end{pmatrix}, c(s_t) = \begin{pmatrix} c_{1,s_t} \\ c_{2,s_t} \\ c_{3,s_t} \end{pmatrix}, u = \begin{pmatrix} u_{1,s_t} \\ u_{2,s_t} \\ u_{3,s_t} \end{pmatrix},$$

$$X_t = c(s_t) + \sum_{j=1}^{p} A(s_t) X_{t-j} + \Gamma(s_t) t + B(s_t) u_t \tag{51}$$

$$\Omega(s_t) = E[B(s_t) u_t u_t' B(s_t)'] = B(s_t) I_n B(s_t)' \tag{52}$$

In the second step we identify $B(s_t)$. Identification of $B(s_t)$ requires n^2 restrictions. $[n(n+1)/2]$ restrictions are imposed upon (52) because the variance covariance matrix of the error term is an identity matrix (i.e., $u_t u_t' = \Sigma_u = I_n$). This implies that full identification needs extra $[n(n+1)/2]$ restrictions. Sims (1980) derives these restrictions by ordering endogenous variables recursively. In this set up endogenous variables are ordered and it is assumed that the fundamental disturbances have contemporaneous effects on the variable itself and on all the other variables below it. The choice of which restriction to impose is subject to the structural VAR literature.[13] We choose the recursive form of identification by imposing the restriction that the policy instrument does not enter into inflation and output equation contemporaneously.[14] This is consistent with the empirical model of Rudebusch and Svensson (1999) and the theoretical model of Svensson (1997). We also impose the restriction that inflation does not affect output contemporaneously.

Cecchetti (1996) argues that when we try to discern the relationship between the policy instrument and the target variables we need to add other variables in the model. His argument is based on the empirical findings of Sims (1992) and Christiano et al. (1996a; 1996b). Sims (1992) using a VAR including only prices, output and interest rate finds a positive reaction of prices to interest rate shock. This puzzling result has been called the *price puzzle*. The most commonly accepted explanation of the price puzzle is that the variables included in the VAR do not reflect the full information set of central banks. This is so because policy

[13] For a detailed review of the structural VAR literature see Canova (2007).

[14] The same recursive identification scheme has been used by Ehrmann et al. (2003).

is likely to respond to forecast of future economic conditions; VARs may attribute the subsequent movements in output and inflation to the policy action. One solution to the prize puzzle is to include commodity prices or other asset prices in the VAR. Since these prices are sensitive to changing forecasts of future inflation, they can be used as proxies of the central bank's additional information.[15]

Cecchetti and Ehrmann (1999) estimate policy preferences for the euro area countries including at least four variables. We also employ a four-variable model by introducing a long-term interest into a trivariate MRS model. We do so because a long-term interest rate is a forward-looking variable reflecting market expectations. Cecchetti and Ehrmann (1999) use dummy variables to account for institutional changes. However, our experiment with linear VAR shows evidence of non-normality and heteroscedasticity. This implies that there are structural breaks or regime switching changes (see Canova 2007) in line with the history of EMS.[16] We employ an MRS model both because of the history of the EMS system and because of recent empirical evidence that macro-variables are subject to regime switching (see Ang and Bekaert, 1998).

In line with Cecchetti and Ehrmann (1999) we compute the inverse slope $1/\gamma(s_t)$ at each regime as the 12-quarter average of the impact of policy shock on output, divided by the 12-quarter average impact on inflation. The state dependent unconditional volatilities of output and inflation are measured using the smooth probabilities regarding the current economic state.

5 Data and Empirical Results

This section analyses empirical results concerning both the static and dynamic model. We focus on the case of the euro area countries and the UK. In what follows we utilize both a trivariate and a quadravariate MRS model to estimate equation (51). The trivariate MRS VAR model includes the policy instrument and the target variables. We use on a monthly basis the three-month treasury bill rate as a proxy for the policy instrument. The treasury bill is available both for all countries and

[15] Barth and Ramey (2001) provide an alternative interpretation of the price puzzle. They argue that a contractionary monetary policy affects both aggregate demand and aggregate supply. For example, an increase in the rate of interest will raise the cost of holding inventories. This negative supply shock will increase prices and reduce output. In this interpretation, the price puzzle is due to the cost channel rather than to a misspecified VAR.

