Modeling and identifying central banks' preferences*

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Abstract

We propose an approach to identify independently the parameters describing the structure of the economy from those describing central bank preferences. We first estimate a parsimonious structural model for US inflation, US output-gap and the world commodity price index. We then proceed to the identification of central bank preferences by estimating by GMM the Euler equations for the solution of the intertemporal optimization problem relevant to the central bank. The empirical analysis of the structural model shows that the persistency of real interest rates effects on aggregate demand is sufficient to generate an autoregressive structure in any interest rate rule. From estimation of the Euler equations, we infer that strict inflation targeting together with real interest rate smoothing delivers an optimal policy rule which matches the observed path of real interest rates over the sample 1983:1-1998:3. These findings imply that the output gap enters into the optimal interest rate rule only as a leading indicator of future inflation, and we reject the hypothesis that output stabilization is an independent argument in the loss function of the Fed.

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1. Introduction

A growing body of empirical literature has established interest rate rules as a convenient way to model and interpret central banks' policy. An interest rate rule relates the setting of a short-term money market rate (such as the Federal Funds rate in the US) to a central bank's perception of the inflation and output gaps. The plausibility of such rules has either been simply postulated (as in Taylor, 1993, from which this literature originates), or may be derived by solving the intertemporal optimization problem for a suitable loss function. In the latter case, derivation of the interest rate rule makes it clear that estimated coefficients can only be interpreted as convolutions of the parameters describing central bank preferences and of those determining the structure of the economy. But, although this point is clear in theory (see e.g. Svensson, 1996), somewhat surprisingly there are very few reported attempts in the literature (Lippi, 1998 Ch.8; Cecchetti, McConnell and Perez-Quiros, 1999) to recover the preferences parameters of the central bank from estimated interest rate rules. This is even more surprising if one considers that a large and influential strand of literature (originating with Barro and Gordon, 1986) has proceeded from the assumption that central banks' desire to stabilize output beyond the natural rate may be at the origin of many observed inflation episodes. Recently, some authors (Posen, 1993; Blinder, 1997) have expressed a different opinion, suggesting that time inconsistency might not, after all, be the most accurate characterization of central banks' decision making. Thus we believe that it would be of some interest, to both sides of this controversy, if more direct evidence on the determinants of central banks policy choices were available.

On the empirical side a consensus view has emerged that estimated forward looking interest rate rules are generally consistent with the "inflation targeting" approach. The theoretical models put forward by Svensson and coauthors in a number of papers (Svensson, 1997 and 1998, Rudebusch and Svensson, 1998) provide the foundations for the empirical estimation of these rules. Empirical research has generally found evidence that central banks do react to observed output gaps (see e.g, for the case of Germany, Clarida, Gali and Gertler, 1997). However, it is often unclear in this literature whether the fact that central banks set interest rates in response to both expected inflation and expected output gaps is *compatible* with the (often stated as prioritary) inflation-control objective, or whether it is indeed *instrumental* to it (as it would be the case in the event of aggregate demand shocks, as in Svensson, 1996, and Goodfriend and King, 1997).

To settle this issue, again, availability of more direct evidence on whether central banks decisions are the outcome of trading off output vs. inflation stabilization would be useful.

A related problem is that, to be able to match the data, simulated or estimated interest rate rules have always needed to include a term in the lagged interest rate. This can be rationalized by assuming some partial adjustment mechanism between current interest rates and the equilibrium rate or - which is perhaps less arbitrary - by assuming that interest rate smoothing enters as an additional explicit objective into central banks' preferences (as argued in Goodfriend, 1987). However, this point is really open to debate. For instance Sack (1998) and Rudebusch (1998) have argued that the persistence of policy rates can instead be related to persistence in the structure of the economy, while Brainard type uncertainty could explain the observed smooth response of policy rates to macroeconomic conditions. We believe that, to settle the debate also on this issue, it would be quite helpful if more direct evidence were available.

Accordingly, the first aim of this paper is to propose an approach which allows to identify the parameters describing central bank preferences separately from those characterizing the structure of the economy. To this purpose, while previous literature has used the GMM methodology to estimate central banks' reaction functions, we observe that a more natural object for GMM estimation are instead the first order conditions derived from a central bank's optimization problem. Based on this estimation, we then compare optimal and actual interest rate behavior, to select a structure of central bank's preferences capable of delivering the observed behavior of policy rates.Thus we can explore to what extent monetary policy decisions have been motivated, if at all, by the desire to stabilize output as an objective in its own right[1]. On the basis of the same approach, we can also precisely formulate and test alternative hypotheses justifying the observed persistence or sluggishness in the setting of interest rates.

We apply this methodology to the US, as this has been both the most widely studied case so far and is also the most natural (and perhaps only) example of an (almost) closed economy. We consider a parsimonious specification for inflation, the output gap and the commodity price index. This choice of variables is driven by the wide consensus on the minimal set of macroeconomic variables to

[1]Although we do not discuss whether the discretionary behavior of the central bank leads to the emergence of an inflation bias (in fact we assume this issue away by setting potential output as the target level for output), in principle our methodology could be extended to address this issue empirically.

analyze monetary policy making (see, for example, Christiano, Eichenbaum and Evans,1998). Accordingly, our paper is structured as follows. In section 2 we illustrate the identification problem related to interest rate rules and set out our strategy for empirical investigation. In section 3 we present the estimates of a small structural model of the US economy. In the section 4, we identify parameters describing central bank's preferences from the GMM estimation of the policy maker's Euler equations, which have been obtained as a solution to the intertemporal optimization problem of the central bank. We then proceed to evaluate optimal and actual interest rate behavior. As both the strict and flexible inflation targeting models are rejected, we finally examine to what extent real interest rate smoothing is a plausible additional target in the central bank's objective function. Section 5 concludes.

2. Interest rate rules and central banks' preferences

The successful work by Taylor (1993) has revived interest in the estimation of central banks' reaction functions. The very simple, myopic, framework used in the original paper has been extended to the GMM estimation of forward looking interest rate rules (Clarida, Gali and Gertler, 1997 and 1998), where interest rate are modelled as a function of lagged interest rates, the gap between the expected and target rates of inflation and the gap between current (or expected) and full capacity output. It is perhaps surprising that the GMM methodology has been used to estimate reaction functions, while the optimization problem of the central banks provides first order conditions which are instead a more natural object of GMM estimation. We thus propose an alternative empirical route, based on the estimation of a small structural model for the economy and of the Euler equations for the solution of the central banks' optimisation problem. This strategy allows the identification of the parameters describing central banks' preferences. We then generate interest rates from the optimal rule and compare them with observed policy rates. This allows the selection of the best model to describe the actual behavior of the central bank.

