EUROPEAN CENTRAL BANK

WORKING PAPER SERIES

NO 600 / APRIL 2006

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1 The author wishes to thank several colleagues at the ECB for valuable comments on previous versions of the paper, in particular Huw Pill, Oreste Tristani, Alessandro Calza and Claus Brand. This paper is partly based on previous work undertaken together with Beatrice Pierluigi (ECB), which was presented at the Oswald Distinguished Speaker Seminar at the University of Kansas on 22 October 2004. I also thank the Editorial Board of the Working Paper Series and a referee for constructuve comments. The views expressed in this paper are only of the author and are not necessarily shared by the European Central Bank.

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ISSN 1561-0810 (print)
ISSN 1725-2806 (online)

CONTENTS

Abstract

This paper estimates a hybrid New Keynesian model on euro area data and evaluates the performance of different simple policy rules and of the optimal unconstrained rule under commitment. The study reaches two main conclusions. First, inflation is found to be mainly forward-looking in the euro area, which implies the optimal policy reaction to cost push shocks is a muted one. Second, a "speed limit" rule of the type recently proposed by Walsh (2003) is able to closely approximate the performance of the optimal rule under commitment. The optimal speed limit rule is also characterised by super-inertia, making it a first difference rule similar to those recently proposed as a possible solution to measurement problems in the level of the natural interest rate and of potential output.

Keywords: Euro area, hybrid New Keynesian model, monetary policy rules, commitment, speed limit policies.

JEL: E52, E58

Non-technical summary

This paper estimates a hybrid New Keynesian model on the euro area economy based on quarterly data over a sample period ranging between 1987 and 2004, which is considered to be representative of the situation prevailing since the introduction of the euro, in particular due to the low level and stationary behaviour of inflation during this period. The specification of the model is based on Rudebusch (2002), and features a backward-looking IS curve, a hybrid Phillips curve, as well as expectational and transmission lags. A main finding of the empirical exercise is that inflation is mainly forward-looking in the euro area, broadly in line for example with Gali, Gertler and Lopez Salido (2001); hence intrinsic inflation persistence is found to be very low.

Based on the model's estimated parameters, the unconstrained optimal policy rule under commitment is simulated. A second contribution of this article is to compare the performance of the optimal rule under commitment with that of some simple linear rules which have been proposed in the literature. This analysis reaches three main results:

1. Broadly consistent for example with Walsh (2003) and McCallum and Nelson (2004b) for the US economy, it is found that an optimized "speed limit" policy rule (i.e. a rule in which the interest rate reacts to the *rate of change* of the output gap, rather than to its level) closely tracks the performance of the unconstrained optimal rule under commitment against the background of the economy's parameters. Interestingly, the optimal speed limit policy rule can be approximated as the first difference of the nominal interest rate reacting to the rate of change in the output gap. This result is found to be relatively robust to possible reasonable changes in the parameters of the economy (in particular, the degree of forward-lookingness in output) and in the central bank loss function.
2. The optimal speed limit policy features a negligible reaction to cost-push shocks, which reflects the fact that inflation has little intrinsic persistence in the estimated model of the euro area. The reaction to demand shocks, by contrast, is found to be strong, reflecting the high estimated persistence of the output gap.

3. Finally, the optimal speed limit policy is, in the baseline exercise as well as in all the other considered variants, close to a first difference rule. In spite of this, the rule is able to deliver low interest rate volatility.

This paper does not address the issue of the *operationality* of the rules in a context where the policy-maker is confronted with uncertainty (McCallum and Nelson, 1999). While developing this analysis goes beyond the scope of this paper, it is notable that there is at least one important dimension of uncertainty, namely measurement error in the levels of the output gap and the natural interest rate. Measurement error might become a decisive argument in favour of policies based on targeting the rate of change in the output gap, rather than its level, from an operational perspective. It is particularly noteworthy that a policy rule such as the optimal SL rule identified in this paper, where the first difference in the nominal interest rate reacts to the first difference in the output gap, can alleviate measurement problems related to *both* the output gap and the natural interest rate, issues which have been prominent in the recent work of Orphanides (2003), Orphanides and Williams (2002) and Williams (2004).

1 Introduction

New Keynesian models have gained a central place in the study of monetary policy in recent years (Clarida, Gali and Gertler, 1999). A distinctive feature of these models is the prominent role attributed to forward-looking behaviour and private sector expectations, which makes pre-commitment desirable in monetary policy-making (Woodford, 2003). The advantages of commitment in monetary policy-making are clear. Because in New Keynesian models today's output and inflation depend on their expected future values, expectations of future policy matter inasmuch as, if not more than, current policy decisions. However, while there is wide agreement on the possible benefits of commitment, there is much less consensus on *how to implement commitment*, for example in terms of targeting rules (advocated for example by Svensson, 2003) or instrument rules (advocated by, among others, McCallum and Nelson, 2004a). As noted by Woodford (1999) and McCallum (1999), the optimal way to carry out monetary policy under commitment is to follow a highly *history-dependent* policy. Since, under commitment, this inertial feature of the optimal rule feeds into private sector expectations and hence (in a forward-looking model) current output and inflation, a more gradual and hence preferable adjustment is made possible in response to shocks hitting the economy.

This study aims at shedding some light on this matter, with particular reference to a hybrid New Keynesian model estimated on the euro area economy. The empirical model follows Rudebusch (2002) and includes a backward-looking IS curve and a hybrid New Keynesian Phillips curve. Based on the model's estimated parameters, we compute the policy rule of the central bank which is the unconstrained optimal one under commitment (optimal commitment rule).[1] The central bank commits itself to follow the same policy rule at all times, and this commitment (which is assumed to be believed by the private sector) allows the achievement of a better trade-off between inflation, output and interest rate stabilization. Because our model includes cost-push shocks and due to the fact that interest rate volatility is penalized in the central bank loss function, the optimal rule under commitment displays significant inertia and history dependence. A first original contribution of this paper is to derive the optimal rule under commitment against the background of our estimated model of the euro area economy, and to evaluate its performance.

[1] A recent paper by Adalid, Coenen, McAdam and Siviero (2005) analyses the robustness of interest rate rules across four different models of the euro area economy. However, none of the models examined in that paper can be defined, strictly speaking, as a hybrid New Keynesian model.

