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MACROECONOMIC VOLATILITY TRADE-OFF AND MONETARY POLICY REGIME IN THE EURO AREA

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Abstract

This research uncovers a well-defined monetary policy regime starting in 1986 in the aggregate Euro Area. Both alternative solution-estimation methods employed - optimal control *cum* GMM, and dynamic programming *cum* FIML - identify a regime of strict inflation targeting with interest rate smoothing. The unemployment gap, properly estimated as *quasi* real-time information, is a relevant element in the information set of the monetary authority, despite not being included in its preferences.

The emergence of the regime relates to the improvement of the volatility trade-off between inflation and unemployment gap since the mid-80s. Additional improving factors have been milder supply shocks and better ability of policymakers to set the interest rate closer to optimum.

Keywords: Monetary Policy Regime, Euro Area, Optimal Control, Dynamic Programming, GMM, FIML.

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Macroeconomic Volatility Trade-off and Monetary Policy Regime in the Euro Area

1. Introduction*

Along the last thirty years, the macroeconomic performance of the current Euro Area, in terms of the main stabilisation policy objectives, has changed markedly. Figure 1 illustrates this change, showing five years averages of the variability of quarterly inflation and unemployment gap (u-gap), of the aggregate Euro Area between 1972:I and 2001:II. The macroeconomic volatility performance of the Euro Area has clearly improved since 1986, with low and systematically decreasing variability of both inflation and u-gap.

We interpret this picture within Taylor's (1979) framework. The transitory Phillips trade-off between the levels of inflation and unemployment gap implies a permanent trade-off between their variability around desired levels. As further developed by Taylor (1994) and Fuhrer (1997), the permanent variability trade-off is interpretable as an efficiency policy frontier for the monetary policy regime. This policy frontier - often called Taylor curve - is negatively sloped and convex to the origin. Its *locus* depends on the policy regime and on the variability of the shocks hitting the economy, and its slope is a function of the structure of the economy, including the elasticity of the transitory Phillips curve. The optimal policy choice yields a specific combination in the efficiency frontier, which is a function of the relative weight attached to inflation and activity gap volatility in the policymaker's loss function. In this context, the distance between actual macro performance and the frontier may be interpreted as a measure of the policy inefficiency.

This paper investigates the contribution of a new monetary policy regime to the favourable shift in the volatility trade-off of the Euro Area, observed since 1986 and reinforced thereafter. In the process, we must isolate this factor from the other three possibly driving the implied shift of the Taylor curve and/or the position of the economy relative to that efficiency frontier, namely: (i) changes in the structure of the economy; (ii) shifts in the degree of smoothness of shocks buffeting the Area; and (iii) improvement in the efficiency of monetary policy.

In order to pursue this approach, we need to estimate the Euro Area policymaker's preferences in a framework that allows for simultaneous identification of the Area macroeconomic structure, the supply shocks, and policy efficiency.[1] Two recent studies for the US case, Favero and Rovelli (2001) and Dennis (2001), seem to fit these requirements. They both use a small macroeconomic model suggested by Rudebusch and Svensson (1999) to represent aggregate supply and aggregate demand, together with an interest rate equation describing conditions for optimality of the policymaker's actions. Such optimality conditions are derived by Favero and Rovelli using optimal control, while Dennis uses dynamic programming, building on the use of inverse-control theory by Salemi (1995). In terms of econometric estimation of the system, the two approaches - optimal control and dynamic programming - lead to two different estimators, GMM and FIML, respectively.

Given the balanced assessment of strengths and weaknesses of these two methods, we refine and adapt both the Favero and Rovelli (2001) and Dennis (2001) frameworks to the Euro Area, and compare the results. An important refinement refers to the u-gap series used in the estimation. Instead of using measures available from official sources at the time of the research, we build a *quasi* real-time estimate of the u-gap, which is closer to the information available to policymakers in real-time, *i.e.* at the time of actual decisions.

Even though its observed shift in volatility parallels that of the US, the Euro Area case has two important particularities that render our goal potentially more complex. First, there was no formal unique European monetary policy regime until the European Monetary Union (EMU) in 1999, and, until then, the national monetary authorities operated within heterogeneous monetary policy institutional frameworks – Cukierman (1992, chapter 19). Second, the Euro Area time series are weighted averages of the 11 member-states forming the EMU, as published in the Area Wide Model Database (AWMD) by the European Central Bank (ECB), possibly masking structural heterogeneity.

In spite of these difficulties, the data and the events in the European monetary integration throughout 1979-1999 motivate our hypothesis that the variability trade-off improvement is concurrent with the *de facto* emergence of a well-defined monetary policy regime in the aggregate Euro Area in the mid-80s. Such regime would be associated to the leadership of the exchange rate mechanism of the European Monetary System by German monetary policy. The Bundesbank initiated a new regime in 1986, stabilising the inflation target at 2 percent per year, after having gradually decreased it since the beginning of the 80s.

The exchange rate events and the nominal convergence record in the Euro Area motivate our claim concerning the monetary policy regime emergence in 1986. In fact, after April 1986 there were almost no realignments of exchange-rate parities within the exchange rate mechanism of the European Monetary System. Even the 1992-93 exchange rate crisis turned out to have no significant structural consequences. Exchange rate stability, together with the liberalisation of capital movements – capital controls were practically ineffective after 1986[2] -, explains why monetary policy of individual countries has significantly lost autonomy after 1986-87. Furthermore, nominal convergence towards Germany – especially in terms of inflation rates – had already been achieved, in large part, by the second half of the 80s.

In addition to the recent historical record, the hypothesis of a new informal monetary regime since 1986 - anticipating the formal 1999's EMU - is also compatible with arguments put forth previously in different contexts. McCallum (1997) noted that in many episodes of monetary history institutional changes lag behind actual policy changes. Muscatelli and Trecroci (2000) surveyed evidence of this hypothesis, to which Muscatelli *et al.* (2000) added new results. Doménech *et al.* (2002) present evidence that led them, in Doménech *et al.* (2001), to study a model of the EMU Area with data beginning in 1986:I.

The rest of the paper is outlined as follows. Section 2 discusses an appropriate optimising model for monetary policy analysis in the Euro Area, describes the data and presents structural stability tests. Section 3 briefly explains two alternative solution-estimation procedures and comparatively discusses their results. Finally, Section 4 offers some concluding remarks.

2. A Model for Monetary Policy Analysis in the Euro Area

Our structural model derives from a simple optimising framework for monetary policy analysis, in which the loss functional of the central bank describing its intertemporal preferences is minimised subject to the dynamic structure of the aggregate economy. This section sets up the model for optimisation, which, in turn, is solved in section 3. Thus it presents and identifies the dynamic economic structure - an AD-AS system - and the loss functional - an intertemporal aggregation of quadratic loss functions.

Aggregate Demand and Aggregate Supply

The structure of the Euro Area aggregate economy is modelled as a simple backward-looking aggregate demand - aggregate supply system similar to the one applied by Rudebusch and Svensson (1999) to US data. Aggregate demand is basically an IS equation expressed in terms of u-gap, and aggregate supply an expectations augmented Phillips equation with the short-term trade-off between u-gap and inflation.

Rudebusch and Svensson's motivation for using this model was threefold: tractability and transparency of results; good fit to recent US data; and proximity to many policymakers' views about the dynamics of the economy, and to the spirit of many policy-oriented macro-econometric models, including some used by central banks. In addition, we have three reasons of our own.

First, it has been widely used in recent empirical studies of monetary policy rules or regimes. That is the case, among many others, of Favero and Rovelli (2001), Dennis (2001), and, for European countries, Peersman and Smets (1999), Taylor (1999), and Aksoy *et al*. (2002). To be sure, the intensive use does not necessarily mean that this model effectively represents the structure of actual developed economies - see Cukierman (2001). It reflects, though, its sensible theoretical and empirical properties, from which Goodhart (2000) stresses the realistic inclusion of monetary transmission lags.