Our point can be made considering the simplest possible version of the inflation targeting problem. The central bank faces the following intertemporal optimisation problem:

$$Minimize \quad E_t \sum_{i=0}^{\infty} \delta^i L_{t+i} \tag{2.1}$$

where:

$$L = \frac{1}{2}\left[(\pi_t - \pi^*)^2 + \lambda x_t^2\right] \tag{2.2}$$

where E_t denotes expectations conditional upon the information set available at time t , δ is the relevant discount factor, π_t is inflation at time t , π^* is the target level of inflation, x represents deviations of output from its natural level, λ is a parameter which determines the degree of flexibility in inflation targeting. When $\lambda = 0$ the central bank is defined as a strict inflation targeter. As the monetary instrument is the policy rate, i_t , the structure of the economy must be described to obtain an explicit form for the policy rule. We consider the following specification for aggregate supply and demand in a closed economy[2]:

$$x_{t+1} = \beta_x x_t - \beta_r\left(i_t - E_t\pi_{t+1} - \bar{r}\right) + u_{t+1}^d \tag{2.3}$$

$$\pi_{t+1} = \pi_t + \alpha_x x_t + u_{t+1}^s \tag{2.4}$$

As shown in Svensson (1997), the first order conditions for optimality may be written as follows:

$$\frac{dL}{di_t} = (E_t\pi_{t+2} - \pi^*) = -\frac{\lambda}{\delta\alpha_x k}E_t x_{t+1} \tag{2.5}$$

$$k = 1 + \frac{\delta\lambda k}{\lambda + \delta\alpha_x^2 k} \tag{2.6}$$

By using (2.4) in (2.3) we obtain:

$$E_t\pi_{t+2} = E_t\pi_{t+1} + \alpha_x[\beta_x x_t - \beta_r(i_t - E_t\pi_{t+1} - \bar{r})] \tag{2.7}$$

and by substituting (2.7)in (2.5) we derive an interest rate rule:

$$\begin{aligned} i_t = {} & \bar{r} + \pi^* + \left(\frac{1 + \alpha_x\beta_r}{\alpha_x\beta_r}\right)(E_t\pi_{t+1} - \pi^*) + \\ & + \frac{\beta_x}{\beta_r}x_t + \frac{\lambda}{\delta\alpha_x k}\frac{1}{\alpha_x\beta_r}E_t x_{t+1} \end{aligned} \tag{2.8}$$

[2]Alternatively the supply equation could be reformulated to include a forward looking term in inflation expectations. Moreover in an open-economy both demand and supply equations would include terms in the real exchange rate and foreign prices. This additions would imply new channels of monetary policy transmission to our problem, without altering its fundamental structure.

A number of comments on this rule are in order:

- If the rule is estimated as a single equation, then the fitted parameters are convolutions of the parameters describing central banks preferences (π^*, λ, δ) and of those describing the structure of the economy $(\alpha_x, \beta_r, \beta_x, \bar{r})$. Thus the estimated parameters in the interest rate rules are not "deep" in the sense of Lucas (1976).

- As the structure of the economy cannot be identified from the estimation of the rule only, it is impossible to assess if the responses of central banks to output and inflation are consistent with the parameters describing the impact of the policy instrument on these variables. Note, for example, that the estimation of an interest rate rule relating the policy rate to the output gap and to the deviation of expected inflation from target does not help to distinguish a strict inflation targeter($\lambda = 0$, in the terminology of Svensson), from a flexible inflation targeter $(\lambda > 0)$.

- Econometric identification of the rule requires the timing assumption that the central bank can set policy rates in response to contemporaneous macro variables in the economy, but policy rates do not have a contemporaneous impact on those variables. This assumption is commonly used to identify VAR models of the monetary transmission mechanism.

- In order to make (2.8) consistent with the data, the rule has been interpreted as delivering "target" interest rates, and a sluggish adjustment of actual to target rates has been imposed (Clarida, Gali and Gertler, 1997). Direct estimation of the policy rule does not allow to identify a structure of central bank's preferences which is consistent with interest rate smoothing.

- There is only one empirical implication of the rule which can be confronted with the data independently from the identification of the parameters of interest, namely whether the parameter describing the reaction of policy rates to a gap between expected and target inflation is larger than one. In fact a monetary policy which accommodates changes in inflation, $\frac{\partial i_t}{\partial E_t \pi_{t+1}} \leq 1$,will not in general converge to the target rate π^*. This empirical prediction is the one which has attracted most of the discussion on estimated monetary policy rules (See again Clarida, Gali and Gertler, 1997).

In order to provide a better mapping from central banks' behavior to their preferences we propose an alternative strategy. First, estimate the structure of the economy to identify the parameters of the aggregate supply and demand functions. Second, estimate the Euler equation for the solution of the intertemporal problem to identify central banks preferences. In this step (and in reference to the simple example analyzed above), given the knowledge of $\alpha_x$and β_r , we can identify directly, from the estimation of the first order conditions (2.5), the λ and π^* associated to each assumed value of the discount rate, δ . Third, test if the monetary policy rule consistent with the structure of the economy and the preferences of the central bank matches the actual behavior of policy rates.

3. A stylized representation of the structure of the US economy

The first step of our empirical strategy is the estimation of a small structural model for the US economy, to derive the empirical counterpart of equations (2.4)-(2.3) in the stylized example of the previous section. The empirical literature on the US monetary transmission mechanism has recently reached a consensus (Christiano, Eichenbaum and Evans, 1998) on the minimal set of variables needed to describe congruently the US aggregate demand and supply for the analysis of monetary policy. Following this lead, we concentrate on three macroeconomic variables: the output gap, inflation and the commodity price index, and use quarterly data for the period 1960-1998. The output gap is measured as the percentage difference between GDP and the Hodrick-Prescott filtered series for GDP with smoothing parameter set to 1600. This is in line with the approach followed in the recent empirical literature on monetary policy rules, with which we want to directly compare our results.[3] Inflation is measured by annual log CPI changes. Commodity prices have been extensively used as a leading indicator for inflation in the recent VAR literature on the monetary transmission mechanism, to obtain a solution for the "price puzzle". We measure them with the IMF price index for all commodities.