[16] In the period from 1979 to 1986 the EMS experienced 11 realingments followed by a stable period up to the currency crises of the 1990s. The EMS was the subject of speculative attacks in 1993 and 1995.

for the whole period of investigation.[17] We also use monthly CPI and industrial production to construct the inflation rate and the industrial production growth rate.[18]

5.1 Estimation of Policy Preferences: The Case of the Static Model

We compute policy preferences and the slope of the supply curve for two different samples. The two samples cover the periods from March 1979 to December 1998 and from March 1979 to December 2008. We choose these two periods to investigate whether the introduction of the single European currency had any impact on policy preferences. Tables 1 and 2 present results from the trivariate MRS model. We distinguish each regime on the basis of their volatilities. We call regime 1, the regime with a low volatility and regime 2 the regime with the high volatility. The first observation is that most of the $\lambda(s_t)$s are very high. Exception to this is the case of Spain and the UK. Spain in the low volatility regime put a considerable weight on the stability of the output gap. This might be due to widespread agreement that Spain and Italy experienced higher inflation rate than the EMS average during 1987-1992. During this period, without any realignment, tensions were building up for these two countries in the form of growing loss of competitiveness (see De Grauwe 1997). The choice for these countries was either to devalue or to deflate their economies but suffering further loss of competitiveness. Italy opted out of the EMS after the speculative attack in 1992 and Spain increased the band around the central parity.

Alternatively, the UK put equal weights on output gap and inflation variability in the high volatility regime (i.e. regime 2). High volatility regime was associated with high inflationary expectations and low economic growth. Under such circumstances, monetary authorities put some weight on output gap stability. This undermines the credibility of monetary authorities concerning the objective of low and stable inflation. However, the UK was subject to speculative attacks in 1992 forcing the Bank of England to opt out of the ERM. Unlike Spain and the UK, the euro area as a whole put more weight on inflation stability in the high volatility regime than in the low volatility regime.[19] Emphasis on

[17] We could also use the short-term money market rate given by the 60b line of IFS data base. However, it is only available for the period before the introduction of the European single currency.

[18] Data for CPI and industrial production were extracted by the lines 64 and 99 of IFS data base.

[19] Euro area data are contsructed as a weighted average of seven EMU countries. Although the aggregate GDP, of these represents more than 92 percent of euro area

inflation variability, especially in the high volatility regime, indicates a strong determination to keep inflation under control. This is consistent with the high antinflationary credibility of Germany.

It is worth noting that all countries put more weight on inflation stability than on output gap stability in the regime where the slope of the supply curve is flatter. Countries emphasize inflation stability in regimes where the disinflation cost in terms of output gap is high. This might be due to the effort of EMS countries to establish anti-inflationary credibility. The slope of the supply curve (i.e. $1/\gamma$) varies across countries with Germany, Spain and the UK having the flattest supply curves among the six countries. In this simple model, our results translate into the fact that these countries face a flatter output gap-inflation variability frontier than the other EMU countries. The implication of a flatter frontier is that the disinflation cost in terms of output gap is relatively low. Germany having a long established anti-inflationary credibility could enjoy a low disinflation cost in terms of the output gap.

Parameters	Belgium	France	Germany	Italy	Spain	Euro	UK
The Period from 1979:04 to 1998:12							
γ_1	-2.37	-2.35	-2.04	0.6	-1.63	-0.137	-1.26
γ_2	-1	-0.57	-1.08	-1.07	-0.25	-0.26	-0.58
λ_1	95.30%	91.40%	91.70%	139.40%	87.50%	87.20%	73.80%
λ_2	89.60%	72.20%	85.30%	86.20%	52.20%	56.20%	56.40%
The Period from 1979:04 to 2008:12							
γ_1	-0.64	-0.69	-3.39	-0.06	-0.33	-0.5	-1.63
γ_2	-0.4	-0.41	-0.76	-0.94		-0.43	-1.06
λ_1	84.70%	75.70%	94.80%	27.40%	87.80%	71.40%	78.60%
λ_2	77.80%	65.30%	80.40%	84.70%	58.60%	68.10%	70.50%

Table 1: Estimated Policy Preferences with the Trivariate MRS VAR

Table 1 also presents estimated policy preferences for the full sample (i.e. March 1979 to December 2008). The results indicate that after the introduction of the single European currency, countries increased the weight assigned to stabilizing inflation. This is so because monetary policy is conducted by a new institution, the ECB. The need to earn anti-inflationary credibility led the ECB to put emphasis on inflation stability.