Second, even though most of the uses of the model relate to the US, it is reasonable to expect the structure of the Euro Area to be broadly similar, as both are large and relatively closed economies - see Rudebusch and Svensson (2002). In support of this belief, Agresti and Mojon (2001) found that the business cycle of the aggregate Euro Area is similar to the US in several respects, and Angeloni *et al.* (2002) show how the responses of the Area's output and inflation to monetary actions are quite close to those typically reported for the US. In fact, both Peersman and Smets (1999) and Taylor (1999) have successfully estimated this model with aggregate data of a core of EMU countries.

Third, the unemployment gap series that we use has been computed within a system that features a similar Phillips equation - specifically, a backward-looking version of the one in Aguiar and Martins (2002).

We proceed now with the identification of the specific formulation of the Rudebusch and Svensson's AD-AS system that best fits the Euro Area aggregate data - quarterly time-series 1972:I-2001:II. For the period 1970-1998, the data source is the Area Wide Model Database (AWMD) published in Fagan *et al* (2001), whilst for subsequent periods compatible updates are taken from several issues of the ECB Monthly Bulletin.

The inflation rate - π - is measured through the GDP deflator, and the nominal short-term interest rate - i - is the quarterly average of the 3-month interest rate EURIBOR. Our *proxy* for exogenous supply shocks is the deviation of imported from domestic inflation - $Im\pi$, in percentage points. The unemployment gap - x, in percentage points - is computed as a time-varying NAIRU minus the actual unemployment rate.

The unobservable NAIRU is computed from a backward-looking version of the unobserved components model estimated by maximum likelihood with the Kalman filter in Aguiar and Martins (2002). By using the filter updating equations from each period, instead of the end of sample smoother, we are able to suitably interpret our u-gap series as *quasi* real-time estimates. In fact, each u-gap is an optimal estimate in each time period, given the identified model and the information available at that period.[3] Here, we clearly differ from Favero and Rovelli (2001) and Dennis (2001), which use estimates of the gap obtained at the time of their research. Our *quasi* real-time estimates of the gap are conceptually closer to the policymakers' real-time perceptions about the state of the economy.

The assumptions about the timing of information gathering can be quite relevant for policy analysis, as has been argued in the literature, and as can be illustrated in our case. In the literature, the importance of using data available to policymakers in real-time in *ex-post* evaluations of monetary policy has been profusely shown, for the US case, by Orphanides (2001a and 2002). Nelson and Nikolov (2001) also report a pattern of official real-time output gap misperceptions in the UK during the 70s similar to the one identified by Orphanides for the US. In both cases, the authors inspected the information actually used at the meetings of monetary policy committees.[4]

Here, however, we cannot use proper real-time information, not only because there is no Euro Area aggregate real-time statistical data for almost the whole sample period, but also because we evaluate the policy of a notional central bank. Instead, we adopt a *quasi* real-time approach, as explained above.[5] Figure 2 illustrates, for our case, the discrepancies between *ex-post* and *quasi* real-time estimates. It shows the u-gap series given by the Kalman smoother (*i.e.* using for each period the entire sample information) and the unsmoothed series given by the Kalman filter (*i.e.* using for each period the information available up to then). The difference is interpretable as the *quasi* real-time gap measurement error faced by policymakers.

With this Euro Area data set (*quasi* real-time u-gaps and aggregate macro data from AWMD) we first identify the AD-AS system, combining information from both OLS and FIML estimations, and then submit it to structural stability tests. The best Rudebusch-Svensson type specification, for the entire sample, turns out to be the following system:

$$\begin{cases} x_t = c_1 + c_2 x_{t-1} + c_3 x_{t-2} + c_4 x_{t-3} + c_5 (i_{t-3} - \pi_{t-3}) + \varepsilon_t^d \\ \pi_t = c_6 \pi_{t-1} + c_7 \pi_{t-2} + c_8 \pi_{t-3} + (1 - c_6 - c_7 - c_8)\pi_{t-4} + c_9 x_t + c_{10}(Im\pi_{t-1}) + \varepsilon_t^s \end{cases} \tag{1}$$

where the equations are, respectively, the IS function - representing aggregate demand - and the Phillips function - representing aggregate supply.[6]

This specification implies a transmission of monetary actions to the u-gap similar to Peersman and Smets' (2001), in spite of the differences in empirical methods and data, and is compatible with Angeloni *et al.*'s (2002) extensive reading of the evidence on the Euro Area transmission of policy. In short, interest rate changes affect output temporarily, with effects peaking at more or less one year, while inflation hardly moves during the first year, and gradually changes over the subsequent few years.

The need for structural stability tests arises from the Lucas critique, to which this AD-AS system is, in theory, subject. In fact, if the true dynamic behaviour of inflation and u-gap includes forward-looking elements - as dynamic general equilibrium analysis and the new Keynesian theory prescribe -, the reduced form coefficients of this backward-looking model are not stable when the monetary policy regime changes. Simulations in Lindé (2000) suggest that the Lucas critique may be quantitatively important for the Rudebusch-Svensson model. In complete contrast, Rudebusch's (2002a) simulations suggest the empirical irrelevance of the Lucas critique, corroborating estimation results in Estrella and Fuhrer (1999). Thus, as usual, the actual importance of the Lucas critique is an empirical matter of structural stability, which should be addressed prior to the use of the model for policy analysis.

We put our AD-AS system to test for structural stability over the entire sample. As there is no clear *a priori* about the timing of possible structural breaks, the appropriate test is based on the Andrews (1993, equations 4.1 and 4.2, page 835) *sup-Wald* statistic. It turns out that the null hypothesis of no structural change is rejected.[7]

The dates of the structural breaks, estimated with Hansen's (2001) procedure, are 1995:II for the Phillips equation and 1996:II for the IS, when jointly estimated by FIML. As there is no evidence of other breaks, the hypothesised 1986 change in policy regime has no Lucas critique effect on our AD-AS structure of the Euro Area. In what follows, in spite of the instability of the system in the mid-90s, we use the data up to 2001:II, since we need the degrees of freedom for the proper estimation during the new monetary regime period beginning in 1986. As summed up below in the concluding remarks section, we try to infer the relevance of ignoring the mid-90s structural break as we go along, by comparing the results with data truncated at 1995:II.

Central Bank's Preferences

Following fairly standard assumptions in the literature, we model central bank's preferences as an intertemporal loss functional. In each period the loss function is quadratic in the deviations of inflation and u-gap from their desired levels (π^* and zero, respectively), as well as in the change in the interest rate, which is the policy instrument.[8] Future values are discounted at rate δ, and the weights λ and μ are nonnegative.

$$L_t = E_t \sum_{\tau=0}^{\infty} \delta^{\tau} \frac{1}{2}\left[(\pi_{t+\tau} - \pi^*)^2 + \lambda x_{t+\tau}^2 + \mu(i_{t+\tau} - i_{t+\tau-1})^2\right] \tag{2}$$

The inclusion of u-gap variability in *L* is generally considered compatible with the statutes of modern central banks, such as the US Fed. Even inflation targeting regimes, which have a formally quantified commitment to price stability, also have a second order objective concerning growth and employment - see Svensson (2001). However, the ECB statutes, similarly to the Bundesbank's, are not entirely clear on the significance that real activity stabilisation has in its legal mandate, as they merely state in the 2nd article of its Chapter II, that (ECB, 2002, page 2)

> "[…] the primary objective of the ESCB shall be to maintain price stability. Without prejudice to the objective of price stability it shall support the general economic policies in the Community […]"

The ECB Governing Council, when announcing its stability-oriented monetary policy strategy, established that (ECB, 1998, article 2º)

> "As mandated by the Treaty establishing the European Community, the maintenance of price stability will be the primary objective of the ESCB. Therefore, the ESCB's monetary policy strategy will focus strictly on this objective."

This led some authors - for instance, Goodhart (1998) - to argue that output is not supposed to enter the true ECB objective function. In general, McCallum (2001a) also argues that, for uncertainty reasons, monetary policy should not respond strongly to output gaps. All summed-up, we specify our baseline loss, *L*, as a flexible inflation targeting regime, which nests the strict inflation targeting case - no concern with the variance of the gap. We let the evidence discriminate which of these systems better fits the revealed preferences of the Euro Area notional policymaker.