Our baseline specification is a VAR for these three variables, for the period 1960-1983. Parameters are stable across the two subsamples 1960-1982 and 1983-1998, but more precisely estimated over the full sample. Therefore, we have maintained this larger sample for the estimation of the structural model, even

[3] In fact, quadratic deterministic trends are often used as an alternative to HP filtering. We have made experiments with these two alternative measures for the cycle and found that they deliver very similar results.

if we restrict ourselves to the shorter sample 1983-1998 for the estimation of the policy rule (see below, section 4.1). Lags of the policy rate are included as exogenous variables.[4] We take this augmented VAR as the reduced form of our structural model. Diagnostic statistics for the reduced form are reported in Table 1.

Insert Table 1 here

The diagnostic tests deliver satisfactory results, after the introduction of dummies to take care of outliers generated by shocks to the commodity price index.

Insert Table 2 here

The full specification of the structural model is described in Table 2. We reproduce below, for easier reference, the structure of the estimated model, without dummies:

$$\begin{aligned} x_t &= \beta_1 x_{t-1} - \beta_2 x_{t-3} - \beta_3 \left(i_{t-2} - E_{t-2}\pi_{t-1} - \bar{r} \right) + \beta_4 \left(i_{t-3} - E_{t-3}\pi_{t-2} - \bar{r} \right) \\ &\quad + u_t^d && (3.1) \\ \pi_t &= \alpha_0 + \alpha_1 \pi_{t-1} - \alpha_2 \pi_{t-4} + \alpha_3 \pi_{t-5} + \alpha_4 x_{t-1} + \alpha_5 \Delta_4 lpcm_t + u_t^s && (3.2) \\ \Delta_4 lpcm_t &= \gamma_0 + \gamma_1 \Delta_4 lpcm_{t-1} - \gamma_2 \Delta_4 lpcm_{t-2} + u_t^c && (3.3) \end{aligned}$$

All parameters are positive. We take care of the presence of expectations by estimating the system simultaneously and by imposing the appropriate cross-equation restrictions. In particular:

$$E_{t-j-1}\pi_{t-j} = \alpha_0 + \alpha_1 \pi_{t-j-1} - \alpha_2 \pi_{t-j-4} + \alpha_3 \pi_{t-j-5} + \alpha_4 x_{t-j-1} + \alpha_5 \Delta_4 lpcm_{t-j}$$

for j=1,2. Since the structural model (3.1)-(3.3) imposes further restrictions relative to the reduced form, we test these by comparing the unrestricted reduced form with the restricted reduced form implicit in the structural model. On the basis of the outcome of the test[5] we conclude that the rather standard structure

[4] The contemporaneous policy rate is omitted, following the conventional approach to identification (see Christiano, Eichenbaum and Evans, 1998).

[5] As shown by Hendry (1996), the relevant test statistic is distributed as a χ^2 with a number of degrees of freedom equal to the number of overidentifying restrictions in the structural model. In our case we have 42 over-identifying restrictions and the observed value for the χ^2 is 78.01, with a tail probability of 0.006. However when we correct for the small sample size as suggested by Sims (1981), the value of the statisitic is reduced to 37.51, with a tail probability of 0.068 . Hence the restrictions are not rejected when the correction is implemented, although they would be without correction.

of the model (3.1)- (3.3) is not inconsistent with the data, although there might be some room for improving on our specification.[6]

Equation (3.1) identifies aggregate demand. Note the persistence of the effect of real interest rates on demand. As we show in the next section, this justifies an autoregressive structure in the interest rate rule, even when the central bank does not care for interest rates smoothing . We also note that we can identify the equilibrium long-term interest rate as: $\bar{r} = \frac{\beta_0}{\beta_3 - \beta_4}$. Our parameter estimates imply an equilibrium real rate around two per cent.

Equation (3.2) identifies aggregate supply. Both commodity price inflation and the lagged output gap are significant. Taking into account the dynamic structure of aggregate demand and supply, it takes about nine months for monetary policy to have a first impact on inflation. Also, from (3.3) there is no significant feedback from real US monetary policy rates to commodity price inflation, hence commodity price inflation may be considered strongly exogenous for the estimation of the parameters of interest in the aggregate demand and supply equations. Our estimates for the parameters in the model are very close to those obtained by Rudebusch and Svensson(1998), who adopt a similar specification on a slightly different sample. The impact effect of monetary policy on inflation, measured by -$\beta_3\alpha_4$, is small and, given the persistence in the output gap and inflation, it takes a rather long-time for monetary policy to achieve its long-run impact of $\frac{-(\beta_3 - \beta_4)\alpha_4}{(1-\beta_1+\beta_2)(1-\alpha_1+\alpha_2-\alpha_3)}$. The impact and the long-run effects are estimated respectively at -0.01 and -0.47.

4. Identifying central bank preferences

Identification of central bank preferences is achieved by specifying a loss function and by minimizing it intertemporally with respect to the monetary policy instrument, subject to the constraint given by the structure of the economy. We consider in turn strict inflation targeting, flexible inflation targeting and the combination of inflation targeting with real interest rate smoothing.

[6] By comparing the reduced form with the structural model we note that the statistic for the validity of the restrictions increases definitely when the impact of the interest rates on the supply function is set to zero. Allowing for a direct effect of monetary policy on the supply side is an interesting possibility, which we plan to consider in future work.

4.1. Strict inflation targeting

Central bank's preferences are described by the following intertemporal loss function:

$$E_t \sum_{i=0}^{\tau} \delta^i L_{t+i} \tag{4.1}$$

where E_t denotes expectations conditional upon the information set available at time t , δ is the discount factor applied by the central bank, and τ the length of its horizon. The loss function L is specified as:

$$L = \frac{1}{2} \left[(\pi_t - \pi^*)^2 \right] \tag{4.2}$$

where π_t is inflation at time t and π^* is the target level of inflation. The central bank minimizes (4.1)-(4.11) under the constraints (3.1)-(3.3). The first order conditions for optimality are:

$$\sum_{i=0}^{\tau} \delta^i E_{t+j} \left(\pi_{t+i+j} - \pi^* \right) \frac{\partial \pi_{t+i+j}}{\partial i_{t+j}} = 0 \qquad j = 1, ..., \tau \tag{4.3}$$

where, due to the linearity of the structure of the economy, the terms $\frac{\partial \pi_{t+i+j}}{\partial i_{t+j}}$ are constant. Svensson (1996) notes that there is a simple solution to this problem. In fact, the structure of the economy is such that π_{t+j+3} can be controlled by i_{t+j} and it is not affected by i_{t+j+1}, i_{t+j+2}...., so each i_{t+j} can be chosen such that $E_{t+j} \left(\pi_{t+j+3} - \pi^* \right) = 0$. Using the law of iterated expectations, we may write: $E_{t+j} \left(\pi_{t+i+j} - \pi^* \right) = 0$, for i >3. The first order conditions (4.3) can thus be simplified as:

$$E_t \left(\pi_{t+3} - \pi^* \right) = 0 \tag{4.4}$$

(4.4) is the natural object to be estimated by GMM, although in this simple case the estimation would not be very informative, ast it would just set π^* to the sample mean of inflation. (4.4) also implies that the three-period ahead expectation of the deviation of inflation from its target is orthogonal to all information available at time t.[7] From the policy viewpoint, strict inflation targeting implies