A second contribution of this article is to compare the performance of the optimal rule under commitment with that of some simple linear rules which have been proposed in the literature. The advantage of simple rules over the fully optimal rule under commitment is their easier interpretability, which may make them more useful guidelines for actual policy-setting. On the other hand, one would ideally like to ensure that, by following a simple rule, the central bank does not compromise too much on its performance in terms of maximising its welfare criterion. We consider three simple rules, which have gained some prominence in the literature. The first is a simple Taylor rule without interest rate smoothing, which should be expected not to have a particularly favourable performance since it does not possess any history-dependence feature. The next rule we consider is a Taylor rule with interest rate smoothing, where history-dependence is captured by the presence of the lagged nominal interest rate in the rule.[2] Finally, we consider a "speed limit" policy rule of the type recently proposed by Walsh (2003) and McCallum and Nelson (2004b), which implies a policy reaction to the *rate of change* in the output gap, rather than to its *level*. The coefficients of the proposed simple rules are all optimized within the class of rules, namely chosen so as to maximize the central bank welfare criterion.

A main result of this study, which is broadly consistent with those of Walsh (2003) and McCallum and Nelson (2004b) for the US economy, is that an optimized speed limit policy rule closely tracks the performance of the unconstrained optimal rule under commitment against the background of the economy's parameters as estimated on euro area data. Interestingly, the optimal speed limit policy rule can be approximated as the first difference of the nominal interest rate reacting to the rate of change in the output gap. It is thus interpretable as a rule in first differences, which resembles the first difference rules recently proposed for the US economy, albeit with different motivation, by Orphanides and Williams (2002) and Williams (2004). We also carry out some robustness analysis of this result, finding that this conclusion is qualitatively maintained over a range of different parameters in the central bank loss function. Moreover, it is shown that the conclusions are also robust if one assumes that the estimated, backward-looking IS curve is mis-specified and that the true model of output is partly forward-looking.

The paper is structured as follows. We specify the hybrid New Keynesian model and discuss some issues related to optimal monetary policy rules under commitment in Section 2. We estimate the model on euro

[2]This rule has been already considered for the euro area in Peersman and Smets (1999) and Ehrmann and Smets (2003).

area data in Section 3. In Section 4 we analyse the performance of the considered policy rules. Section 5 concludes.

2 Policy rules in a hybrid New Keynesian model

2.1 Model specification

It has become customary to estimate a hybrid version of a New Keynesian (henceforth HNK) macroeconomic model of the euro area economy. In this model, inflation is determined in a Phillips curve equation containing both a forward-looking and a backward-looking element (Gali and Gertler, 1999). The hybrid model is normally found to have a better empirical performance than a purely forward-looking one, and it encompasses the pure New Keynesian model as a special case on the basis of a restriction which can be tested.[3]

Specifically, the model is typically made of the following two equations:

$$y_t = \alpha y_{t-1} + (1-\alpha)E_t y_{t+1} + \sigma \widehat{r}_t + \varepsilon_t^y, \quad (1)$$

$$\pi_t = \gamma \pi_{t-1} + (1-\gamma)E_t \pi_{t+1} + k y_t + \varepsilon_t^\pi, \quad (2)$$

where y is the output gap, $\widehat{r}$ is the deviation of the real interest rate from its equilibrium level (i.e. the real interest rate gap), π is the deviation of inflation from the central bank target, ε_t^y and ε_t^π are respectively a demand and a cost-push i.i.d. shock (for example, the cost-push shock is a mark-up shock as explained by Steinsson, 2003) with standard deviations σ_y and σ_π. We also assume, in line with the literature (Amato and Laubach, 2004) that the two shocks are uncorrelated with each other. The parameters α and γ are those determining the degree of inertia in the model. If $\alpha = \gamma = 0$, the model is completely forward-looking, while the opposite holds true if $\alpha = \gamma = 1$.

2.2 Optimal interest rate rules under commitment

The emphasis given to private sector forward-looking behaviour in New Keynesian models in the determination of output and inflation highlights the benefits which can be reaped through commitment by the central bank to a monetary policy rule. In fact, output and inflation today are determined not only – or even not mainly – by current policy actions, but also – and perhaps primarily – by the expectation of the future conduct of policy (Woodford, 2003). In other words, commitment to a policy rule is a means by which a policy maker can steer the expectations of

[3] Several papers have attempted at providing microfoundations to the presence of backward-looking behaviour in the model. These include, for example, explanations based on habit formation (Fuhrer, 2000), rule of thumb behaviour (Amato and Laubach, 2004) and price indexation (Christiano, Eichenbaum and Evans, 2001).

the private sector in a direction which is most useful for stabilization purposes.

Let us assume, in line with the literature, that the model in (1)-(2) describes the structure of the economy and that the central bank wishes to minimize a loss function defined as:

$$L_0 = E_0 \sum_{t=0}^{\infty} \delta^t \left[\lambda_\pi \pi_t^2 + \lambda_y y_t^2 + \lambda_i \widehat{i}_t^2 \right], \tag{3}$$

where $\widehat{i}_t = \widehat{r}_t + E_t \pi_{t+1}$ is the deviation of the nominal interest rate from its steady state level, and $0 < \delta < 1$ is a discount factor. Woodford (2003) has shown that the loss function in (3) is consistent with the maximization of a social utility function, because it contributes to undoing the distortions in the economy due to the existence of monopolistic competition and sluggish price adjustment.[4] In this loss function we are assuming that the central bank is also concerned with deviations of the nominal interest rate from the steady state, for example due to financial stability considerations and in order to minimize the risk of the nominal interest rate hitting the zero bound on nominal interest rates (Rotemberg and Woodford, 1998).