In what concerns the inclusion of the changes in the interest rate, we follow a relatively standard practice in the empirically oriented literature, which is to consider that the policymaker also dislikes variations in the policy instrument - the so-called interest rate smoothing. Even though theoretical central bank loss functions do not include the instrument as part of the final goals of policy - see Walsh (1998) -, the fact is that optimal interest rates simulated from models with such loss functions are substantially more volatile than actual short-term interest rates - Sack (2000). Central banks seem to prefer to change interest rates in small discrete steps in the same direction over extensive periods, and reverse the path of rates only infrequently - for a review, see, for example, Sack and Wieland (2000).[9] Although several authors have argued that the evidence of policy inertia has little structural content, mostly reflecting econometric problems - see Rudebusch (2001), for instance -, recent simulations and estimations in Favero (2001) and English *et al.* (2002) reiterate the evidence in favour of intentional smoothing.

Before we proceed to the optimisation exercises, a brief reference to the exclusion of money and exchange rates is in order. Following the currently consensual monetary policy analysis framework - see McCallum (2001b) -, no monetary aggregate is included in our model, implying that money is not considered relevant for policy, neither as an instrument nor as an intermediate target.[10] As a result, though, the estimates should be interpreted with some caution, since no distinction between money supply and money demand surfaces in the model and, thus, some coefficients may be reflecting mixed effects from demand and policy changes.

As for the absence of an exchange-rate variable as an intermediate or final target, it is grounded in two arguments. On one hand, exchange rates are likely to matter less in a policy rule of a large and relatively closed economy like the Euro Area than in a small open economy - see Peersman and Smets (1999). On the other hand, the evidence in Clarida and Gertler (1997) indicates that the Bundesbank's concerns with the DMark exchange-rate when conducting monetary policy were essentially related to its importance as a determinant of domestic inflationary pressures rather than as a final target *per se*. This seems to be the case for the ECB as well, as recently put forward by Gaspar and Issing (2002). And this role of the exchange-rate as determinant of inflationary pressures is already implicitly considered in our model, through the exogenous shock variable in the Phillips curve, which is the lagged deviation of imported from domestic inflation.

3. Monetary Policy Regime in the Euro Area

This section begins with the description of two alternative ways of solving and linking the optimisation problem to the estimation of policymakers' structural preference parameters jointly with the aggregate economic structure and shocks. Such alternatives yield different estimation methods and, thus, different estimates, which we compare and use in testing the hypothesis of emergence of a new monetary policy regime around 1986, concurrent with the improvement in the volatility performance of the aggregate Euro Area.

Frameworks for Estimating Policymakers' Preferences

For the sake of realism and estimation feasibility, we circumscribe the optimisation problem to a discretionary policy regime, in which the policymaker solves for the optimal closed-loop system, *i.e.* sets its policy sequentially, in each period, given the then observed state of the economy. In this case, the monetary authority chooses in each period the interest rate that minimises the loss functional subject to the dynamic economic structure:

$$Min(L_t) = \underset{i_t}{Min}\, E_t \sum_{\tau=0}^{\infty} \delta^{\tau} \frac{1}{2}\left[(\pi_{t+\tau} - \pi^*)^2 + \lambda x_{t+\tau}^2 + \mu(i_{t+\tau} - i_{t+\tau-1})^2\right] \qquad \forall t \qquad (3)$$

subject to system (1).

As the policy control variable is the short-term interest rate, the solution is, irrespectively of the adopted method, an expression describing the optimal interest rate as function of the state variables of the system. Once supplemented by an innovation, that expression joins the system describing the dynamics of the economy, and estimation of the structural parameters of the model may proceed.

The approach devised by Favero and Rovelli (2001) - henceforth equivalently referred to as "optimal control *cum* GMM" and "Euler-GMM" - is based on the Euler equation of the system - first order condition -, which in our case takes the form

$$E_t \sum_{\tau=0}^{\infty} \delta^{\tau} \left[(\pi_{t+\tau} - \pi^*) \frac{\partial \pi_{t+\tau}}{\partial i_t} \right] + E_t \sum_{\tau=0}^{\infty} \delta^{\tau} \lambda \left[x_{t+\tau} \frac{\partial x_{t+\tau}}{\partial i_t} \right] + \left[\mu(i_t - i_{t-1}) - \mu\delta E_t(i_{t+1} - i_t)\right] = 0 \qquad (4)$$

This equation is then truncated at four quarters ahead, and the partial derivatives in it are expanded and written as function of the relevant aggregate-supply and aggregate-demand coefficients in (1). At this stage, the expression of the first-order condition conveniently includes the cross-equation restrictions of the system, ensuring that the loss function is properly minimised subject to the constraints given by the economy structure. Further supplemented with an innovation - to allow for estimation - the Euler equation becomes

$$\begin{aligned} &\delta^3 E_t(\pi_{t+3} - \pi^*)[c_9.c_5] + \delta^4 E_t(\pi_{t+4} - \pi^*)[c_9.c_2.c_5 + c_6.c_9.c_5] + \\ &\lambda\delta^3 E_t x_{t+3}[c_5] + \lambda\delta^4 E_t x_{t+4}[c_2.c_5] + [\mu(i_t - i_{t-1}) - \mu\delta E_t(i_{t+1} - i_t)] + \varepsilon_t^p = 0 \end{aligned} \qquad (5)$$

Favero and Rovelli justify truncation at four quarters with two arguments. First, discounting in the infinite-horizon loss function means that expectations about the state of the economy carry less relevant information for the present conduct of policy, as they relate to periods further ahead. Second, expanding the horizon would complicate the equation and bring collinearities to the system, causing great difficulties to estimation. We argue, in addition, that the four-quarter forecast horizon seems to be in line with the forecasting needs and abilities of real world policymakers - see, for instance, the macroeconomic projections in IMF (2001), and in the Greenbook available at each FED open market committee meeting as discussed in Perez (2001). Moreover, evidence from estimated policy rules suggests that actual policy involves forecast horizons of inflation not beyond four quarters – see, for example, Orphanides (2001b), and Boivin and Giannoni (2002).

Equation (5) is jointly estimated with the system (1), generating estimates of the coefficients describing the monetary policy regime - μ, λ, and π^* - as well as of the aggregate-demand and aggregate-supply coefficients, and the system's innovations. Because expectations are replaced by actual observations, estimation uses GMM, as it seems reasonable to assume that policymakers use efficiently the information available when forming expectations. Following Favero and Rovelli's procedures, we use four lags of all the system's variables as instruments, and base inference in a heteroescedasticity and auto-correlation-consistent variance-covariance matrix.[11] Employing this method in the more restricted loss function of strict inflation targeting with interest rate smoothing is straightforward, setting λ to zero in equation (5).

An alternative to Favero and Rovelli's is the method recently designed by Dennis (2001) - hereafter equivalently designated "dynamic programming *cum* FIML" and "Lagrangean-FIML" - after the inverse control strategy used by Salemi (1995). This method uses the result that with a quadratic objective function and linear stochastic constraints the postulated policymaker optimisation problem fits into the stochastic linear regulator problem - see Ljungqvist and Sargent (2000) -, and, as such, Chow's (1997) Lagrangean solution can be employed.