[7] Such orthogonality properties could be exploited to perform joint tests of the relevant specification of central bank preferences together with the hypothesis of rational expectations.

an extremely aggressive monetary policy, capable of cancelling from the dynamic process of inflation expectations the stickiness embodied in the autoregressive structure of actual inflation. As a test of the strict inflation targeting model we first derive the implied optimal interest rates rule and then compare the predicted and actual policy rates. In order to derive the optimal interest rate rule, consider that:

$$E_t\pi_{t+3} = \alpha_0 + \alpha_1 E_t\pi_{t+2} + \alpha_2\pi_{t-1} + \alpha_3\pi_{t-2} + \alpha_4 E_t x_{t+2} + \alpha_5 E_t\Delta_4 lpcm_{t+3} \quad (4.5)$$

and:

$$E_t x_{t+2} = \beta_1 E_t x_{t+1} - \beta_2 x_{t-1} - \beta_3\left(i_t - 4E_t\pi_{t+1} - \bar{r}\right) + \beta_4\left(i_{t-1} - 4E_{t-1}\pi_t - \bar{r}\right) \quad (4.6)$$

Then, by using (4.5) and (4.6) in (4.4), we have:

$$\begin{aligned}\pi^* \;=\;& \alpha_0 + \alpha_1 E_t\pi_{t+2} + \alpha_2\pi_{t-1} + \alpha_3\pi_{t-2} + \alpha_5 E_t\Delta_4 lpcm_{t+3} + \\ & \alpha_4\beta_1 E_t x_{t+1} - \alpha_4\beta_2 x_{t-1} + \\ & -\alpha_4\beta_3\left(i_t - E_t\pi_{t+1} - \bar{r}\right) + \alpha_4\beta_4\left(i_{t-1} - 4E_{t-1}\pi_t - \bar{r}\right)\end{aligned} \quad (4.7)$$

Rearranging (4.7) we obtain the following quasi-standard forward-looking interest rate rule:

$$\begin{aligned}\left(i_t - E_t\pi_{t+1} - \bar{r}\right) \;=\;& \frac{\beta_4}{\beta_3}\left(i_{t-1} - E_{t-1}\pi_t - \bar{r}\right) \\ & + \frac{1}{\beta_3\alpha_4}\left(\alpha_0 + \alpha_1 E_t\pi_{t+2} + \alpha_2\pi_{t-1} + \alpha_3\pi_{t-2} - \pi^*\right) \\ & + \left(\beta_1 E_t x_{t+1} - \beta_2 x_{t-1}\right)\frac{1}{\beta_3} + \frac{\alpha_5}{\beta_3\alpha_4} E_t\Delta_4 lpcm_{t+3}\end{aligned} \quad (4.8)$$

Note that the optimal rule features interest rate persistence even if interest rate smoothing does not enter into the central bank's preferences. Such persistence is entirely due to the dynamic structure of the economy (as noted also by Sack, 1998). The parameters estimated from the structural model illustrate how aggressive would the optimal monetary policy be under strict inflation targeting. As the point estimates of β_3 and α_4 are respectively 0.12 and 0.11, the optimal reaction function would feature a parameter on $(\alpha_0 + \alpha_1 E_t \pi_{t+2} + \alpha_2 \pi_{t-1} + \alpha_3 \pi_{t-2} - \pi^*)$ of about one hundred $\left(= \frac{1}{\beta_3 \alpha_4}\right)$. To compare actual and optimal interest rate behavior (conditional on strict inflation targeting) we estimate by GMM the following unrestricted equation:

$$\begin{aligned}\left(i_{t-1} - E_{t-1}\pi_t - \bar{r}\right) &= c_0 + c_1 \left(i_t - E_t \pi_{t+1} - \bar{r}\right) \\ &+ c_2 \left(\alpha_0 + \alpha_1 E_t \pi_{t+2} + \alpha_2 \pi_{t-1} + \alpha_3 \pi_{t-2} - \pi^*\right) \\ &+ c_3 \left(\beta_1 E_t x_{t+1} - \beta_2 x_{t-1}\right) + c_4 E_t \Delta_4 lpcm_{t+3}\end{aligned} \tag{4.9}$$

If actual and optimal interest rates do not systematically diverge, then (5) should deliver a congruent specification for the interest rate and the following restrictions should not be rejected:

$$c_1 = \frac{\beta_3}{\beta_4}, c_2 = -\frac{1}{\beta_4 \alpha_4}, c_3 = -\frac{1}{\beta_4}, c_4 = -\frac{\alpha_5}{\beta_4 \alpha_4}$$

The interest rate rule has been estimated on the sample 1983-1998, since the policy regime is likely to differ in the pre- and post-1983 samples. The appropriate GMM estimator takes into account the existence of a MA(2) structure in the residuals, generated by having three-periods ahead expectations in the first order conditions. The results reported in Table 3 clearly illustrate that while (5) is broadly consistent with the data, the above restrictions are overwhelmingly rejected.

Insert Table 3 here

We conclude that the strict inflation targeting model identifies correctly the variables to which the Fed reacts, but does not predict correctly the magnitude of the coefficients. In fact, the actual response of the Fed to the relevant variables is much smoother than the one predicted by the strict inflation targeting model.