Assuming that there is agreement about the benefits of commitment in monetary policy, the important question becomes: how should commitment be implemented by the monetary authority? A simple way suggested in the literature has been that the central bank should systematically follow a Taylor-type rule which ensures a determinate solution, i.e. consistent with the Taylor principle (Taylor, 1999). However, Woodford (1999, 2003) and McCallum (1999) have shown that there is an optimal target criterion for the central bank which ensures the minimization of a loss function as in (3) (albeit not including a term penalizing interest rate volatility) under the constraint given by the structure of the economy in (1) and (2), which deviates from the targeting criterion implicit in an optimal rule under discretion. In a model without inflation inertia and no concern for interest rate volatility, the optimal target criterion is as follows:[5]

$$\pi_t + \frac{\lambda_y}{k}(y_t - y_{t-1}) = 0 \tag{4}$$

[4]It should be noted that in the presence of inflation inertia, the target inflation rate should also depend on the *recent past rate of inflation*, unlike in the more common case in which inflation is entirely forward-looking (Clarida, Gali and Gertler, 1999). We leave this complication aside in the analysis, since the loss function in (3) continues to be valid if one substitutes the inflation rate with its quasi-differenced level (see Woodford, 2003, and Amato and Laubach, 2004). Moreover, if γ is low (and we find this to be the case later on when estimating the model on euro area data) then inflation and quasi-differenced inflation will be very strongly correlated.

[5]See Woodford (2003), in particular p. 563. Jensen and McCallum (2002) have

Importantly, this optimal target criterion implements the optimal responses to demand and cost push disturbances regardless of the assumed statistical properties of the disturbances. This optimal target criterion differs from the common concept of, for example, a Taylor rule, which is given by:

$$\pi_t + \frac{\lambda_y}{k} y_t = 0 \tag{5}$$

The key point to emphasize here is that, in the optimal targeting criterion, it is the *rate of change* in the output gap, rather than its *level*, that should determine the acceptable deviation of inflation from the long run inflation target. This holds irrespective of the fact that it is the level of the output gap which enters the central bank loss function in (3), and which contributes to creating inflationary pressure (see eq. (2)).

The feature of the optimal targeting criterion in (4) which improves on the more common targeting criterion in (5) is its *history-dependence*. It is in fact immediate to see that the optimal targeting criterion depends not only on variables dated t, as the alternative targeting criterion in (5), but also on the output gap dated $t-1$. The usefulness of this commitment to follow a history-dependent monetary policy rule is immediately evident when considering the reaction of the economy to an adverse cost-push shock.

The focus in this paper is the *implementation* of the targeting criterion in (4) by means of *instrument* rules. Notably, McCallum and Nelson (2004b) report that an instrument rule reacting very strongly to deviations of output and inflation from the targeting criterion in (4) can represent a very good approximation to an optimal targeting rule. The rule proposed by McCallum and Nelson (2004b) is:

$$\widehat{i}_t = \mu_2 \widehat{i}_{t-1} + (1-\mu_2)\mu_1[\pi_t + \frac{\lambda_y}{k}(y_t - y_{t-1})], \tag{6}$$

where $\mu_2 > 0$ is the speed of partial adjustment parameter and $\mu_1 > 0$ the feedback parameter. If the latter coefficient is very large (feedback is very strong), a good approximation to the optimal targeting rule can be achieved.

In practice, the main concern in devising an instrument rule as in (6) is the risk that it might create excessive interest rate volatility. McCallum and Nelson (2004a), however, find this concern unfounded since, in equilibrium, a strong reaction does not necessarily imply paying a high cost in terms of interest rate volatility, because the movements in output

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recently demonstrated that there is a target criterion which can deliver a lower level of the loss than the one shown here. However, the difference is likely to be very small, as indicated for example by McCallum and Nelson (2004b).

and inflation to which the interest rate rule reacts will be themselves very small under the proposed rule. McCallum and Nelson highlight that an instrument rule involving feedback from the targeting criterion in (4) and with some concern for interest rate smoothing (for example including partial adjustment) is likely to approximate the optimal targeting rule quite well.

Against this background, the main objective of this paper is to evaluate how well simple policy rules with interest rate smoothing perform in comparison with the unconstrained optimal instrument rule. In particular, we will evaluate the performance of four different types of rules. The first one is the unconstrained optimal rule under commitment, which we denote the "OC rule" in the continuation. This rule has, by definition, the best possible performance in terms of central bank loss, and the focus of the analysis will thus be on how much would be lost if the central bank decided to follow simple constrained interest rate rules, compared with the first best.

The first simple rule that we consider is the TS rule:

$$\widehat{i}_t = \varphi_i \widehat{i}_{t-1} + \varphi_\pi \pi_t + \varphi_y y_t \tag{7}$$

namely a Taylor rule with interest rate smoothing. Next, we analyse a simple "speed limit" (SL) policy rule which is defined as follows:

$$\widehat{i}_t = \varphi_i \widehat{i}_{t-1} + \varphi_\pi \pi_t + \varphi_y (y_t - y_{t-1}) \tag{8}$$

This rule involves feedback from the rate of change in the output gap, rather than from its level as in the policy rule in (7). Walsh (2003) defines the targeting criterion in (4), the deviations from which the rule in (8) reacts to, as a "speed limit" one. Walsh finds that aiming at this targeting criterion, albeit under discretion, leads to a good performance in terms of central bank loss in models of the US economy, so it is an interesting question to check whether the same concept holds true for a model of the euro area economy and under commitment. Moreover, the SL rule corresponds, in practice, to the feedback rule proposed by McCallum and Nelson (2004b) and which is found to well approximate the performance of the optimal unconstrained instrument rule in a variety of models.

Finally, for the sake of completeness we also analyse a simple Taylor rule without interest rate smoothing (T rule),

$$\widehat{i}_t = \varphi_\pi \pi_t + \varphi_y E_t y_t \tag{9}$$

We evaluate the performance of this rule in terms of average loss for the central bank given the loss function postulated in (3), against the background of an estimated hybrid New Keynesian model of the euro area, to which we turn in the next section.

3 Estimation of the model on euro area data

In this section we estimate an slightly different version of the hybrid New Keynesian model, in order to take into accounts transmission and expectational lags, closely following the Rudebusch (2002) model of the US economy.