Table 2 shows results from the four-variable MRS model. There are two key findings. First, in the high volatility regime the weight put on

GDP we scale the weight so that it represents 100 percent of euro area GDP. The weights are taken from the explanatory notes accompanying the August 2008 update of the Area-Wide Model (AWM) database.

Parameters	Belgium	France	Germany	Italy	Spain	Euro	UK
The Period from 1979:04 to 1998:12							
γ_1	NA	-2.15	-3.29	-0.30	NA	-8.70	-1.93
γ_2	NA	-0.15	-0.51	-0.81	NA	-0.97	-1.23
λ_1	NA	91.2%	95.5%	64.3%	NA	98.0%	80.7%
λ_2	NA	41.7%	76.7%	82.9%	NA	84.3%	72.8%
The Period from 1979:04 to 2008:12							
γ_1	-1.37	-3.58	-2.83	-0.11	-6.54	-2.04	-2.07
γ_2	-1.18	-0.25	-0.59	-0.55	-0.79	-3.78	-0.10
λ_1	81.8%	94.1%	93.9%	39.8%	96.5%	90.9%	82.1%
λ_2	79.5%	52.4%	76.3%	77.2%	76.9%	94.9%	18.2%

Table 2: Estimated Policy Preferences with the Quadravariate MRS VAR

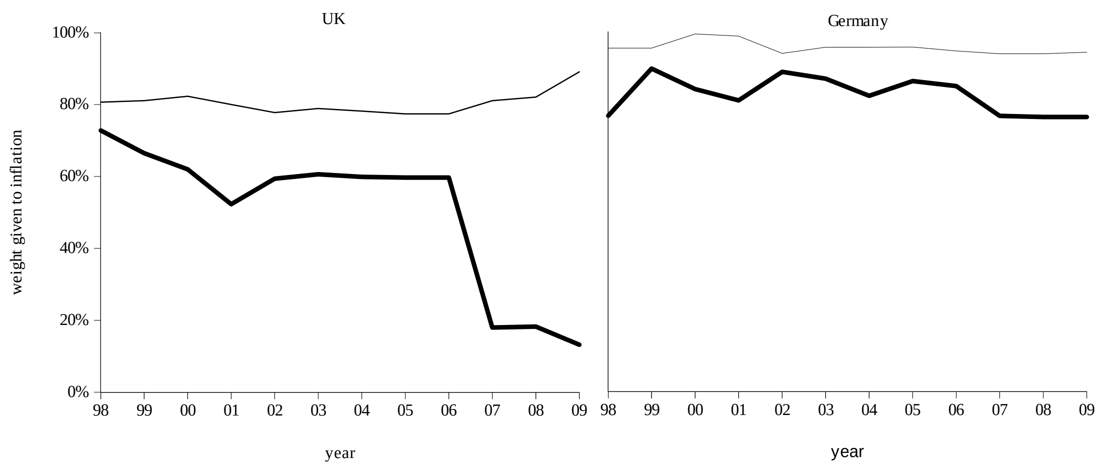
inflation stability was reduced. This might be due to the extra information provided by forward-looking variables such as long-term interest rate. Under the expectations theory of the term structure of interest rates, the long-term nominal interest rate depends on expectations of the future short-term interest rate. A decline of long-term interest rate would be interpreted as a current contractional policy expected to reduce future inflation and future short-term interest rates. Conversely, an increase in the long-term interest rate is interpreted as current inflationary policy to be followed by a higher inflation and future short-term interest rates. Figure 1 shows that long-term interest rates both in the euro area and the UK fall after July 2008. This is related to the second key finding where in the case of the UK the weight on inflation stability has fallen sharply in the second period. More concretely, the weight on inflation has fallen from 72% in the first period to 18% in the second period. A decline of long-term interest rate will reflect market expectations concerning a decline of future inflation. However, expected low future inflation might be due to an expected imminent recession. Expectation of severe recession may have forced the Bank of England to focus on aggregate demand rather than keeping inflation under the target of 2% inflation rate.