4.2. Flexible inflation targeting

Under flexible inflation targeting, central bank preferences are still described by the intertemporal loss function:

$$E_t \sum_{i=0}^{\tau} \delta^i L_{t+i} \tag{4.10}$$

while the loss function L is now:

$$L = \frac{1}{2}\left[(\pi_t - \pi^*)^2 + \lambda x_t^2\right] \tag{4.11}$$

where λ is a weight which determines the degree of flexibility in inflation targeting. The central bank is subject to the constraints given by (3.1)-(3.3). The first order conditions can be written as:

$$E_t \sum_{i=0}^{\tau} \delta^i E_t (\pi_{t+i} - \pi^*) \frac{\partial \pi_{t+i}}{\partial i_t} + E_t \sum_{i=0}^{\tau} \delta^i \lambda E_t x_{t+i} \frac{\partial x_{t+i}}{\partial i_t} = 0 \tag{4.12}$$

In this case the rich dynamics of the constraints would tend to generate complicated Euler equations, with many collinear terms. This collinearity would be an increasing function of the length of the assumed horizon, τ . To obtain a manageable solution we simplify the problem and consider a one-year horizon ($\tau = 4$).[8] The conditions for optimality may thus be written:

$$\begin{aligned}
&\lambda E_t x_{t+2} \frac{\partial x_{t+2}}{\partial i_t} + \delta \lambda E_t x_{t+3} \left(\frac{\partial x_{t+3}}{\partial i_t} + \frac{\partial x_{t+3}}{\partial x_{t+2}} \frac{\partial x_{t+2}}{\partial i_t} \right) \qquad (4.13)\\
&+\delta^2 \lambda E_t x_{t+4} \frac{\partial x_{t+4}}{\partial x_{t+3}} \left(\frac{\partial x_{t+3}}{\partial i_t} + \frac{\partial x_{t+3}}{\partial x_{t+2}} \frac{\partial x_{t+2}}{\partial i_t} \right)\\
&+\delta E_t (\pi_{t+3} - \pi^*) \left(\frac{\partial \pi_{t+3}}{\partial x_{t+2}} \frac{\partial x_{t+2}}{\partial i_t} \right)\\
&+\delta^2 E_t (\pi_{t+4} - \pi^*) \left(\frac{\partial \pi_{t+4}}{\partial x_{t+3}} \left(\frac{\partial x_{t+3}}{\partial i_t} + \frac{\partial x_{t+3}}{\partial x_{t+2}} \frac{\partial x_{t+2}}{\partial i_t} \right) + \frac{\partial \pi_{t+4}}{\partial \pi_{t+3}} \left(\frac{\partial \pi_{t+3}}{\partial x_{t+2}} \frac{\partial x_{t+2}}{\partial i_t} \right) \right)\\
= {} & 0
\end{aligned}$$

and, substituting for the estimated parameters:

$$-\lambda E_t x_{t+2} \beta_3 + \delta \lambda E_t x_{t+3} (\beta_4 - \beta_1 \beta_3) + \delta^2 \lambda E_t x_{t+4} \beta_1 (\beta_4 - \beta_1 \beta_3)$$

[8]This choice is supported by evidence in the "Greenbook", which publishes (with a five-year delay) real-time Fed forecasts for inflation and unemployment up to four quarters ahead. Moreover, we have checked the robustness of our choice of the horizon can by extending it by one period, and testing if the additional variables involved in the Euler equation attract significant coefficients. We have done so by setting $\tau = 5$, in all our empirical applications and found support for the choice $\tau = 4$.

$$
\begin{aligned}
&-\delta E_t\left(\pi_{t+3}-\pi^*\right)\alpha_4\beta_3+\delta^2E_t\left(\pi_{t+4}-\pi^*\right)\alpha_4\left(\beta_4-\beta_3\left(1+\beta_1\right)\right)\\
=\;&0 \qquad (4.14)
\end{aligned}
$$

which can be rearranged as:

$$
\begin{aligned}
&E_t\pi_{t+3}=\pi^*+\delta E_t\left(\pi_{t+4}-\pi^*\right)\left(\frac{\beta_4-\beta_3\left(1+\beta_1\right)}{\beta_3}\right)+\\
&-\lambda\left(E_tx_{t+2}\frac{1}{\alpha_4\delta}-E_tx_{t+3}\frac{\left(\beta_4-\beta_1\beta_3\right)}{\alpha_4\beta_3}-\delta E_tx_{t+4}\frac{\beta_1\left(\beta_4-\beta_1\beta_3\right)}{\alpha_4\beta_3}\right) \qquad (4.15)
\end{aligned}
$$

The corresponding unrestricted equation is then[9]:

$$
E_t\pi_{t+3}=c_0+\delta E_t\left(\pi_{t+4}-c_0\right)c_1-E_tx_{t+2}\frac{c_2}{\delta}+E_tx_{t+3}c_3+\delta E_tx_{t+4}c_4 \qquad (4.16)
$$

Estimation results for eq.(4.16) and a Wald test vis-à-vis eq.(4.15) are reported in Table 4. Note that we can test the validity of the theoretical model (i.e. the flexible inflation targeting hypothesis) independently from the identification of π^* and λ. For instance, consider the coefficient on the deviation of expected inflation at time t+4: the restriction $c_1=\left(\frac{\beta_4-\beta_3(1+\beta_1)}{\beta_3}\right)$ is independent from the identification of π^* and λ. Symmetrically, if the restrictions implied by eq. (??) were accepted, then we would be left with only two preference parameters to be estimated: π^* and λ. However, looking at the estimates of the unrestricted model we immediately see that the Euler equation derived from flexible inflation targeting is not consistent with the data. In fact the point estimate of c_1 is as high as 0.87, so that the restriction $c_1=\left(\frac{\beta_4-\beta_3(1+\beta_1)}{\beta_3}\right)=-1.24$ is clearly rejected.[10] This suggests that actual interest rates are positively correlated, while according to the optimal rule of equation (4.15)they should be negatively correlated. Hence actual monetary policy has been by far less aggressive than what would be implied under flexible inflation targeting. Also the estimates of c_2, c_3, and c_4,although only marginally significant, have a different sign from that predicted by the theoretical model.

[9]Following a common practice in the empirical literature on the simulation of interest rate rules, we have fixed the discount rate $\delta=.975$, which implies a discount rate of 2.5%. If δ is left unrestricted, we obtain a negative point estimate, altough hardly significant.

[10]We also checked that the confidence intervals on $c_1$and$\left(\frac{\beta_4-\beta_3(1+\beta_1)}{\beta_3}\right)$ do not overlap, so that the results of the test are robust to the explicit consideration of uncertainty on all the estimated parameters.

Insert Table 4 here

Since the estimated parameters in the Euler equation are significantly different from those predicted by the flexible inflation targeting model, there would be no point in deriving the implicit interest rate rule and compare it with the data.