The empirical model is specified as follows:

$$y_t = \alpha_1 y_{t-1} + \alpha_2 y_{t-2} - \sigma(i_{t-1} - E_{t-1}\overline{\pi}_{t+3} - \overline{r}_{t-1}) + \varepsilon_t^y \tag{10}$$

$$\pi_t = \gamma\pi_{t-1} + (1-\gamma)E_{t-1}\overline{\pi}_{t+3} + ky_{t-1} + \varepsilon_t^\pi \tag{11}$$

where y is a measure of the output gap, i is the short-term nominal interest rate, π is the annualised percentage changes in the price level, $E_{t-1}\overline{\pi}_{t+3}$ is a survey-based measure of average inflation over the subsequent four quarters, lagged one quarter, $\overline{r}_t$ is the time-varying equilibrium rate of interest, and ε_t^y and ε_t^π are i.i.d. shocks.

Some observations on this specification are in order. The IS curve is backward-looking; this reflects the empirical problems associated with estimating a forward-looking IS curve, as documented in Fuhrer and Rudebusch (2004), which are also confirmed in preliminary analysis on the euro area data used in this paper. The model features a lag in the transmission of monetary policy in equation (10), and an expectational lag in the Phillips curve (see Rudebusch, 2002, for further details). An important advantage of Rudebusch's specification is that the model can be estimated by OLS.

The estimation is based on quarterly euro area data from 1987:Q1 to 2004:Q4 (72 usable quarterly observations).[6] The choice of the sample period is important to ensure stability of the estimated parameters. The main purpose of this study, in fact, is to evaluate policy rules which may be optimal in the context of the environment prevailing after the introduction of the euro, and therein lies the policy-relevant content of the analysis. It is therefore of paramount importance to ensure that the data come from a sample period which is as close as possible, especially in terms of the monetary policy regime and its credibility, to the one currently prevailing in the euro area. Although the hybrid New Keynesian model is in principle construed to be policy-invariant, there are nevertheless certain features of the model (such as, notably, the degree of inflation persistence) which might not, as a matter of fact, have this desirable property (Erceg and Levin, 2003). Euro area inflation appears to be a stationary variable (see below) starting after the second oil

[6] The source for all the data is the ECB's area wide model, apart from inflation expectations (for which see Forsells and Kenny, 2002).

counter-shock (in 1986), but is a non-stationary variable if one extends the sample back to the early 1980s. The stationarity of inflation after the oil counter-shock is a quite convincing indication that the post-1986 sample can be used to estimate parameters which are immune from the Lucas critique. The empirical evidence appears to confirm that this is indeed the case, as will be described shortly.

Turning to the data, inflation is the annualised quarterly change in the GDP deflator. As a measure of the inflation expectations over the following year, data from the European Commission Consumer Survey are used.[7] Since the model in (10)-(11) requires variables to be stationary, some de-trending is required. According to standard unit root tests, the inflation rate and the measure of inflation expectations are stationary, while the log of real GDP and the real interest rate, $r_t = i_t - E_t\overline{\pi}_{t+4}$, are trending variables. We de-trend the real interest rate by applying the HP filter, in order to control for a secular decline in its level, which reflects the trend decline in population and total factor productivity growth experienced in the euro area in the last two decades (see ECB, 2004).[8] As far as the euro area output gap is concerned, the "common cycle" measure of Proietti, Musso, and Westermann (2002) is used, an indicator which is derived using a production function approach. As documented by Proietti, Musso and Westermann (2002), this indicator comes out very well from specification tests as well as an explanatory variable for euro area inflation, which is arguably a feature that any good measure of the euro area output gap should have.

The result of the estimation is reported below (standard errors in parentheses):[9]

$$y_t = \underset{(0.09)}{1.47} y_{t-1} - \underset{(0.09)}{0.52} y_{t-2} - \underset{(0.04)}{0.18} (i_{t-1} - E_{t-1}\overline{\pi}_{t+3} - \overline{r}_{t-1}) + \varepsilon_t^y \qquad (12)$$

$$\overline{R}^2 = 0.96,\ DW = 1.87,\ \sigma_y^2 = 0.20$$

$$\pi_t = \underset{(0.12)}{0.16} \pi_{t-1} + 0.84 E_{t-1}\overline{\pi}_{t+3} + \underset{(0.12)}{0.39} y_{t-1} + \varepsilon_t^\pi \qquad (13)$$

$$\overline{R}^2 = 0.44,\ DW = 2.04,\ \sigma_\pi^2 = 0.94$$

[7] Specifically, the question on price trends over the following 12 months is converted into a quantitative measure using the approach suggested by Forsells and Kenny (2002).

[8] Applying a linear trend for de-trending the real interest rate leads to similar results, but to a somewhat poorer fit in the IS equation.

[9] In the Phillips curve equation we impose that the sum of the coefficients for past inflation and inflation expectations sum to one, as in Rudebusch (2002), after running a preliminary Wald test.

On the basis of the diagnostic statistics, the model appears to be well specified and stable. The coefficients have the expected sign and are (with the exception of the coefficient on past inflation) all significant at the 5% level or more. One important consideration in evaluating this specification is, in particular, stability, given the change in regime related to the introduction of the euro. To evaluate this crucial property of the model, we run Chow out-of-sample forecasts tests at various dates around the first quarter of 1999 (the date of the introduction of the euro), finding no evidence of a rejection of the null of stability. We also break the sample period in two equivalent parts – before and after the mid 1990s – and run breakpoint Chow parameter stability tests, again finding no rejection of the null.

It is interesting to compare the estimated coefficients with those reported by Rudebusch (2002). As regards the Phillips curve, one main difference with Rudebusch's results is that inflation is found to be much more forward-looking on the euro area data. This is likely to reflect more the different sample period (starting in 1968 in Rudebusch's analysis, thus covering the high inflation period in the 1970s, in 1987 in this paper) than a difference between the euro area and the US as such.[10] For the IS curve, the high degree of persistence of the output gap is similar to the results in Rudebusch (2002), while the estimated impact of a change in the real interest rate gap is found to be larger, although still in line with values which are considered appropriate for a large, closed economy like the euro area.[11]

A main lesson which can be drawn from the estimation of the Rudebusch (2002) model on euro area data is that inflation has little intrinsic persistence, while output is a very persistent process. This implies that demand shocks have a more protracted effect on output and inflation, despite their smaller average size, than cost-push shocks, also taking into account transmission lags. This intuitive consideration will soon find confirmation in the analysis of optimal policy rules based on this model, which assign a more important role to demand shocks than to cost push shocks.