The approach begins by writing the dynamic constraints in state-space form:

$$A_0X_{t+1} = AX_t + Bu_t + C + E_{t+1} \tag{6}$$

where u stands for the control variable - the interest rate, i - and X is the vector of state variables. In our case (see the Appendix for details)

$$X_t = \begin{bmatrix} \pi_t & \pi_{t-1} & \pi_{t-2} & \pi_{t-3} & x_t & x_{t-1} & x_{t-2} & i_{t-1} & i_{t-2} & \Delta i_{t-1} & Im\pi_t \end{bmatrix}' \tag{7}$$

The Lagrangean solution consists of introducing a vector of Lagrange multipliers, and setting to zero its derivatives in order to the control and state variables, thus obtaining a set of first-order conditions. The multipliers and the derivatives of the policymaker objective function with respect to the control and state variables are written as linear functions and, together with (6) and the first order conditions, yield a solution to the policymaker problem that is an optimal state-contingent linear policy rule

$$u_t = GX_t + g \tag{8}$$

This rule is computable, for a specific set of values of the model structural parameters, with simple calculus and algebra - see the Appendix and Chow (1997, sections 2.3-2.4, pages 22-25). In our specific case, G is a (1×11) vector, and the optimal linear policy rule takes the form

$$\begin{aligned} i_t = {} & g_0 + g_1\pi_t + g_2\pi_{t-1} + g_3\pi_{t-2} + g_4\pi_{t-3} + \\ & g_5x_t + g_6x_{t-1} + g_7x_{t-2} + g_8i_{t-1} + g_9i_{t-2} + g_{10}Im\pi_t \end{aligned} \tag{9}$$

Once supplemented with an innovation, (9) joins the equations in (1) in a three equations system. Under the assumption of normality, the residuals of this system are used to compute the data log-likelihood function, conditional on the first 4 observations, which is then maximised by numerical methods with respect to the model structural parameters - the aggregate-supply and demand coefficients, c_1 through c_{10}, and the policymaker's preference parameters, λ, and μ. The procedure can be similarly employed in cases of more restricted loss functions, such as one of strict inflation targeting with interest rate smoothing - in which case λ is set to zero in the solution equations leading to the optimal linear policy rule, without, however, changing its form.

Dennis' approach consists of a sequence of steps involving a component of dynamic solution and another of estimation. At each step, the solution component consists in using the Lagrangean method to solve for the optimal linear policy rule, given certain values of the model coefficients - c_1 through c_{10}, λ and μ. Then, in the estimation component, this optimal *feed-back* rule joins the aggregate-demand and aggregate-supply equations, in a three equations system, from which the model structural coefficients are re-estimated, by maximum likelihood. Solution and estimation are sequentially repeated until both converge into a set of estimates of the structural parameters of the model.[12]

Since this approach does not generate a direct estimate of π^*, we compute it as the sample average of the nominal interest rate minus the estimate of the real equilibrium interest rate - which is given by $c_1/(-c_5)$ in system (1).

In addition to estimating the monetary policy regime, and the Phillips coefficient, measuring the trade-off between the levels of u-gap and inflation, both frameworks offer some information concerning the volatility of the supply shocks, given by the standard deviation of the aggregate-supply equation. Moreover, the standard error of the optimising interest rate equation can be seen as an indication of the ability of policymakers to maintain interest rates close to optimum, and, thus, to maintain the economy close to the Taylor curve. This interpretation is, however, subject to caution, as inverse control theory attributes this error to specification imperfections.

Euro Area 1972-1985 *versus* 1986-2001

We now apply comparatively the estimation procedures just described to the case of the aggregate Euro Area. Motivated by the macroeconomic record of the Area, briefly reviewed in section 1, we compare the results before and after 1986.

Table 1 summarises the results for our baseline loss function - flexible inflation targeting with interest rate smoothing. The left-hand side shows that, for 1972:I-1985:IV, both procedures estimate an inflation target somewhat above 9 percentage points and a real equilibrium interest rate a bit below 1 percentage point, but fail to estimate reasonable and precise coefficients associated to the deviations of the gap and inflation from their targets. The right-hand side highlights the change in monetary policy and macroeconomic conditions after 1986, revealing that the inflation target seems to have fallen below 3 percentage points, while the real interest rate of equilibrium has risen substantially to around 4.5 percentage points. However, as in the first sub-sample, both procedures fail to generate sensible and precise estimates of λ and μ. Hence, we conclude that a regime of flexible inflation targeting with interest rate smoothing is not compatible with the aggregate Euro Area data, neither before nor after 1986.

In table 2 we inspect whether a loss function with strict inflation targeting and interest rate smoothing is more appropriate to describe the Euro Area case - a hypothesis that seems compatible with the statutes of the ECB, as mentioned in section 2. Before 1986 the weight of interest rate smoothing is not precisely estimated, at standard confidence levels, and the previous results in terms of inflation target and equilibrium real interest rate are broadly confirmed. There is some evidence against the regime of strict inflation targeting during the 1972-1985 period. In fact, the standard error of the residuals of the optimising interest rate equations is, in both procedures, larger than in table 1 and, furthermore, the J-test reveals that the moments orthogonality conditions for GMM estimation are now rejected at one percent significance.

In contrast to the previous results, the right-hand side of table 2 shows that a monetary policy regime of strict inflation targeting with interest rate smoothing can be well identified and estimated for the sample period beginning in 1986. The Euro Area inflation target is estimated quite precisely at 2.7 percentage points by both procedures, and the equilibrium real interest rate is estimated - also with accordance between procedures - at 4.5 percentage points. The weight of interest rate smoothing in the policymaker's loss function is statistically significant at less than 5 percent in both procedures - even though with a large discrepancy in the estimates, which is further discussed below.

The results are thus compatible with the hypothesis formulated in section 1 - that the emergence of a well-defined monetary policy regime targeting a low inflation rate is part of the explanation for the improvement in the Taylor trade-off observed in the aggregate Euro Area since 1986. Using the sub-sample 1986:I-2001:II, we identify the aggregate regime as one strictly targeting the inflation rate at 2.7 percentage points, with a significant element of policy instrument smoothing. Notably, this regime identification seems to be quite robust, as it is confirmed by the two alternative procedures employed.[13] The accordance between our results from the two methods may shed some light on the discrepancies found in the original applications to the US by Favero and Rovelli (2001) and Dennis (2001). The discrepancies between their results include different inference regarding the weight of the output gap in the policymaker's objective function, and different inflation targets and equilibrium real interest rates. In view of our research, maybe such disagreements have arisen not from the different procedures, bur rather from differences in sample periods, discount factors, and output gap series.

As for the other three factors of volatility improvement in the Euro Area, we have already checked in section 2 that there has been no significant change in the aggregate economic structure in the 80s. In turn, the supply shocks seem to have been milder in the second sample period, as the standard deviation of the Phillips equation residual decreased by around 40 percent. Also, there is some evidence that the ability of the notional policymaker to run interest rates closer to their optimal path has improved after 1986. In fact, with a remarkable consistency, the standard deviation of the Euler equation residual fell by 42 percent, and that of the optimal linear policy rule fell by 43.5 percent. This interpretation, however, should be considered tentative, not only because control theory ascribes a model specification meaning to the deviation of the control variable from its optimal path, but also because the residuals have different meanings across the sub-samples, as there is no clear policy regime before 1986.

Taking now a closer look at the identified regime of strict inflation targeting after 1986, we find two strong indications that the u-gap, in spite of not being a final objective, has been considered valuable information for monetary policy in the aggregate Euro Area. First, if the lagged u-gaps are excluded from the instrument set in the GMM estimation, results are quite different. Notably, the interest rate smoothing weight is not precisely estimated, the Phillips elasticity looses its significance, several estimates change substantially, and the standard error of the residual of the Euler equation doubles its value. Second, as table 3 shows, the optimal linear policy rule obtained through the dynamic programming *cum* FIML approach indicates that the policy instrument reacts substantially to the u-gaps. In fact, optimal interest rates react slightly more to each additional percentage point of u-gap than to an additional point of the inflation rate, both in the cumulated short-run - 0.215 *versus* 0.203 - and in the long-run - 2.323 *versus* 2.190.