4.3. Real interest rate smoothing

As a possible solution to the rejection of the models described in sections 4.1 and 4.2, we introduce a real interest rate smoothing objective in the characterization of central bank's preferences.[11] The loss function is modified accordingly:

$$L = \frac{1}{2}\left[(\pi_t - \pi^*)^2 + \mu\left[(i_t - E_t\pi_{t+1} - r) - (i_{t-1} - E_{t-1}\pi_t - r)\right]^2 + \lambda x_t^2\right]$$

The first order conditions are:

$$\begin{aligned}
& -\delta^2\lambda E_t x_{t+2}\beta_3 + \delta^3\lambda E_t x_{t+3}(\beta_4 - \beta_1\beta_3) + \delta^4\lambda E_t x_{t+4}\beta_1(\beta_4 - \beta_1\beta_3) + \\
& -\delta^3 E_t(\pi_{t+3} - \pi^*)\alpha_4\beta_3 + \delta^4 E_t(\pi_{t+4} - \pi^*)\alpha_4(\beta_4 - \beta_3(1+\beta_1)) + \\
& +\mu(1+\delta)\left(i_t - E_t\pi_{t+1} - \bar{r}\right) - \mu(i_{t-1} - E_{t-1}\pi_t - r) - \mu\delta\left(E_t i_{t+1} - E_t\pi_{t+2} - \bar{r}\right) \\
= \; & 0
\end{aligned} \tag{4.17}$$

For the purpose of estimation, they can be written as:

$$\begin{aligned}
\left(i_{t-1} - E_{t-1}\pi_t - \bar{r}\right) = \; & (1+\delta)\left(i_t - E_t\pi_{t+1} - \bar{r}\right) - \delta\left(E_t i_{t+1} - E_t\pi_{t+2} - \bar{r}\right) \\
& -\frac{\delta^3}{\mu}E_t(\pi_{t+3} - \pi^*)\alpha_4\beta_3 \\
& +\frac{\delta^4}{\mu}E_t(\pi_{t+4} - \pi^*)\alpha_4(\beta_4 - \beta_3(1+\beta_1)) \\
& -\frac{\delta^2}{\mu}\lambda E_t x_{t+2}\beta_3 + \frac{\delta^3}{\mu}\lambda E_t x_{t+3}(\beta_4 - \beta_1\beta_3) \\
& +\frac{\delta^4}{\mu}\lambda E_t x_{t+4}\beta_1(\beta_4 - \beta_1\beta_3)
\end{aligned} \tag{4.18}$$

Results are reported in Table 5.

[11] See Goodfriend, 1987, Svensson, 1998, and Walsh, 1998 Ch.10, for a discussion of this issue.

Insert Table 5 here

Three parameters are estimated : a constant, which is a convolution of $\bar{r}$ and π^*, $\frac{1}{\mu}$ and λ. Since the estimate of the latter is not significantly different from zero, we reject the hypothesis of *flexible* inflation targeting *cum* interest rate smoothing and re-estimate the equation by imposing $\lambda = 0$. The results for the resulting *strict* inflation targeting *cum* interest rate smoothing model are reported in Table 6. The point estimate for μ is 0.286, with a 95 per cent confidence interval ranging from 0.10 to 0.47. Cross-equation restrictions are not rejected and the ability of the model to track actual interest rates is quite good, as shown in Figure 1

Insert Table 6 here
Insert Figure 1 here

We conclude that the hypothesis of *strict* inflation targeting *cum* real interest rate smoothing, delivers an interest rate rule which fits well the observed path of interest rates. A notable implication of the finding that $\lambda = 0$ is that, since 1983, the role of output gaps in determining monetary policy has been that of a leading indicator of inflation and not of an independent policy target.

5. Conclusions

In this paper we developed an approach to identify central banks' preferences, which differs from the standard practice of estimating unrestricted (forward-looking) interest rate rules. Since estimated parameters in a monetary policy rule are convolutions of "deep" parameters describing central banks' preferences and those describing the structure of the economy, it is not possible to identify central banks' preferences from the direct estimation of monetary policy rules. However such preferences can be naturally identified from the first order conditions of the central banks' intertemporal optimization problem for a given structure of the economy.

We applied our approach to the US, taken as an example of a closed economy. We first estimated the parameters describing the structure of the economy by considering a parsimonious specification for inflation, the output-gap and the commodity price index. Next, we estimated by GMM the Euler equations obtained from the first order conditions for optimality under the alternative hypotheses that central bank preferences are described by strict inflation targeting, flexible inflation targeting and then by (flexible or strict) inflation targeting with real interest rate smoothing.

Our empirical analysis of the structure of the economy has shown that the persistency of real interest rates in aggregate demand is sufficient to generate an autoregressive structure in any interest rate rule. From the estimation of Euler equations, we also infer that strict inflation targeting together with real interest rate smoothing delivers an optimal interest rate rule which closely replicates the observed path of real interest rates over the sample 1983:1-1998:3. These findings also imply that the output gap enters the interest rate rule only as a leading indicator of future inflation, and reject the hypothesis that output stabilization is an independent argument in the loss function of the Fed.

We believe that direct estimation of the Euler equation is an appropriate approach to the identification of central bank preferences. Hopefully the framework used in this paper can be extended to accommodate more complex structural models and also alternative hypotheses on central banks' behavior.

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Table 1: Diagnostic statistics on the unrestricted system

	Autocorr.: AR 1-5	Normality	Het.: ARCH (4)
Eq 1	F(5,124) = 1.0296 [0.4033]	Chi^2(2)= 5.0107 [0.0816]	F(4,121) = 0.6835 [0.6047] Xi^2 F(38, 90) =1.5493 [0.0471]
Eq 2	F(5,124) = 2.0249 [0.0796]	Chi^2(2)= 2.7121 [0.2577]	F(4,121) = 0.6835 [0.6047] Xi^2 F(38, 90) =1.5493 [0.0471]
Eq 3	F(5,124) = 1.2414 [0.2938]	Chi^2(2)= 6.497 [0.0388]	F(4,121) = 0.6835 [0.6047] Xi^2 F(38, 90) =1.5493 [0.0471]
System	F(45,333) = 1.3174 [0.0926]	Chi^2(6)= 10.157 [0.1182]	Xi^2 F(228,513) =1.2519 [0.0209]

Note to Table 1.