For robustness analysis, we also use the HNK model estimated by Smets (2003), which, to the author's knowledge, is the only other available model of the same type estimated on euro area data which can be

[10] Smets (2003), working on euro area data as from 1970, also finds a more backward looking behaviour of inflation. This confirms that the estimated high degree of forward-lookingness of inflation found in this paper probably hinges on the choice of the sample period. See also ECB (2005) on the low intrinsic inflation inertia in the euro area in the current monetary policy regime.

[11] See for example Neiss and Nelson (2003) in general terms, and Rabanal and Rubio-Ramirez (2003) specifically on euro area data.

used for the analysis of the performance of alternative policy rules. The model is estimated in the specification shown in (1)-(2), using GMM, on annual data ranging between 1970 and 1998. The estimated parameters are $\alpha = 0.44$, $\gamma = 0.48$, $\sigma = -0.06$, $k = 0.18$, $\sigma_y = 0.65$, $\sigma_\pi = 0.70$.

4 Policy rules in the euro area

Against the background of the hybrid New Keynesian model of the euro area estimated in the previous section, we solve the model for the optimal feedback rule for the central bank, which is now a quite standard exercise in the literature (on European data see, for example, Peersman and Smets, 1999 and Ehrmann and Smets, 2003; more generally, see the contributions in the volume by Taylor, 1999).

As to the parameters of the central bank loss function in (3), we assume $\lambda_\pi = \frac{1}{2}$, $\lambda_x = \lambda_i = \frac{1}{4}$. In our interpretation, this is the loss function of a "conservative" central bank which places more weight to inflation stability than on output and interest rate stability, which might be considered appropriate given the supremacy of price stability as key objective of monetary policy in the euro area. The weight placed on interest rate stabilization is $\frac{1}{4}$, the same value as, for example, in Peersman and Smets (1999) and close to the value recommended by Rotemberg and Woodford (1997) as being optimal so as to minimize the risk that the nominal interest rate hits the zero bound. It should be noted that the higher weight on inflation volatility also caters for the presence of a limited degree of inflation inertia in the model, as discussed by Amato and Laubach (2004).

The central bank decision problem is essentially to choose $\widehat{i}$ so as to minimize the loss in (3) under the constraint given by the structure of the economy. In the sequel, we consider four possible types of policy rules, namely the OC, TS, SL and T rules as described in Section 2.

4.1 The performance of optimal policy rules

We now turn to the concrete identification of the optimal rules in the estimated model of the euro area, i.e. equations (12) and (13). Moreover, the shocks are assumed to be i.i.d. and uncorrelated with each other. We also use alternative parameter estimates, notably those obtained by Smets (2003) for the euro area, for a robustness check of some of the results.

All computations are done using the DYNARE software in MATLAB (see Collard and Juillard, 2003). The OC rule is identified by means of the OLR algorithm in DYNARE.[12] The parameters of the optimal simple

[12] Note that the OLR algorithm only computes the dynamic conditions for opti-

rules are found by means of a grid search over parameter values which ensure a determinate solution, also performed in MATLAB (using the OSR algorithm in DYNARE). In particular, for each triple $\{\varphi_i, \varphi_\pi, \varphi_y\}$ within the determinacy range, we compute and record the loss for the central bank. The optimal $\{\varphi_i, \varphi_\pi, \varphi_y\}$ is then simply identified as the one for which the computed loss is smallest.

Table I reports the coefficients $\{\varphi_i, \varphi_\pi, \varphi_y\}$ for each of the four considered rules (where relevant), the variance of the variables which enter the central bank loss function (inflation, the output gap and the nominal interest rate) and the per-period value of the loss function.

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mality, not the optimality condition at the inception of the regime. In this sense the OC rule is of the "timeless perspective" type as described in Woodford (2003).

Table I – Performance indicators of alternative policy rules

	OC rule	TS rule	SL rule	T rule
φ_π	/	0.97	$\simeq$0	1
φ_y	/	1.47	1.70	1.49
φ_i	/	0.03	1	/
σ_π^2	1.36	1.41	1.41	1.41
σ_i^2	2.15	5.43	2.43	5.41
σ_y^2	0.67	1.05	0.84	1.04
Loss per period	1.39	2.33	1.53	2.31

Note: Baseline exercise conducted under the assumption that the true model of the economy is given by eq. (12) and (13). The loss per period is in percentage points per quarter.

Predictably, the best performance in terms of loss is given by the OC rule, while the T and TS rules have the worst performance. It is also interesting to note that the optimal TS rule is found to have a very low degree of inertia (in fact, it is very close to the optimal T rule). This is likely to reflect the very high estimated persistence of the output gap, from which it feedbacks very strongly, which appears to be sufficient to impart a high degree of inertial behaviour to the rule. The optimal SL rule, by contrast, which reacts (again strongly) to the less persistent *changes* in the output gap, is found to be very persistent, as it can be specified as a rule in first difference. It needs to be emphasised that for both rules the reaction to the output gap is significantly stronger than that to inflation; this is related to the fact that while the estimated output process is a highly persistent one, the degree of inflation inertia, γ, has been estimated to be quite low. Hence, it is optimal for policy not to react strongly to cost-push shocks, given the transmission lags.

Perhaps the most interesting message coming out of this analysis is the comparison of the central bank loss (last row in the table). While the performance of the optimal TS and T rules is somewhat worse than that of the OC rule, that of the SL rule approximates that of the OC rule significantly more closely. This confirms the conclusion reached by McCallum and Nelson (2004b) about the desirability of SL instrument rules under commitment in New Keynesian models of the type estimated in this paper.

Further insight may be gained by looking at the impulse responses following a demand and cost push shock for each of the considered policy rules, shown in Fig. 1 (demand shock) and Fig. 2 (cost-push shock).

Following a positive demand shock, it is interesting to note that, under the two history-dependent rules (OC and SL), output is kept below the baseline for an extended period, even after the immediate impact of the shock has waned (Fig. 1). This inertial behaviour helps containing inflationary pressure almost immediately, due to the fact that (in the model) inflation is forward-looking. It is also noteworthy that the impulse responses of the SL rule are always very close to those of the OC rule, suggesting that the former almost replicates the latter. Finally, the policy reaction to a demand shock is relatively strong under all the considered rules; this, again, reflects the fact that output is found to be a very persistent process in the empirical analysis.