Figure 1: Long-term interest rates - UK (light) and EU (bold)

In light of this striking result, we estimate recursively the policy preferences for the UK and Germany for the period December 1998 to December 2008. Figure 2 shows that although weights for Germany are stable this is not the case for the UK. In the UK the weight on inflation has decline from 72% in 1998 to 60% in 2002 and remain around this level up to December 2006. However, in December 2007, the weight on inflation was reduced to 18%. Our results are consistent with Groen, Kapetanios and Price (2009) who show, by developing a multivariate extension of the CUSUM test, that the UK RPI inflation was subject to structural breaks after 2001, 2003 and 2005.[20]

[20] Groen, Kapetanios and Price (2009) argue that there may have been temporary breaks induced by the large volatilities in housing and energy after 2000.

Figure 2: state dependent policy preferences



Note: The light line depicts λ_1, the weight on inflation in the low volatility regime, while the bold line depicts λ_2, the weight on inflation in the high volatility regime.

5.2 Estimation of State Dependent Policy Frontiers: The Case of the Dynamic Model

We trace out an efficient policy frontier of a trade-off between output gap variability and inflation variability by varying $\rho(S_{t+1})$ from zero to infinity. However, in order to calculate the efficient frontier we need three pieces of information: the variance of demand shocks $\sigma^2_{d(S_{t+1})}$,the variance of supply shocks $\sigma^2_{s(S_{t+1})}$and the slope of the supply curve $\alpha_1(S_{t+1})$. We start by estimating a state dependent version of (27) and (29) using MRS models.[21] Then we substitute the values of $\alpha_1(S_{t+1})$, $\sigma^2_{d(S_{t+1})}$ and $\sigma^2_{s(S_{t+1})}$ so obtained into $\rho(S_{t+1})$.

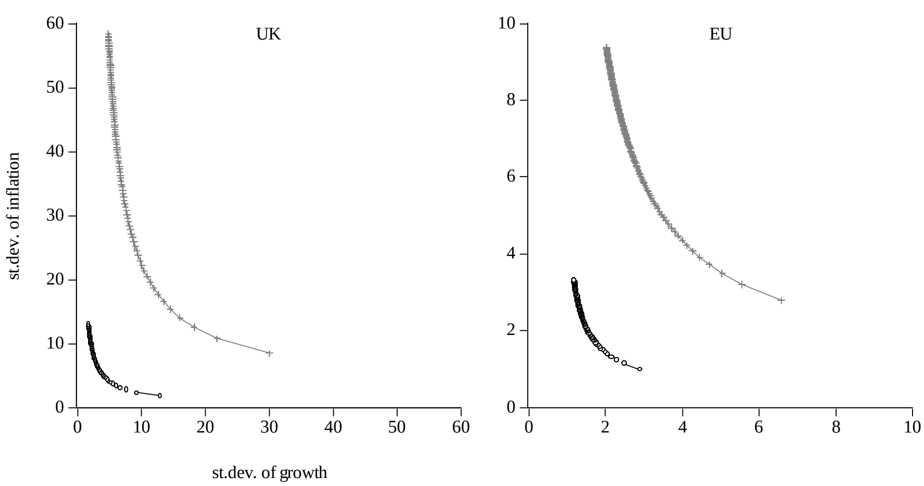
Figure 3 presents the efficient policy frontiers of the UK, both in low and high volatility regime. The striking thing with these frontiers is that they are steep and the optimal points are very close for weights in the range of [2,5]. This has an important implication concerning the credibility of the Bank of England. A rather wide range of weights on output against inflation will lead to similar points on the policy frontier. Although a steep policy frontier indicates that the Bank of England has little to loose in terms of credibility, by increasing the weight on output

[21]As proxies of y_{t+1} and π_{t+1}we use survey data of future inflation and GDP growth puplished by the HM Treasury for the UK and by the ECB for the euro area.

it also implies that emphasis on price stability is relatively expensive in terms of output. A combination of low credibility cost and high output-cost is consistent with results from the static model where we show that the Bank of England has reduced the weight on price stability from 72% to 18%.