Table 3 also shows a clear change in the optimal linear policy rule from the first to the second sub-sample period - a decrease in the explanation of the interest rate by its past and an increase in its reaction to both inflation and the u-gap. The better ability of the optimal linear policy rule to replicate the second moments of actual interest rates in the second sample period also indicates the profound difference between the two eras, as regards the existence of a detectable policy regime. However, the optimal linear *feed-back* rule for 1986:I-2001:II still exhibits a quite large sensitivity of the policy instrument to its past. The magnitude of this auto-regressive effect is coupled with the large estimate of the interest rate smoothing weight obtained within this method - dynamic programming *cum* FIML -, and explains some of the discrepancy between interest rates fitted by the two approaches, apparent in figure 3. Notably, the series generated by Lagrangean-FIML lags both actual and Euler-GMM fitted rates throughout the whole sub-sample, thus exposing the importance of the auto-regressive element of the optimal policy rule in generating the good Lagrangean-FIML fit. Hence, figure 3 calls for a closer examination of the disparity between the estimated weights of interest rate smoothing in the policymaker loss function – $\mu = 2.210$ in Lagrangean-FIML versus $\mu = 0.013$ in Euler-GMM –, which is the major discrepancy between the results of the two methods.

In general, differences in the results could derive from the attributes of the econometric techniques employed in each procedure. However, more specific differences could be more directly linked to the disagreement in the estimates of μ. For example, Soderlind *et al.* (2002) suggest that it would be the case of the horizon truncation specific to the Optimal Control *cum* GMM. Next, we speculatively offer two additional specific reasons, one related to expectations and the other to stationarity.

In the Euler-GMM approach the policymaker's expectations are replaced by actual values of inflation, while in the Lagrangean-FIML approach the optimal linear rule is state contingent, therefore depending only upon observed variables. If the observed smooth path of the actual interest rate merely reflects the inevitable smoothness of policymakers' forecasts - like Goodhart (2000) argues -, then the Euler-GMM method, yielding a smaller estimate of the importance of interest rate smoothing, ends up estimating underlying preferences conceptually closer to the theoretical loss function.

The other possible explanation is related to the different treatment of non-stationarities by the two methods. The Euler equation imposes, by construction, that the relationship between the interest rate and its recent past depends solely on the discount factor - which is calibrated, not estimated. In turn, the Lagrangean computation of the optimal policy rule does not restrict the lagged interest rate coefficients, thus admitting non-stationary results. In fact, the method always finds an optimal linear policy rule, even when the system does not reach a steady-state – Chow (1997, page 25). Stationarity can be checked through expressions (6, without innovations) and (8) above, from where the optimal dynamic path of the state-vector is

$$X_{t+1} = (\tilde{A} + \tilde{B}G)X_t + (\tilde{B}g + \tilde{C}) \tag{10}$$

where $\tilde{A} = A_0^{-1}A$, $\tilde{B} = A_0^{-1}B$, and $\tilde{C} = A_0^{-1}C$.

The state vector converges to an equilibrium – a unique stationary distribution - if and only if the maximum absolute value of the characteristic roots of matrix $(\widetilde{A}+\widetilde{B}G)$ is strictly smaller than unity – Ljungqvist and Sargent (2000, chapter 4). We recall that G is the vector of the optimal policy rule coefficients, and $\widetilde{B}G$ reflects the degree of smoothing in the optimal path of the interest rate.

Table 4 reports the maximum eigenvalues for the two sub-samples and the two policy regimes considered in our estimations. Even though the smaller one corresponds to the most precisely estimated regime and sub-sample, the absolute values are all close to one, i.e. very much on the boundary between stationarity and non-stationarity. This does not seem to be a problem in other monetary policy studies - close to ours in the use of dynamic programming but with calibrated instead of estimated policy preferences - that often report maximum eigenvalues very close to unity.[14] However, we suspect that in cases like ours, where dynamic programming is linked to the estimation of all the parameters, such *quasi* non-stationarity might generate numerical problems in estimating policymakers' preferences, including the relevance of interest rate smoothing.

4. Concluding Remarks

The empirical research in this paper uncovers a well-defined monetary policy regime starting in 1986 in the aggregate Euro Area, in spite of the institutional prevalence of national monetary policies until 1999. Remarkably, both alternative solution-estimation methods employed - optimal control *cum* GMM and dynamic programming *cum* FIML - identify a regime of strict inflation targeting with significant interest rate smoothing, with a target around 2.7 percentage points. The unemployment gap, although not showing up as an argument in the objective function of the notional monetary authority, is a relevant element of the information set used in policy formulation. Thus, our current emphasis in *quasi* real-time information concerning the gap is well justified, but so it is its replacement by real-time data as it becomes available for future research concerning the analysis of ECB policymaking.

The emergence of the regime in 1986 has been concurrent with an apparent improvement of the volatility trade-off between inflation and unemployment gap since the mid-80s. The results, always according to both methods, also indicate that other improving factors have been milder supply shocks and some increase in the ability of policymakers to set the interest rate closer to its optimal path. Similar conclusions about the factors of volatility improvement - although dated earlier in the 80s - have arisen in the research of the US case by Favero and Rovelli (2001) and Dennis (2001).

A structural break in the mid-90s may also have played a role in reducing volatility, but it is too soon to isolate its causes and effects - at least within our framework. The truncation of the 1986-2001 sub-sample at 1995 - not reported in section 3 - results in an imprecise estimation of the loss function parameters, especially with Euler-GMM, which is more sensitive to small sample problems. Still, the Lagrangean-FIML estimate of the weight of interest rate smoothing does not change markedly, and the inclusion of unemployment as a policy objective is clearly rejected. The estimate of the inflation target, in turn, is higher in 1986-1995 than in 1986-2001. Hence, at the moment we can only conjecture that the mid-90s structural break detected in the AD-AS system is related to a reduction in the desired level of inflation, but not to a significant change of the remaining features of the policy regime.

We confirm that interest rate smoothing is an open problematic issue, not only with regard to theoretical explanations but also concerning empirical estimation. The two methods we used yield quite different estimates of the importance of instrument inertia in the Euro Area loss function, in line with the original studies of Favero and Rovelli (2001) and Dennis (2001) for the US. Our tentative assessment of this issue suggests that the larger estimates are coupled with *quasi* non-stationary optimal paths of the interest rate, inflation and unemployment gap.

Appendix: State-space format and Lagrangean solution to the policymaker's optimisation problem

The matrices and vectors of the state-space representation of the dynamic constraints of optimisation - expression (6) in the text - can be detailed as follows:

$$X_t = \begin{bmatrix} \pi_t & \pi_{t-1} & \pi_{t-2} & \pi_{t-3} & x_t & x_{t-1} & x_{t-2} & i_{t-1} & i_{t-2} & \Delta i_{t-1} & Im\pi_t \end{bmatrix}'$$

$$B = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 1 & 0 \end{bmatrix}'$$

$$C = \begin{bmatrix} 0 & 0 & 0 & 0 & c_1 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}'$$

$$E_t = \begin{bmatrix} \varepsilon_t^s & 0 & 0 & 0 & \varepsilon_t^d & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}'$$

$$A_0 = \begin{bmatrix} 1 & 0 & 0 & 0 & -c_9 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix}$$

$$A = \begin{bmatrix} c_6 & c_7 & c_8 & 1-c_6-c_7-c_8 & 0 & 0 & 0 & 0 & 0 & 0 & c_{10} \\ 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & -c_5 & 0 & c_2 & c_3 & c_4 & 0 & c_5 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & -1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

In the solution component of each step of the dynamic programming *cum* FIML method, we solve the dynamic optimisation problem faced by the policymaker with the Lagrangean method, as described in Chow (1997, equations 2.12-2.26, pages 22-24).