Turning to the impact of a cost-push shock (Fig. 2), also in this case under the history-dependent (OC and SL) rules a prolonged (if small) contraction of output delivers a better stabilization of inflationary pressure, working through private sector expectations. An interesting difference is visible in the interest rate reaction to the cost push shock which, although muted in all cases, is significantly stronger and quicker under the T and TS rules, while under the OC and SL rules it is significantly more gradual. Also in this case the behaviour of the variables of the SL rule follow that prevailing under the OC rule, which is a confirmation that this simple rule is able to mimic the optimal unconstrained rule very closely.

Another notable feature of the SL rule is that, despite its being very persistent, it is able to produce a relatively low volatility in the nominal interest rate. This is in keeping with McCallum and Nelson (2004b)'s view that an instrument rule reacting strongly to deviations from the optimal targeting criterion in (4) does not produce unnecessarily high fluctuations in the nominal interest rate, given its strong stabilizing impact on inflation and the output gap.

The optimal SL rule can be expressed as a first difference rule reacting to deviations of inflation levels from the steady state level and from the rate of change in the output gap:

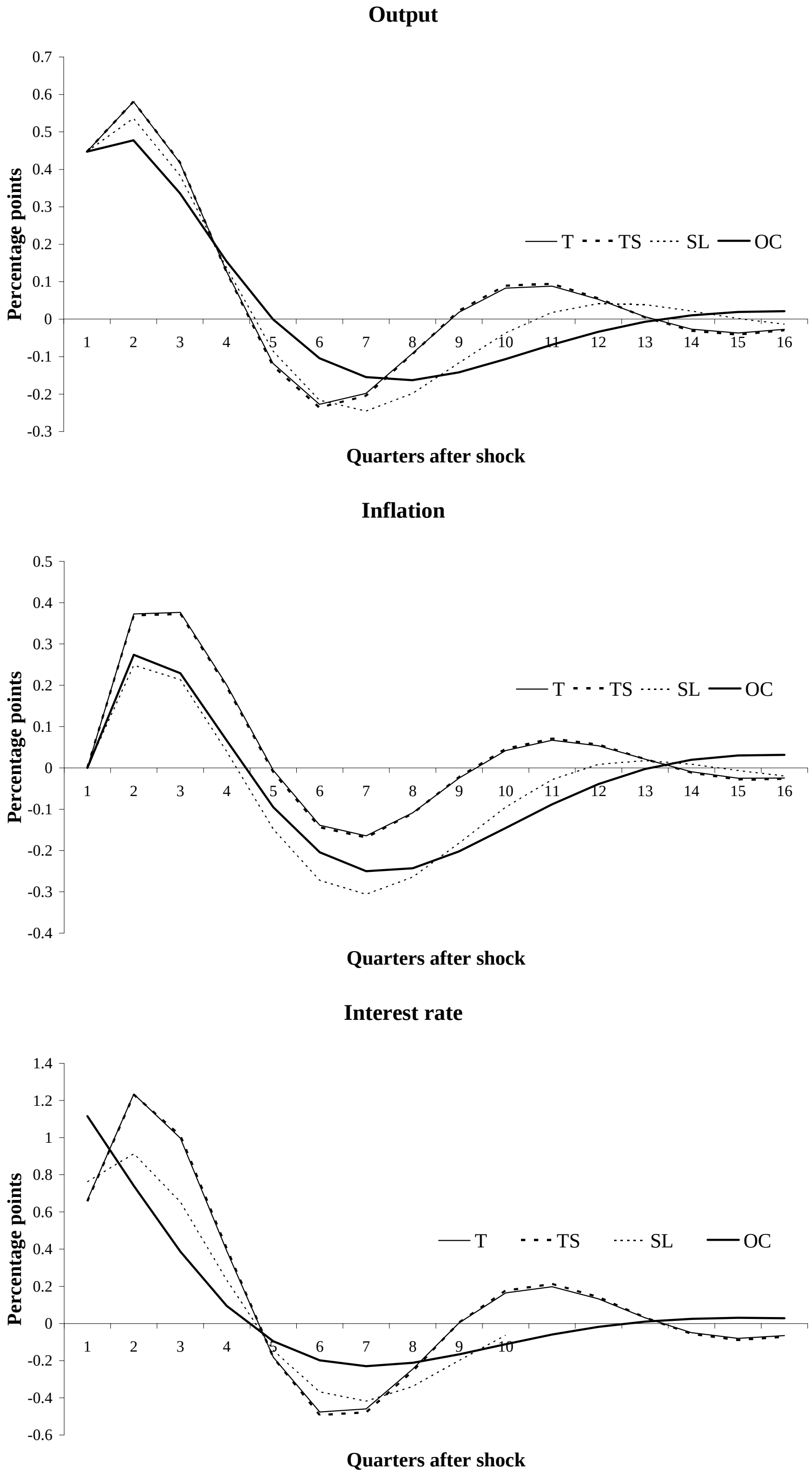
$$\Delta\widehat{i}_t = \varphi_\pi \pi_t + \varphi_y \Delta y_t \tag{14}$$

In the baseline case reported in Table I, the optimal parameters of this rule are $\varphi_\pi \simeq 0$ and $\varphi_y = 1.70$.[13] It is notable that this result has been obtained *without* any assumption of uncertainty about the level of the natural interest rate and of potential output, which are factors that have been shown to support policy rules specified in first differences.