The optimal policy frontiers for the euro area presented in Figure 3 and 4 differ from those of the UK in two respects. First, Figure 4 also shows that the standardized policy frontier of the UK is steeper than the policy frontier of the euro area.[22] Second, the size of the trade-off between inflation variability and output gap variability is a lot lower for the euro area than for the UK. Although the UK enjoys higher credibility concerning the objective of price stability than the euro area, it faces high trade-off between inflation and output gap stability. These results are in line with evidence from the static model where the UK not only does it put less weight on inflation variability but also it has reduced this weight substantially after 2006.

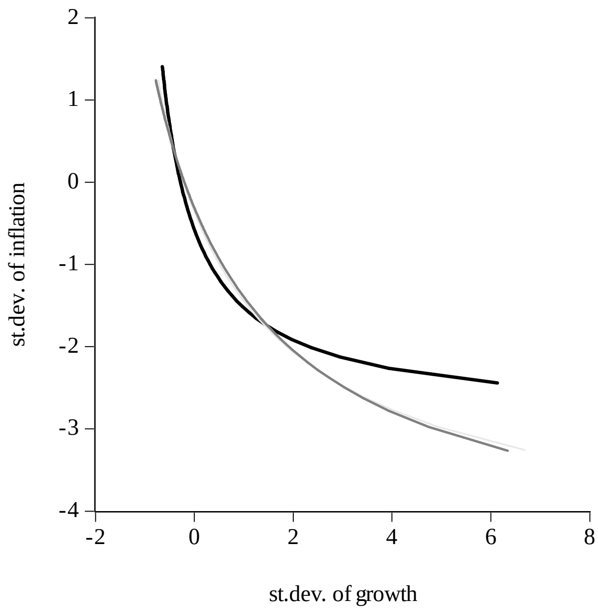
Figure 3: State dependent optimal policy frontiers



Note: The (grey) line with the crosses depicts the optimal policy frontier in the high volatility regime; the (black) line with the circles depicts the optimal policy frontier in the low volatility regime.

[22]For ease of exposition we have only presented the policy frontiers of the high volatility regime.

Figure 4: Standardised state dependent optimal policy frontiers in the high and low volatility regimes



Note: The black line depicts the optimal policy frontier in the high volatility regime for the UK; the grey line depicts the optimal policy frontier in the high volatility regime for the EU. It is worth mentioning that the corresponding graph for the low volatility regime is almost identical.

6 Summary and Conclusions

The aim of this paper is to estimate the monetary policy preferences of a number of EMU countries and the UK. We do so, by adopting the framework suggested by Cecchetti and Ehrmann (1999). We extent the work of Cecchetti and Ehrmann (1999) in two respects. First, we allow policy preferences to be state dependent by assuming the data generating process (DGP) of inflation and output gap to follow a Markov process. Second, we introduce dynamics into the relevant supply and demand curves. However, when introducing dynamics into the static model used by Cecchetti and Ehrmann (1999), we can only estimate an optimal policy frontier rather than policy preferences explicitly.

Empirical results from the static model show that all EMU countries, examined for the purpose of this paper, put a lot of weight on inflation variability. Alternatively, the UK put less weights on inflation stability than the euro area countries included in our sample. After 2006 the Bank of England, in the high volatility regime, reduced the weight put on inflation from 72% to 18%. The change of monetary policy preferences in the UK might be explained by two factors. First, estimates of state dependent optimal policy frontiers show that the Bank of England enjoys higher anti-inflationary credibility and higher trade-off between inflation and output gap variability than the euro area. The combination of high anti-inflationary credibility and high trade-off between inflation variability and output gap variability, especially in the high volatility regime, tempts the Bank of England to focus on the stability of output variability. This is consistent with recent disagreements between the UK and the rest of the euro area countries concerning the appropriate policy that should be pursued to face the current recession. The results for the UK support the view that a loose monetary policy should be followed by a loose fiscal policy. By contrast, the results for the euro area countries support the view that a loose monetary policy should not be accommodated by loose fiscal policy in view of the requirements of the Stability and Growth Pact.