A vector of Lagrange multipliers, Λ, is introduced, and its derivatives in order to the control and states variables are set to zero, giving a set of first-order conditions. In order to solve these conditions for the control variable and the multiplier, $\Lambda(X)$ is approximated by a linear function

$$\Lambda(X) = HX + h \tag{A.1}$$

The derivatives of the objective function with respect to the control and state variables are written as linear functions as well

$$\frac{\partial}{\partial x} L(X,u) = K_{11}X + K_{12}u + k_1 \tag{A.2}$$

$$\frac{\partial}{\partial u} L(X,u) = K_{21}X + K_{22}u + k_2 \tag{A.3}$$

Expressions (A.1) - (A.3), together with the linear constraints (expression (6) in the text, excluding the innovation vector E_{t+1}) and with the first-order conditions, are the basis for the solution. From the first-order conditions relative to the control variable, and the linear approximations (A.1) and (A.3), the optimal state-contingent linear policy rule is obtained

$$u_t = GX_t + g \tag{A.4}$$

where

$$G = -(K_{22} + \delta B'HB)^{-1}(K_{21} + \delta B'HA) \tag{A.5}$$

$$g = -(K_{22} + \delta B'HB)^{-1}\left[k_2 + \delta B'(HC + h)\right] \tag{A.6}$$

Analogously, using the linear approximation (A.1) and (A.2) for adequate substitution in the first-order conditions relative to the state-vector, we obtain

$$H = K_{11} + K_{12}G + \delta A' H(A + BG) \tag{A.7}$$

$$h = (K_{12} + \delta A' HB)g + k_1 + \delta A'(HC + h) \tag{A.8}$$

Substituting equation (A.5) into equation (A.7) gives the matrix Riccati equation

$$H = K_{11} + \delta A' HA - (K_{12} + \delta A' HB)(K_{22} + \delta B' HB)^{-1}(K_{21} + \delta B' HA) \tag{A.9}$$

This equation can be solved iteratively for *H*. Given *H*, equation (A.5) is used to compute *G*, equation (A.6) to calculate *g*, and equation (A.8) to obtain *h*.

In our specific problem, k_1, k_2 and K_{12} are zero, and $K_{22} = \mu$; K_{11} is a (11×11) matrix of zeros except for $K_{11}[1,1]=1$, $K_{11}[5,5]=\lambda$, and $K_{11}[10,10]=\mu$; and K_{21} is a (1×11) vector of zeros except for $K_{21}[1,8]= -\mu$.

Notes

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[1] We use official aggregate data of the Euro Area, from the Area Wide Model Database (AWMD) or computed from the AWMD, as described below. We study the Area as a whole, as our aim is to see if the aggregate data reveal any well-identified global economic structure, and policy regime, throughout a period in which (except for 10 observations at the end of the sample) nations, not the Area, were the formal economic units.

[2] See European Commission (1997, pages 25-46 and Appendix C).

[3] Assuming that the policymaker uses our trend-cycle decomposition model and limits its information to the series in the model, there are essentially two differences between our *quasi* real-time estimates and strict real-time estimates. First, real-time estimates are published with a lag and are subject to subsequent revisions. Second, real-time estimates may be affected by changes in the model identification and parameter estimates.

[4] Alternatively, Croushore and Stark (2001) have built real-time data from snapshots of published data at quarterly intervals.

Notes (continued)

[5] Coenen *et al*. (2001) study the profile of revision of the main macroeconomic variables in the Euro Area during 1999 and 2000, using the numbers published in the ECB Monthly Bulletin - an approach that should be highly helpful in future research on EMU policymaking with real-time data.

[6] We impose dynamic homogeneity into the Phillips curve, as that hypothesis is not rejected in an unconstrained estimation and has two advantages: it reduces by one the number of coefficients, and it complies more clearly with the natural rate hypothesis.

[7] This result is in contrast with the failure to reject stability typically obtained in the US case - see, for example, Rudebusch and Svensson (2002) and, with mixed forward-backward-looking equations, Rudebusch (2002b). It should be noted, however, that these studies perform tests covering breakpoints only until the end of 1992, at most, so they could be missing more recent structural breaks, namely on the second half of the 90s. Our tests, after the adequate 15 percent trimming, cover possible break dates between 1976:I and 1997:II.

[8] We assume that the relevant arguments in the Euro Area policymaker loss function are variables of the aggregate Area, deliberately disregarding the possibility that nation-level economic performance might affect the decisions of some or all members of the Governing Council - see Aksoy *et al.* (2002) on that topic.

[9] Despite its empirical appeal, the theoretical foundations for interest rate smoothing are far from being consensual. The literature has offered several explanations for optimal policy inertia: (i) concerns with financial stability - Cukierman (1992); (ii) maximisation of policy efficiency with less instrument variability, in view of forward-looking agents - Goodfriend (1991); (iii) policymakers' reaction to uncertainties -

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Notes (continued)

Goodhart (1998 and 2000); (iv) concerns with reputation and credibility - Goodhart (1996); and (v) concerns with the zero bound of nominal interest rates - Rudebusch (2001).

[10] Applied to the Euro Area, this may seem at odds with the Bundesbank record of explicit monetary targets since 1974, and with the ECB formal first pillar for policy, which is a monetary aggregate growth targeting - see ECB (1998). But, in fact, the Bundesbank behaved much more as an inflation targeter than a money targeter - see Von Hagen (1995) and Bernanke and Mihov (1997) -, the role of money targets being mostly political, as argued by Von Hagen (1999). In what regards the ECB, several recent studies have found no evidence that money has been relevant in its policy decisions - Mihov (2001) and Begg *et al.* (2002).

[11] We use Andrews and Mohanan's (1992) pre-whitening and a Bartlett Kernel to weight the auto-covariances, with a bandwith estimated with Andrews' (1991) estimator. We employ the two-step estimator, which is a one-step weighting matrix version of GMM. Covariance estimation is difficult in cases, like ours, of serially correlated moment conditions and small samples - see Hansen *et al.* (1996) and the other articles in that special edition of the Journal of Business and Economic Statistics (vol. 14, n. 3). Our choice of GMM estimator draws largely from Florens *et al.*'s (2001) Monte Carlo results indicating that the two-step estimator generates estimates close to maximum likelihood and is not strongly biased in the estimation of forward-looking Taylor rules.

[12] Richard Dennis' *GAUSS* code has been an invaluable basis for ours', which implements the numerical solution by linear approximations described in Chow (1997).

Notes (continued)

[13] We have also checked the sensitivity of the results to possibly earlier dates of emergence of the well-defined monetary policy regime. It turns out that 1986:I is the first date of beginning of the estimation period in which the interest rate smoothing weight has significance probability below 5 percent. In addition, there is a clear improvement in the main indicators of quality of the estimation at that quarter, in comparison to the results of estimation from sub-sample periods beginning earlier.

[14] For instance, Aksoy *et al.* (2002), with data of the Euro Area member-states, report maximum roots of 0.99 for all countries.

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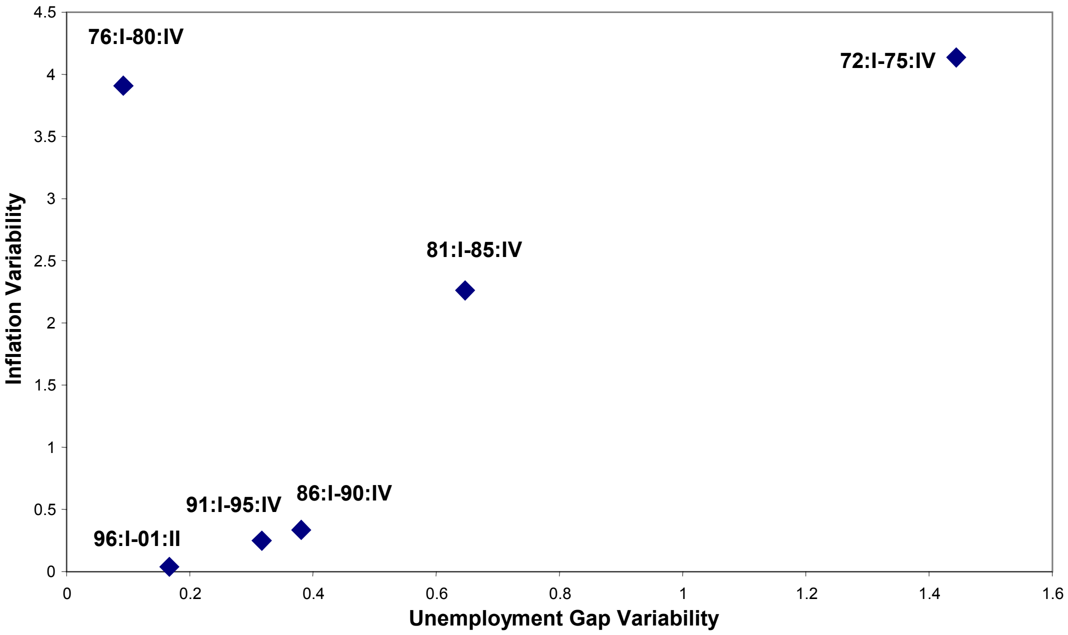
Figure 1. Macroeconomic Volatility in the Aggregate Euro Area 1972-2001



Notes: Data sources - Area Wide Model Database (AWMD, published in Fagan *et al*, 2001), European Central Bank Monthly Bulletin, and authors' calculations.