The statistic for residual autocorrelation is the LM statistic for lags 1 to 5, the two statistics for heterescedasticity test The null of homoscedastic residuals against the alternative of ARCH and heteroscedasticity due to the squares of regressors and their cross products. All the test are performed both separately on each equation and on the system as a whole. For a detailed description of these tests see Doornik and Hendry (1997). The estimated system is :

$$\begin{pmatrix} x_t \\ \pi_t \\ \Delta_4 lcpm_t \end{pmatrix} = A(L) \begin{pmatrix} x_{t-1} \\ \pi_{t-1} \\ \Delta_4 lcpm_{t-1} \end{pmatrix} + B(L) i_{t-1} + C \begin{pmatrix} oil73 \\ oil75 \\ oil783 \\ dum862 \\ dum773 \end{pmatrix} + \begin{pmatrix} u_t^d \\ u_t^s \\ u_t^c \end{pmatrix}$$

x_t = output gap (difference between real GDP and HP filtered GDP with smoothing parametr set at 1600), π_t = CPI annual inflation rate, $\Delta_4 lcpm_t$ = IMF commodity price index (annual growth rate), i_t = Federal funds rate (average value in the last month of each quarter), $dum7323$ = dummy taking a value of 1 in 1973:1 and 1973:2, zero otherwise, $dum751$ = dummy taking a value of 1 in 1975:1, zero otherwise, $dum773$ = dummy taking a value of 1 in 1977:3, zero otherwise, $dum783$ = dummy taking a value of 1 in 1978:1, zero otherwise, $dum862$ = dummy taking a value of 1 in 1986:2, zero otherwise.

Table 2: Structural model
Structural equations and diagnostic statistics
Estimation Method: SURE, Sample (adj.):1960:1-1998:3

$\pi_t = \alpha_0 + \alpha_1\pi_{t-1} - \alpha_2\pi_{t-4} + \alpha_3\pi_{t-5} + \alpha_4 x_{t-1} + \alpha_5\Delta_4 lpcm_t$		
$-\alpha_6 dum862 + \alpha_7 dum782 + u_t^s$		
R^2 0.976	Adj R^2 0.975	S.E. of reg 0.456
DW stat 1.987	Mean dep. var 4.45	S.D. dep var 2.90

$x_t = \beta_1 x_{t-1} - \beta_2 x_{t-3} - \beta_3 \left(i_{t-2} - E_{t-2}\pi_{t-1} - \bar{r}\right) + \beta_4 \left(i_{t-3} - E_{t-3}\pi_{t-2} - \bar{r}\right)$		
$+\beta_5 dum782 - \beta_6 dum751 + u_t^d$		
R^2 0.824	Adj R^2 0.806	S.E. of reg 0.711
DW stat 2.02	Mean dep var -0.041	S.D. dep var 1.615

$\Delta_4 lpcm_t = \gamma_0 + \gamma_1\Delta_4 lpcm_{t-1} - \gamma_2\Delta_4 lpcm_{t-2} - \gamma_3\Delta_4 lpcm_{t-4} + \gamma_4\Delta_4 lpcm_{t-5}$		
$+\gamma_5 dum7323 - \gamma_6 dum751 + \gamma_7 dum783 - \gamma_8 dum862 - \gamma_9 dum773 + u_t^c$		
R^2 0.923	Adj R^2 0.918	S.E. of reg 3.668
DW stat 1.793	Mean dep var 2.873	S.D. dep var 12.782

Note to Table 2.
Expectation terms are specified as:

$$\begin{aligned} E_{t-2}\pi_{t-1} &= \alpha_0 + \alpha_1\pi_{t-2} - \alpha_2\pi_{t-3} + \alpha_3\pi_{t-4} + \alpha_4 x_{t-2} + \alpha_5\Delta_4 lpcm_{t-1} \\ &\quad -\alpha_6 dum862_{t-1} + \alpha_7 dum782_{t-1} \end{aligned}$$

and similarly for $E_{t-3}\pi_{t-2}$.

(Table 2 cont.) **Estimated coefficients:**

	Coefficient	Std. Error	t-Statistic	Prob.
α_0	0.0883	0.0690	1.2805	0.20
α_1	1.0931	0.0353	30.9622	0.00
$-\alpha_2$	-0.4166	0.0833	-5.0001	0.00
α_3	0.2940	0.0638	4.6070	0.00
α_4	0.1221	0.0278	4.3986	0.00
α_5	0.0160	0.0032	5.0361	0.00
$-\alpha_6$	-1.3754	0.4395	-3.1297	0.002
α_7	1.0236	0.4476	2.2868	0.023
β_0	0.0437	0.0791	0.5521	0.582
β_1	1.0507	0.0468	22.4643	0.00
$-\beta_2$	-0.2746	0.0453	-6.0619	0.00
$-\beta_3$	-0.1377	0.0399	-3.4508	0.001
β_4	0.1120	0.0405	2.7622	0.006
β_5	3.3098	0.6835	4.8423	0.00
$-\beta_6$	-1.8100	0.6814	-2.6563	0.008
γ_0	0.4118	0.3074	1.3397	0.181
γ_1	1.1541	0.0652	17.709	0.00
$-\gamma_2$	-0.1723	0.0772	-2.2325	0.026
$-\gamma_3$	-0.4364	0.0769	-5.6721	0.000
γ_4	0.2547	0.0649	3.9215	0.000
γ_5	12.356	1.9562	6.3164	0.000
$-\gamma_6$	-16.727	3.8858	-4.3046	0.000
γ_7	7.1929	3.7248	1.9311	0.054
$-\gamma_8$	-6.7065	3.5938	-1.8661	0.063
$-\gamma_9$	-15.878	3.6220	-4.3839	0.000

Table 3: Optimal vs. actual interest rate rule

Estimation method: GMM, Sample (adj.):1983:1 - 1997:3
Bandwidth: Fixed (4)
Estimated equation is 5:
Instruments: π_t ... π_{t-4} , x_t ... x_{t-2}, $\Delta_4 lpcm_t$ ... $\Delta_4 lpcm_{t-4}$, i_t , i_{t-1}

	Coefficient	Std. Error	t-Statistic	Prob.
c_0	0.352	0.142	2.51	0.015
c_1	0.936	0.034	27.55	0.0000
c_2	-0.20	0.12	-1.73	0.088
c_3	-0.573	0.147	-3.88	0.000
c_4	-0.060	0.013	-4.34	0.000

R-squared 0.767 S.E. of regression 0.911
Mean dependent var 3.26 J-statistic 0.157

Restrictions: $c_1 = \frac{\beta_3}{\beta_4}, c_2 = -\frac{1}{\beta_4 \alpha_4}, c_3 = -\frac{1}{\beta_4}, c_4 = -\frac{\alpha_5}{\beta_4 \alpha_4}, c_5 = \frac{1}{\alpha_4} \frac{\delta}{\beta_3}$

$$c_1 = \frac{0.138}{0.112}, c_2 = -\frac{1}{0.112 * 0.122}, c_3 = -\frac{1}{0.112}, c_4 = -\frac{0.016}{0.112 * 0.122}$$