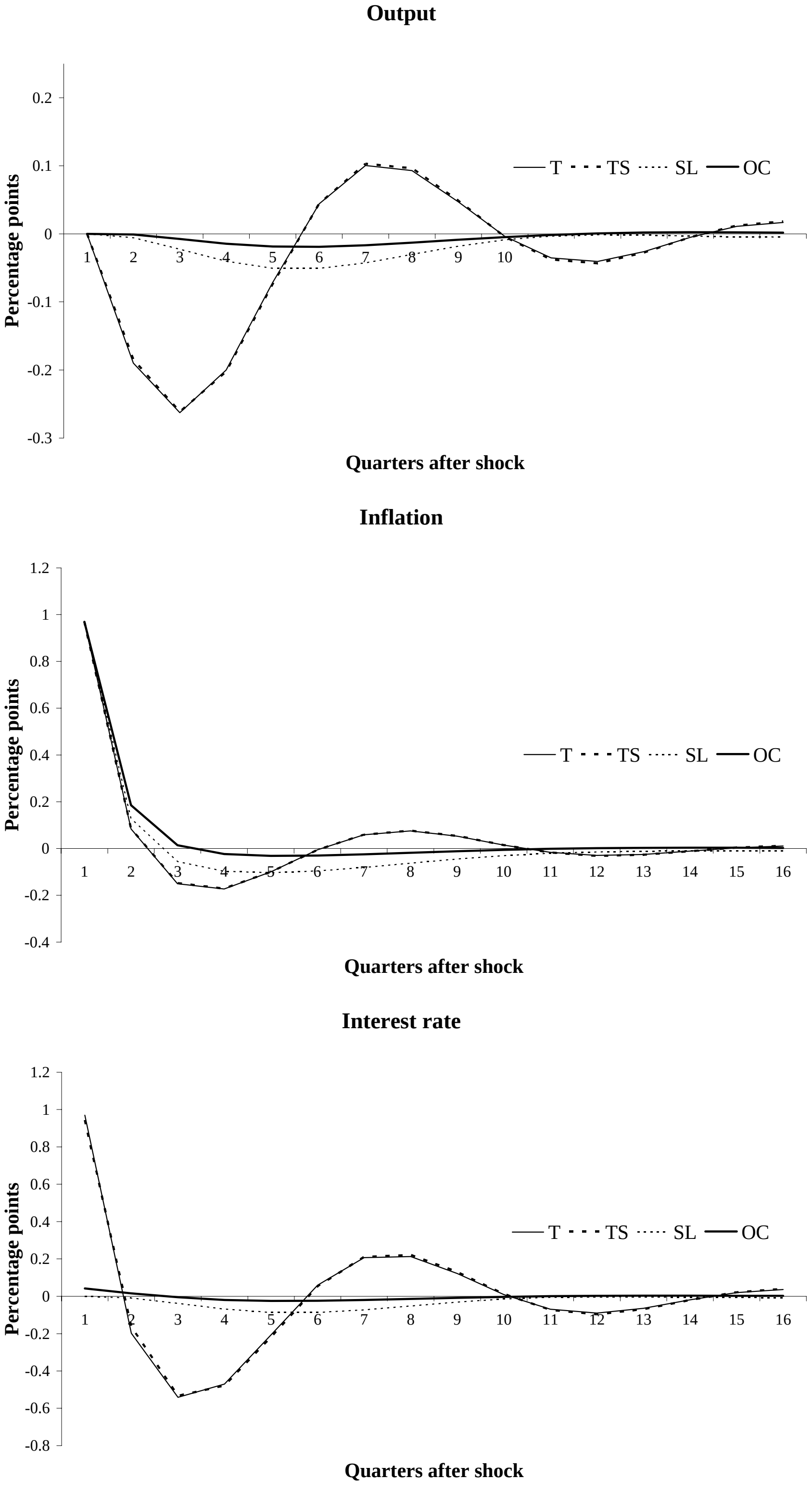
When repeating the analysis of the relative performance of the different policy rules based on the parameter estimates of Smets (2003), we come to a slightly different conclusion since the performance of the TS

[13]Note that, in order to ensure the determinacy of the equilibrium, φ_π cannot be exactly zero and has to be slightly positive, even if arbitrarily small.

<u>Figure 1</u> – Impulse responses to a one standard deviation demand shock under different policy rules



<u>Figure 2</u> – Impulse responses to a one standard deviation cost push shock under different policy rules



rule is slightly better than that of the SL rule (see Table II).[14] Both rules, however, still approach the performance of the OC rule very closely, so our conclusion as regards the desirability of the SL rule is not fundamentally altered. In addition, it is interesting to note that the optimal SL rule (second column from the right in Table II) is close to a nominal income targeting rule, since φ_π and φ_y are very close. Intuitively, this reflects the higher inflation persistence estimated by Smets (2003), which creates the need for policy to react more strongly to cost-push shocks.

Similar conclusions can be reached also when changing the parameters of the central bank loss function, as partly explained in the next section. It appears, therefore, that the favourable performance of the simple rules (and in particular of the SL rule) is relatively unaffected by the specific structural parameters used in the analysis.

Table II – Performance indicators of alternative policy rules

	OC rule	**TS rule**	**SL rule**	**T rule**
φ_i	/	1.03	1.07	/
φ_π	/	0.31	0.41	1.83
φ_y	/	0.19	0.37	-0.31
σ_i^2	1.75	1.75	1.84	10.58
σ_π^2	2.49	2.54	2.62	3.35
σ_y^2	2.19	2.19	2.56	2.31
Loss per period	2.23	2.25	2.41	4.90

Note: The simulation is conducted under the model parameters estimated by Smets (2003): in the model (1)-(2), with $\alpha = 0.44$, $\gamma = 0.48$, $\sigma = -0.06$, $k = 0.18$, $\sigma_y = 0.65$, $\sigma_\pi = 0.70$.

4.2 Some robustness analysis

In this section we carry out some robustness analysis of the key results of the paper. The outcome of the analysis is reported in Table III below. In particular, we consider two variants of the baseline specification. First, we change the model of the economy in order to allow for forward-looking output. Second, we change the parameters of the central bank loss

[14] The absolute levels of the variances and the central bank loss are remarkably higher than in the baseline case. This is due to the low absolute level of σ estimated in Smets (2003), which forces the central bank to move the nominal interest rate much more than in the baseline case, which is costly for the monetary authority. Note that our exercise is not directly comparable to that by Ehrmann and Smets (2003), who use the same parameter values, since Ehrmann and Smets assume a different central bank loss function (i.e. including $(\Delta i)^2$ instead of i^2).

function, and check whether this modifies the essential features of the optimal SL rule.

In fact, one possible caveat to the analysis conducted thus far is that the estimated IS curve in (12) is a backward-looking one, while output in the baseline hybrid New Keynesian model features (in (1)-(2)) should be at least partly forward looking. While this simplification seems necessary in order to estimate a well specified model on euro area data, it begs the question of whether the results of the previous section are due to this assumption, and are not valid otherwise.