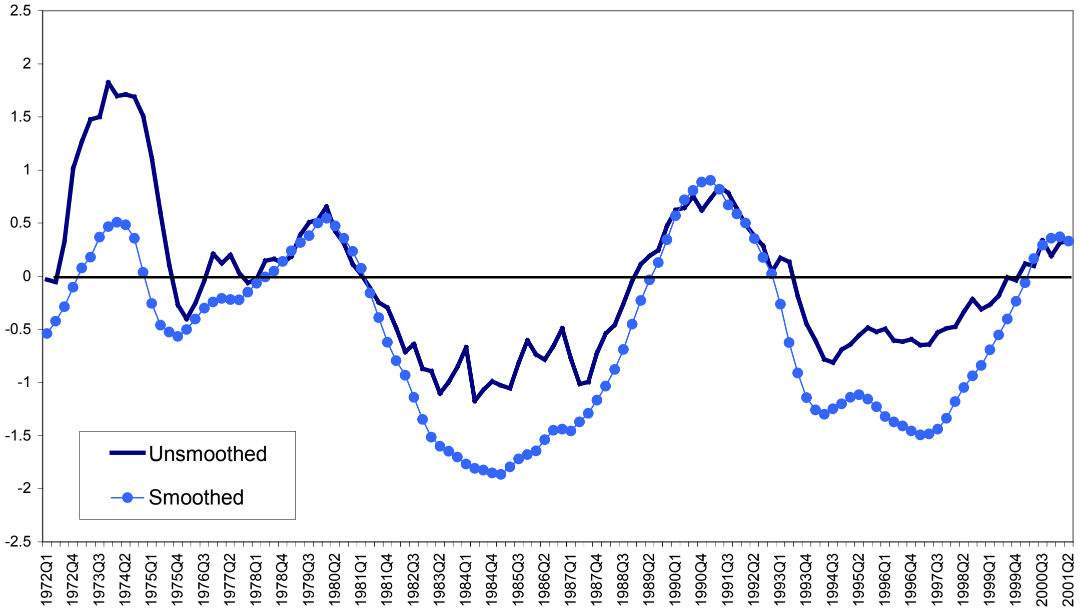
Inflation variability is the average of square deviations of the quarterly inflation rate from its desired level of 0.5 (2 percent annual inflation).

The inflation rate is the first difference of the log of the GDP deflator.

Unemployment gap variability is the average of square deviations of the quarterly unemployment gap from its desired level of zero.

The unemployment gap is computed from a backward-looking version of the unobserved components model of stochastic NAIRU and trend GDP in Aguiar and Martins (2002).

Figure 2. Unsmoothed *versus* Smoothed Unemployment Gap in the Euro Area, 1972-2001



Note: The unsmoothed line is the u-gap estimates given by the Kalman filter - see Harvey (1989, equations 3.2.1 - 3.2.3, pages 105-106), while the smoothed line is the estimate given by the fixed-interval Kalman smoother - see Harvey (1989, equations 3.6.16, page 154).

Table 1. Macroeconomic Structure and Policymaker's Loss Function with Flexible Inflation Targeting and Interest Rate Smoothing

	1972:I - 1985:IV						**1986:I - 2001:II**					
	Optimal Control - GMM			**Dynamic Programming - FIML**			**Optimal Control - GMM**			**Dynamic Programming - FIML**		
	Estimates	**(Test stat)**	**[Prob.]**	**Estimates**	**(Test stat)**	**[Prob.]**	**Estimates**	**(Test stat)**	**[Prob.]**	**Estimates**	**(Test stat)**	**[Prob.]**
IS												
c1	0,027	(2.41)	[0.02]	0,012	(0.59)	[0.28]	0,092	(3.25)	[0.00]	0,098	(2.24)	[0.01]
c2	1,167	(24.36)	[0.00]	1,053	(9.56)	[0.00]	1,246	(16.94)	[0.00]	1,231	(11.03)	[0.00]
c3	-0,023	(-0.28)	[0.78]	0,139	(0.81)	[0.21]	-0,248	(-3.03)	[0.00]	-0,315	(-1.80)	[0.04]
c4	-0,288	(-5.38)	[0.00]	-0,300	(-2.97)	[0.00]	-0,019	(-0.43)	[0.67]	0,075	(0.67)	[0.25]
c5	-0,028	(-7.05)	[0.00]	-0,019	(-2.11)	[0.02]	-0,021	(-3.60)	[0.00]	-0,022	(-2.32)	[0.01]
$\sigma(\varepsilon^{IS})$	0,170			0,163			0,133			0,128		
Phillips												
c6	0,577	(10.95)	[0.00]	0,441	(3.69)	[0.00]	0,578	(19.33)	[0.00]	0,600	(5.58)	[0.00]
c7	0,345	(5.08)	[0.00]	0,337	(2.64)	[0.00]	0,166	(3.54)	[0.00]	0,114	(0.95)	[0.27]
c8	-0,036	(-0.93)	[0.36]	-0,047	(-0.36)	[0.36]	0,041	(0.84)	[0.41]	0,003	(0.03)	[0.49]
c9	0,072	(3.65)	[0.00]	0,340	(1.35)	[0.09]	0,129	(2.40)	[0.02]	0,178	(1.10)	[0.14]
c10	0,047	(4.82)	[0.00]	0,030	(1.79)	[0.04]	0,049	(11.12)	[0.00]	0,050	(3.58)	[0.00]
$\sigma(\varepsilon^{Phillips})$	1,364			1,373			0,838			0,806		
Policy Regime												
π^*	9,390	(36.58)	[0.00]	9.74 †	-	-	2,910	(9.83)	[0.00]	2,660	-	-
λ	-0,240	(-3.52)	[0.00]	96,680	(0.54)	[0.29]	-0,180	(-1.64)	[0.10]	1,724	(0.67)	[0.25]
μ	-0,002	(-1.03)	[0.30]	49,540	(0.92)	[0.18]	0,008	(1.62)	[0.11]	-1,992	(-0.28)	[0.39]
r^*	0,970	-	-	0.68 †	-	-	4,390			4,520	-	-
$\sigma(\varepsilon^{Policy})$	0,008			0,817			0,009			0,466		
J Statistic	0,650	(33.13) ††	[0.51]				0,400	(24.78) ††	[0.99]			

Notes: Discount factor - $\delta = 0.975$.

[Prob.] - one-sided significance probabilities.

† Imprecisely estimated because based on at least one coefficient with too large standard error;

†† J×nobs.

ε^{Policy} - residuals of the Euler equation (optimal control *cum* GMM) and of the Optimal Policy Rule (dynamic programming *cum* FIML).

Optimal Control *cum* GMM instruments - constant, $\Delta\pi_{t-i}$, x_{t-i}, i_{t-i}, $Im\pi_{t-i}$, , i=1,...4.

Dynamic Programming *cum* FIML - standard-errors are the diagonal elements of the inverse of the Information Matrix square-rooted.