Wald tests:F-stat. = 7,653,719 (0.00), Chi-sq.= 30,614,876 (0.00)

Table 4: Euler equation : Flexible inflation targeting

Estimation method: GMM, Sample (adj.): 1983:1 - 1997:3				
Bandwidth: Fixed (3), Kernel: Bartlett				
Estimated equation is: 4.16, with $\delta = 0.975$				
Instruments: π_t ... π_{t-5} , x_t ... x_{t-2}, $\Delta_4 lpcm_t$ ... $\Delta_4 lpcm_{t-4}$, i_t , i_{t-1} , $dum862$				
	Coefficient	Std. Error	t-Statistic	Prob.
c_0	4.094	0.537	7.62	0.000
c_1	0.875	0.066	13.27	0.000
c_2	0.459	0.202	2.27	0.027
c_3	-0.087	0.401	-0.21	0.829
c_4	-0.377	0.217	-1.73	0.087
R-squared 0.723, S.E. of regression 0.58				
Mean dependent var 3.341868, J-statistic 0.16				

Wald test: $\left(\frac{\beta_4 - \beta_3(1+\beta_1)}{\beta_3}\right) = c_1$, F-stat.= 808 (0.00)

Table 5: Euler equation: Flexible inflation targeting and real interest rate smoothing

Estimation method: GMM, Sample (adj.): 1983:1 - 1997:3
Bandwidth: Fixed (3)
Estimated equation (from eq. 4.18):
$(i_{t-1} - E_{t-1}\pi_t) = c_0 + (1+\delta)(i_t - E_t\pi_{t+1}) - \delta(E_t i_{t+1} - E_t\pi_{t+2})$
$-\frac{\delta^3}{\mu}\alpha_4\beta_3 \left[E_t(\pi_{t+3}) - \delta E_t(\pi_{t+4})\left(\frac{\beta_4}{\beta_3} - (1+\beta_1)\right)\right]$
$-\frac{\delta^2}{\mu}\lambda\beta_3 \left[E_t x_{t+2} - \delta E_t x_{t+3}\left(\frac{\beta_4}{\beta_3} - \beta_1\right) - \delta^2 E_t x_{t+4}\beta_1\left(\frac{\beta_4}{\beta_3} - \beta_1\right)\right]$
Instruments: π_t ... π_{t-4} , x_t ... x_{t-4}, $\Delta_4 lpcm_t$ ... $\Delta_4 lpcm_{t-4}$, i_t , i_{t-1}
$\delta = 0.975$

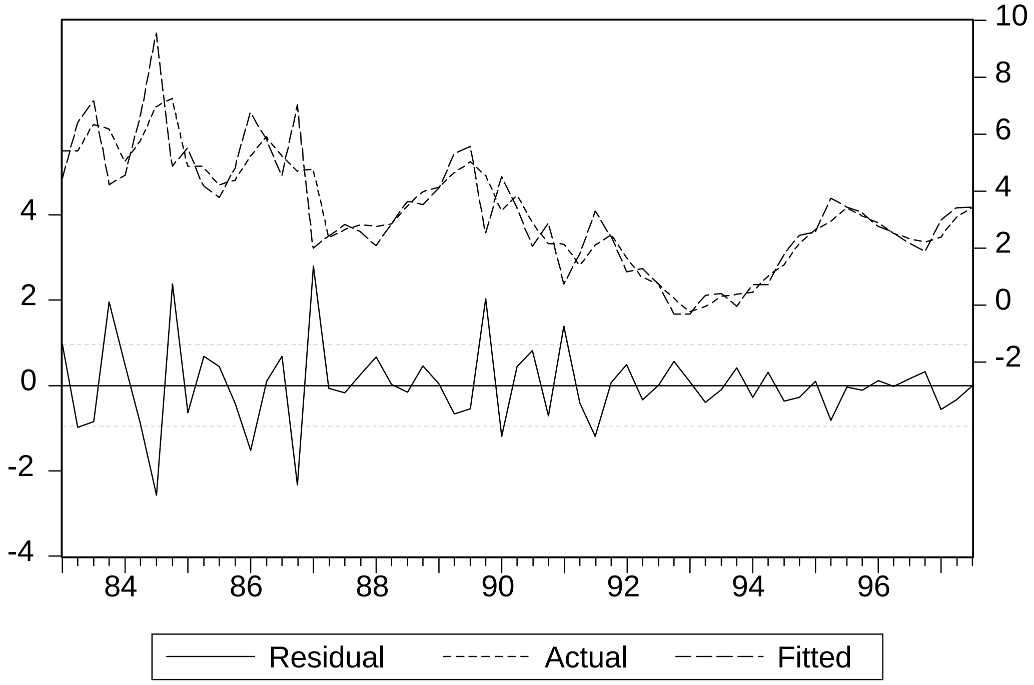
	Coefficient	Std. Error	t-Statistic	Prob.
c_0	0.432	0.201	2.142	0.036
$\frac{1}{\mu}$	3.825	1.983	1.929	0.058
λ	-0.032	0.106	-0.306	0.760

R-squared 0.736	S.E. of regression 0.962
Mean dependent var 3.254	J-statistic 0.17

Table 6: Euler equation: Strict inflation targeting and real interest rate smoothing

Estimation method: GMM, Sample (adj.): 1983:1 - 1997:3				
Bandwidth: Fixed (3)				
Estimated equation: $(i_{t-1} - E_{t-1}\pi_t) =$				
$= c_0 + (1+\delta)(i_t - E_t\pi_{t+1}) - \delta(E_t i_{t+1} - E_t\pi_{t+2})$				
$-\frac{\delta^3}{\mu}\alpha_4\beta_3 \left[E_t(\pi_{t+3}) - \delta E_t(\pi_{t+4})\left(\frac{\beta_4}{\beta_3} - (1+\beta_1)\right)\right]$				
Instruments: π_t ... π_{t-4} , x_t ... x_{t-4}, $\Delta_4 lpcm_t$ ... $\Delta_4 lpcm_{t-4}$, i_t , i_{t-1}				
$\delta = 0.975$				
	Coefficient	Std. Error	t-Statistic	Prob.
c_0	0.403	0.123	3.26	0.002
μ	0.285	0.093	3.07	0.003
R-squared 0.737	S.E. of regression 0.952			
Mean dependent var 3.254	J-statistic 0.17			

Figure 1



Actual and fitted real policy rates. The fitted rates are from the Euler equation under strict inflation targeting and real interest rate smoothing.