Modeling and identifying central bank 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 show how preferences may be identified by simultaneous GMM estimation of the Euler equation for the solution of the optimization problem of the central bank, together with two equations describing the structure of the economy. We apply this approach to the study of the reaction function of the Fed. Our findings suggest that the weight of interest rate smoothing and of output stabilization in the loss function of the Fed is significant, but almost negligible in comparison to the weight placed on inflation stabilization (respectively, one-fiftieth and one-hundreth).

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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 monetary 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 the perceived deviations of inflation and output from their target or equilibrium levels. Taylor (1993), from which this literature originates, simply postulated that this rule might be plausible, and found that it accurately described how monetary policy had been conducted during the Greenspan years. Svensson (1996) later observed that an interest rate rule may be derived by solving the intertemporal optimization problem of a central bank, for a suitable loss function. In this case, derivation of the 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. Although this point is clear in theory, only few authors (Lippi, 1998, ch.8; Cecchetti, McConnell and Perez-Quiros, 1999) have attempted in practice to estimate the preferences parameters of central banks. This is quite surprising, if we consider the lively positive and normative debate which has followed after the original paper of Barro and Gordon (1986). Two implications of their analysis have been influential in shaping the intepretation of monetary policy in later years: first, that many inflation episodes may originate from the attempts of central banks to stabilize output above the natural rate; second, that the inflationary bias increases with the relative weight on output stabilization in the loss function of the central bank.[1] In a recent survey, Clarida, Gali and Gertler (1999) have concluded that monetary policy was far less aggressive in fighting inflation in the pre-Volcker era than in the later period, since it was relatively more focused on output stabilization and it allowed real interest rates to decrease in presence of inflationary shocks.[2] One implication of this observation is that it may be useful to identify with some precision central banks preferences, in order to attribute responsibilities for high inflation, and merits for low inflation. On this point, empirical research has generally found

[1] In addition, Svensson (1997a) has shown that, with employment persistance, there is also a state-contingent inflation bias. This bias remains, even if the employment target equals the long-run natural rate.

[2] This is not, of course, the only explanation for the high inflation of the seventies. According to Orphanides (2000), the policy mistake of keeping US interest rates too low in the face of mounting inflationary expectations was instead due to a persistent *overestimation* of potential output. On the contrary, according to Ireland (1999) it may well have been that inflation was due to the deliberate decision to conduct time-inconsistent policies.

evidence that central banks do react to observed output gaps [3]. 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).

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 (as in Clarida, Gali and Gertler, 1999) or - which is perhaps less arbitrary - by assuming that interest rate smoothing enters as an additional explicit objective in the preference ordering of central banks (as argued in Goodfriend, 1987). However, this point is really open to debate. For instance, Rudebusch (1998) and Sack (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.

To better understand these questions, and if possible to settle them, it would be useful to obtain more direct evidence on whether or to what extent central bank decisions may be described as the optimal outcome of trading off output vs. inflation vs. interest rate stabilization. To address this point we adopt a framework which has been suggested in a number of recent, closely related papers (Svensson, 1997b and 1998a, Rudebusch and Svensson, 1999). These authors were mostly concerned with a formal analysis of the properties and implications of inflation targeting, and observed that this policy regime is consistent with the adoption of (forward-looking) interest rate rules. One further implication of their approach, which we exploit in this paper, is that it also provides a framework for obtaining *structural* estimates of interest rate rules consistent with different monetary policy goals.

In this paper we show that, using the framework of Svensson and others, it is possible to identify the preference parameters of a central bank separately from

[3] See e.g, for the case of the G-5, Clarida, Gali and Gertler (1998). Also, Gerlach and Schnabel (2000) show that a simulated myopic Taylor rule fits reasonably well the average behavior of interest rates in the EMU countries for 1990-98. Johnson and Siklos (1996) estimate Taylor-type reaction functions for a sample of 17 OECD central banks in 1960-90. They find no evidence that - after controlling for unexpected changes in inflation or unemployment - central banks set their interest rates in response to political-economic variables (such as the degree of central bank independence, the timing of elections or the type of government).

the parameters which characterize the structure of the economy. To this purpose we observe that, while previous literature has used the GMM methodology to estimate central bank reaction functions, a more natural object for GMM estimation are instead the first order conditions derived from the underlying optimization problem. This procedure allows to identify and estimate the "deep" parameters describing central bank preferences. In turn, this allows us to assess to what extent monetary policy decisions have been motivated by the desire to stabilize output as an objective in its own right.

We apply this methodology to the US, as this has been a widely researched, but to some extent still unsolved case study, and also as it is a clear example of an (almost) closed economy.[4] As suggested in Clarida, Gali and Gertler (1999) we consider a simultaneous model which includes an IS curve, relating the output gap inversely to the real interest rate, a Phillips curve, relating inflation positively to the output gap, and a forward-looking first order condition for the solution of the central bank optimization problem.[5] In section 2 we analyze formally the identification problem for the preference parameters of a central bank. In section 3 we present our estimation strategy and discuss the results. Section 4 concludes.