Therefore, we repeat the analysis reported in Table I by assuming that, in the IS equation in (12), the output gap is forward-looking with a coefficient of 0.5, and backward-looking with an equal weight. The posited IS curve now becomes

$$y_t = 0.5E_t y_{t+1} + 0.5(1.47 y_{t-1} - 0.52 y_{t-2}) - 0.18(i_{t-1} - E_{t-1}\overline{\pi}_{t+3} - \overline{r}_{t-1}) + \varepsilon_t^y \quad (15)$$

The results of this simulation are reported in the first four columns to the left in Table III. Overall, assuming that output is partly forward-looking does not change the main conclusions of the analysis. In fact, the SL rule continues to approximate the OC rule very closely, although the TS rule now also has almost the same performance. Moreover, it continues to be valid that the optimal SL rule is a first difference rule, with a negligible feedback from inflation and a comparatively stronger (even if smaller compared with the baseline case) feedback from the output gap. This analysis also confirms that the backward-looking specification of the model in (12)-(13) does not, in itself, determine most of the main results of this paper.

Another interesting question is whether the key features of the SL rule are affected by the value of the parameters in the central bank loss function. Two polar cases are considered here. First, an "inflation nutter" central bank attaching no weight to output gap stabilization ($\lambda_y = 0$, $\lambda_\pi = 1$); second, a "liberal" central bank attaching the same weight to inflation and output gap stabilization ($\lambda_y = \lambda_\pi = 0.5$). The outcome of this sensitivity analysis, also reported in Table III, indicates that the optimal SL rule is relatively close to the baseline case in the two other variants, suggesting that the relative weights of the output gap and inflation in the loss function do not matter too much for its overall performance. Moreover, in these variants the performance of the optimal SL rule continues to approximate the OC rule very well as in the baseline case. Hence, the parameters in the central bank loss function do not seem to be key drivers of the results of the analysis either.

Table III – Performance indicators of alternative policy rules: robustness analysis

	Variant (1)				(2)		(3)	
Rule	OC	TS	SL	T	SL	OC	SL	OC
φ_π	/	0.07	$\simeq$0	1	$\simeq$0	/	$\simeq$0	/
φ_y	/	0.37	0.64	1.07	1.82	/	1.35	/
φ_i	/	0.93	1	/	1	/	1	/
σ_π^2	1.09	1.12	1.14	1.08	1.37	1.29	1.33	1.30
σ_i^2	0.25	0.19	0.23	1.53	2.60	2.35	2.77	2.39
σ_y^2	0.55	0.73	0.56	0.60	0.78	0.64	0.73	0.58
Loss	0.75	0.79	0.77	1.07	2.02	1.88	1.72	1.54

Note: Variant (1) is partly forward-looking output as in equation (15); variant (2) is where the output gap does not appear in the loss function ($\lambda_y = 0$, $\lambda_\pi = 1$, i.e. "inflation nutter"); variant (3) is where inflation and the output gap receive the same weight (i.e. $\lambda_y = \lambda_\pi = 0.5$, i.e. a "liberal" central bank).

5 Conclusions

In this paper we have estimated a hybrid New Keynesian model of the euro area economy based on quarterly data over a sample period ranging between 1987 and 2004. The specification of the model is based on Rudebusch (2002). A main finding of this empirical exercise is that inflation is mainly forward-looking in the euro area, broadly in line for example with Gali, Gertler and Lopez Salido (2001).

The importance of the forward-looking component in the euro area Phillips curve makes commitment desirable in monetary policy. The key question is really how to implement commitment, and this has been the main focus of this paper. In particular, we have sought to compare the performance of three simple interest rate rules with the unconstrained optimal rule implemented under commitment against the background of parameter estimates of the model which may be realistic for the euro area economy.

The main conclusions of this article are three. *First*, a speed limit policy (namely, a rule where the nominal interest rate reacts to the first difference in the output gap) appears to have very favourable properties from the standpoint of matching the performance of the optimal rule under commitment. This result is found to be relatively robust to possible reasonable changes in the parameters of the economy (in particular, the degree of forward-lookingness in output) and in the central bank loss function. *Second*, the optimal speed limit policy features a negligible reaction to cost-push shocks, which reflects the fact that inflation is mainly forward-looking (and hence has little intrinsic persistence) in the estimated model of the euro area. The reaction to demand shocks, by contrast, is found to be strong, reflecting the high estimated persistence of the output gap. *Third*, the optimal speed limit policy is, in the baseline exercise as well as in all the other considered variants, slightly super-intertial and hence close to a first difference rule.

An important issue which this paper has not addressed is that of the *operationality* of the rules in a context where the policy-maker is confronted with uncertainty (McCallum and Nelson, 1999). While developing this analysis goes beyond the limited ambitions of this paper, we note that there is at least one important dimension of uncertainty, namely measurement error in the levels of the output gap and the natural interest rate. This point of view is mentioned only in passing by Walsh (2003) in his discussion of the desirability of the "speed limit policies", but it is clear that measurement error might become a decisive argument in favour of policies based on targeting the rate of change in the output gap, rather than its level, from an operational perspective.[15] It is particularly noteworthy that a policy rule such as the optimal SL rule identified in this paper, where the first difference in the nominal interest rate reacts to the first difference in the output gap, can alleviate measurement problems related to both the output gap and the natural interest rate, issues which have been prominent in the recent work of Orphanides (2003), Orphanides and Williams (2002) and Williams (2004).

All in all, our findings bode well for the desirability and the operationality of a first difference speed limit monetary policy rule in the euro area. Yet a final word of caution is in order, since this simple rule has been found to be very close to the optimal one only under the simple structure of the hybrid New Keynesian model estimated in this paper. While this is a standard exercise in the literature, there is no guarantee that the good performance would be maintained under a richer model of the economy, for example including financial frictions. Assessing the robustness of the performance of the rule to changes in the specification of the model is an important task for future research.

[15] Indeed, Walsh (2003) argues that the Fed is already following a policy which can be characterised as a "speed limit" one.

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ISSN 1561081-0

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