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Appendix 1: Detecting structural changes

The algorithm that is used in this paper to detect the possible presence of multiple breaks comprises of the following six steps:

1. Calculate the test statistic under consideration (here the Andrews, 1994, and the Andrews and Ploberger,1994) using the available data.
2. If the statistic is above the critical value split the particular sample into two parts at the corresponding point.
3. Repeat steps 1 and 2 for the first segment until no more (earlier) change-points are found.
4. Mark this point as an estimated change-point of the whole series.
5. Remove the observations that precede this point (i.e. those that constitute the first segment).
6. Consider the remaining observations as the new sample and repeat steps 1 to 5 until no more change-points are found.

The detected breaks for each series are simply all those that have been detected after implementing this algorithm. The following table depicts the break points for each series.

Series	QA	AP	Series	QA	AP	Series	QA	AP	Series	QA	AP
Belgium rate	1985m05	1985m05	Germany rate	1982m11	1982m11	Netherlands rate	1982m09	1982m09	UK rate	1982m08	1982m08
	1994m06	-		1995m05	1995m05		1995m10	1995m10		1992m12	1992m12
	2001m12	-		2003m01	2003m01		1999m02	1999m02		2001m09	2001m09
	2006m11	-		2006m09	2006m09		2003m01	2003m01		2004m07	2004m07
	2008m10	-		2008m10	2008m10		2006m09	2006m09		2008m06	2008m06
Belgium infl	1985m05	1985m05		-	-		2008m10	-	UK infl	1980m06	1980m06
Belgium long	1985m11	1985m11	Germany infl	1982m08	1982m08	Netherlands infl	1982m05	1982m05		1990m12	1990m12
	1996m10	1996m10	Germany long	1984m11	1984m11	Netherlands long	1983m01	1983m01	UK long	1982m10	1982m10
	2002m10	2002m10		1997m08	1997m08		1996m11	1996m11		1997m06	1997m06
	2007m05	2007m05		2003m01	2003m01		2003m01	2003m01		2000m12	2000m12
Belgium growth	-	-		2004m11	2004m11		2007m05	2007m05		2002m09	2002m09
France rate	1984m11	1984m11		2006m05	2006m05		2008m11	2008m11	UK growth	-	-
	1995m12	1995m12		2008m09	2008m09	Netherlands growth	-	-	Euro rate	1984m05	1984m05
	2002m11	2002m11	Germany growth	-	-	Spain rate	1984m02	1984m02		1996m02	1996m02
	2006m09	2006m09	Italy rate	1986m06	1986m06		1996m05	1996m05		2001m12	2001m12
	2008m10	2008m10		1996m12	-		1998m06	1998m06		2006m11	2006m11
France infl	1982m06	1982m06		1998m11	-		2002m01	2002m01		2008m10	2008m10
	1986m07	1986m07		2007m02	-		2006m11	2006m11	Euro infl	1982m08	1982m08
	1992m01	1992m01	Italy infl	1983m01	1983m01		2008m10	2008m10		1994m05	1994m05
France long	1985m05	1985m05		1995m08	1995m08	Spain infl	1986m02	1983m03	Euro long	1985m01	1985m01
	1996m02	1996m02		-	-		1995m06	1992m04		1996m11	-
	2002m10	2002m10	Italy long	1985m01	1985m01	Spain long	1985m02	-		2002m10	-
	2007m05	2007m05		1996m11	-		1996m11	-		2007m05	-
	2008m11	2008m11		2002m09	-		2002m10	-		2008m11	-
France growth	-	-		2007m05	-		2007m05	-	Euro growth	-	-
				2008m06	-	Spain growth	-	-			
			Italy growth	-	-						

Table A1: Detected breaks using the Andrews-Quandt (Andrews, 1993) and the Andrews-Ploberger test (Andrews and Ploberger, 1994)