Table 2. Macroeconomic Structure and Policymaker's Loss Function with Strict Inflation Targeting and Interest Rate Smoothing

	1972:I - 1985:IV						1986:I - 2001:II					
	Optimal Control - GMM			Dynamic Programming - FIML			Optimal Control - GMM			Dynamic Programming - FIML		
	Estimates	(Test stat)	[Prob.]	Estimates	(Test stat)	[Prob.]	Estimates	(Test stat)	[Prob.]	Estimates	(Test stat)	[Prob.]
IS												
c1	0,039	(4.00)	[0.00]	0,014	(0.64)	[0.26]	0,090	(3.16)	[0.00]	0,100	(2.22)	[0.01]
c2	1,123	(25.73)	[0.00]	1,053	(9.61)	[0.00]	1,269	(17.16)	[0.00]	1,227	(11.10)	[0.00]
c3	0,100	(1.36)	[0.18]	0,134	(0.78)	[0.22]	-0,252	(-2.89)	[0.00]	-0,312	(-1.80)	[0.04]
c4	-0,394	(-8.25)	[0.00]	-0,290	(-2.91)	[0.00]	-0,035	(-0.79)	[0.43]	0,071	(0.64)	[0.26]
c5	-0,029	(-9.64)	[0.00]	-0,020	(-2.43)	[0.01]	-0,020	(-3.40)	[0.00]	-0,022	(-2.33)	[0.01]
$\sigma(\varepsilon^{IS})$	0,173			0,164			0,133			0,128		
Phillips												
c6	0,579	(13.26)	[0.00]	0,427	(3.67)	[0.00]	0,589	(19.68)	[0.00]	0,599	(5.65)	[0.00]
c7	0,365	(7.89)	[0.00]	0,331	(2.61)	[0.00]	0,151	(3.42)	[0.00]	0,115	(0.97)	[0.17]
c8	-0,069	(-1.60)	[0.11]	-0,034	(-0.26)	[0.40]	0,040	(0.85)	[0.40]	0,004	(0.04)	[0.48]
c9	0,107	(4.14)	[0.00]	0,450	(2.56)	[0.00]	0,115	(2.32)	[0.02]	0,139	(1.66)	[0.05]
c10	0,039	(4.85)	[0.00]	0,028	(1.71)	[0.04]	0,049	(11.83)	[0.00]	0,048	(3.68)	[0.00]
$\sigma(\varepsilon^{Phillips})$	1,364			1,373			0,840			0,808		
Policy Regime												
π^*	9,040	(31.40)	[0.00]	9.74 †	-	-	2,710	(9.48)	[0.00]	2,669	-	-
μ	-0,001	(-0.72)	[0.48]	43,880	(1.07)	[0.14]	0,013	(2.55)	[0.01]	2,210	(1.63)	[0.05]
r*	1,340	-	-	0.68 †	-	-	4,480			4,518	-	-
$\sigma(\varepsilon^{Policy})$	0,019			0,826			0,011			0,467		
J Statistic	1,073	(54.71) ††	[0.01]				0,397	(24.59) ††	[0.99]			

Notes: Discount factor - $\delta = 0.975$.

[Prob.] - one-sided significance probabilities.

† Imprecisely estimated because based on at least one coefficient with too large standard error;

†† J×nobs.

ε^{Policy} - residuals of the Euler equation (optimal control *cum* GMM) and of the Optimal Policy Rule (dynamic programming *cum* FIML).

Optimal Control *cum* GMM instruments - constant, $\Delta\pi_{t-i}$, x_{t-i}, i_{t-i}, $Im\pi_{t-i}$, , i=1,...4.

Dynamic Programming *cum* FIML - standard-errors are the diagonal elements of the inverse of the Information Matrix square-rooted.

Table 3. Optimal Policy Rule from a regime of Strict Inflation Targeting and Interest Rate Smoothing

	1972:I - 1985:IV			**1986:I - 2001:II**		
	Coefficients	**Sums**	**Long-run Coefficients**	**Coefficients**	**Sums**	**Long-run Coefficients**
$G\pi_t$	0,033	0,071	1,258	0,100	0,203	2,190
$G\pi_{t-1}$	0,020			0,043		
$G\pi_{t-2}$	0,010			0,033		
$G\pi_{t-3}$	0,009			0,027		
Gx_t	0,109	0,057	1,005	0,260	0,215	2,323
Gx_{t-1}	-0,017			-0,064		
Gx_{t-2}	-0,034			0,019		
Gi_{t-1}	0,946	0,944	-	0,913	0,907	-
Gi_{t-2}	-0,002			-0,006		
$GIm\pi_t$	0,001	0,001	0,018	0,005	0,005	0,051
Interest Rate	**Standard Deviation**			**Standard Deviation**		
Fitted	3,087			2,681		
Actual	2,329			2,654		

Notes: Optimisation-estimation method - dynamic programming *cum* FIML.

Discount factor - $\delta = 0.975$.

Sums - sum of coefficients of inflation, gap, interest rate, and imported inflation, respectively.

Long-run coefficients - optimal cumulative reaction of the interest rate to a permanent change in each state variable; for instance, the long-run response to inflation is

$(g_1\pi_t + g_2\pi_{t-1} + g_3\pi_{t-2} + g_4\pi_{t-3})/(1 - g_8 i_{t-1} - g_9 i_{t-2})$.

Fitted Interest Rate - observed interest rates minus residuals of estimation of the optimal policy rule.

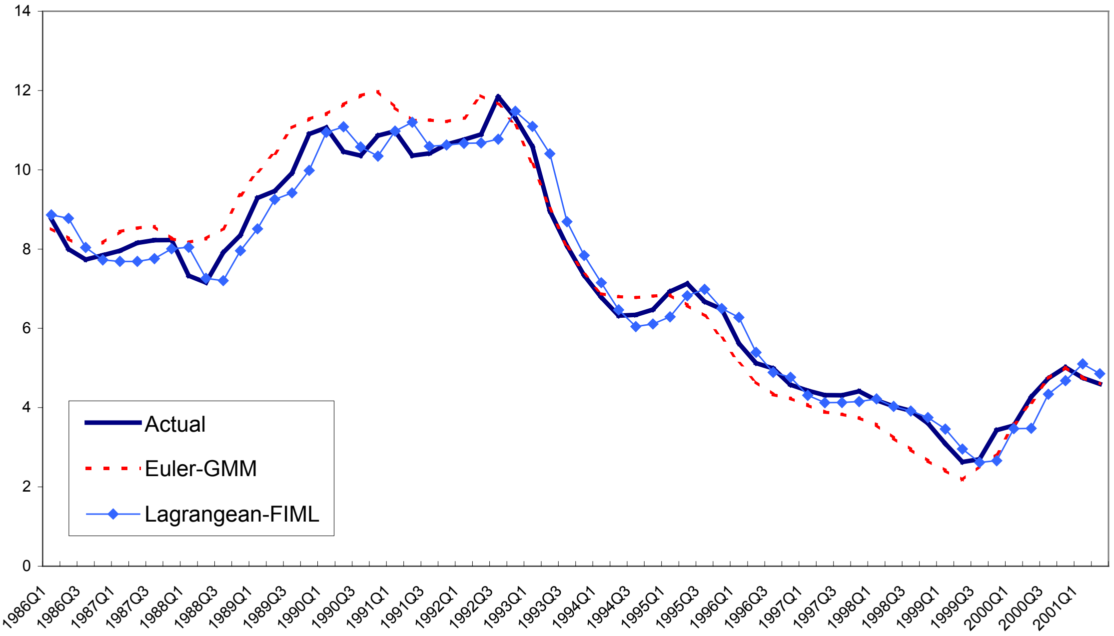
Table 4. Maximum Absolute Value of Eigenvalues of Matrix $(\tilde{A}+\tilde{B}G)$

	1972:I - 1985:IV	**1986:I - 2001:II**
Loss:		
Flexible π targeting (with i smoothing)	0.988	0.996
Strict π targeting (with i smoothing)	0.991	0.984

Notes: Optimisation-estimation method - dynamic programming *cum* FIML.

Discount factor - $\delta = 0.975$.

Figure 3. Actual and Fitted Interest Rates from a regime of Strict Inflation Targeting and Interest Rate Smoothing 1986-2001



Notes: Euler-GMM fitted interest rates - obtained by solving the IS-Phillips-Euler system, using the coefficients from the sub-sample 1986:I-2001:II.

Lagrangean-FIML fitted interest rates - observed interest rates minus residuals of optimal policy rule from the sub-sample 1986:I-2001:II.