2. Interest rate rules and central bank preferences

The successful work of Taylor (1993) has revived interest in the estimation of central bank reaction functions. A simple rule relating the setting of real policy rates to deviations of inflation and output from their target or natural levels has proved successful in describing the behavior of the Fed over the period 1987-1992. The simple framework used in the original paper (as well as in much of the derived literature) has been extended by Clarida, Gali and Gertler (1998 and 1999) to the estimation of forward looking rules, where equilibrium interest rates are modelled as a function of the gap between *expected* and target values for inflation and output. The observed persistence of interest rates is accounted by allowing partial adjustment of observed rates towards their equilibrium. The

[4] Of course, EMU is likely to provide in due time the example of another currency area with a comparable degree of closure. Extending our methodology to open economies is certainly feasible, but would introduce additional complications, which are conceptually independent of the strategy for identification of the preference parameters which we develop below. Thus at this stage we prefer to avoid these problems.

[5] Our choice of variables for the two structural equations is consistent with the set of variables used in other recent analyses of monetary policy using very small macro models, as for example in Christiano, Eichenbaum and Evans (1998).

estimated interest rate rules fit well the data over the larger sample 1960-1996. In this approach a natural explanation of the high inflation of the seventies is that the Fed was reacting too timidly to inflationary shocks. However quite often, in this literature, the rules according to which central banks set their interest rates are discussed as if they were independent of the structure of the economy and of the policy transmission mechanism. And, for the reasons which we discussed in the introduction, this in turn makes it impossible to use estimated interest rate rule to make inferences about the nature of the policy preferences of the central banks. Thus, several relevant questions remain unanswered. For instance, is the output gap only a *leading indicator* of inflation or is output stabilization an independent goal of monetary policy? Do central banks react *optimally* to the observed deviations of each variable from its target? And why do we observe so much *persistence* when they set interest rates? Despite its success in fitting the data, this literature does not respond to these questions.

In this section we consider explicitly an intertemporal optimization model which allows identification and simultaneous estimation of the parameters describing the structure of the economy and central bank preferences. Within this framework, alternative hypotheses on the structure of central bank preferences are directly testable. Consider the following specification for aggregate demand and supply in a closed economy[6]:

$$x_{t+1} = \beta_x x_t - \beta_r \left(i_t - E_t \pi_{t+1} - \bar{r} \right) + u^d_{t+1} \tag{2.1}$$

$$\pi_{t+1} = \alpha_\pi \pi_t + \alpha_x x_t + \alpha_w w_{t+1} + u^s_{t+1} \tag{2.2}$$

where x represents the output gap, π is the inflation rate, i is the policy rate, $\bar{r}$ is the equilibrium real policy rate, w is a vector of exogenous variables affecting inflation, u^d and u^s are i.i.d. demand and supply shocks, E_t defines expectations taken with respect to information available at time t and all parameters are positive. This simple structure describes how real activity responds to movements in monetary policy instruments, and how inflation responds to the output gap. This framework is consistent with different empirical models of the US economy, such as those proposed by Christiano, Eichenbaum and Evans (1998) and Rudebusch

[6]Several modifications of the structure presented in the text could be proposed. For instance, the supply equation could include a forward looking term in inflation expectations. Also, in an open economy both demand and supply equations would include terms in the real exchange rate and foreign prices. These additions would imply new channels of monetary policy transmission, which would complicate our model without altering its fundamental structure.

and Svensson (1999). We shall interpret equations (2.1)-(2.2) as the constraints, subject to which the central bank solves its intertemporal optimization problem.

To illustrate our methodology in a simple framework, consider the case of a central bank adopting strict inflation targeting. The loss function is then:

$$L_{t+i} = \frac{1}{2}\left(\pi_{t+i} - \pi^*\right)^2 \tag{2.3}$$

where π^* is the target level of inflation. The intertemporal optimization problem is:

$$\begin{aligned} &Minimize \quad E_t \sum_{i=0}^{\infty} \delta^i L_{t+i} \\ &subject\ \ to\ (2.1) - (2.2) \end{aligned} \tag{2.4}$$

where E_t denotes expectations conditional upon the information set available at time t and δ is the intertemporal discount factor. Given the simple lag structure postulated in (2.1)-(2.2) , the first order conditions for optimality may be written as:

$$\frac{dL}{di_t} = E_t\left(\pi_{t+2} - \pi^*\right) = 0 \quad , \quad \forall t \; . \tag{2.5}$$

Estimation of the three equation system (2.1)-(2.2)-(2.5) would then allow a direct test of the hypothesis that the central bank has followed strict inflation targeting. To identify the parameters of interest requires the assumption that macroeconomic variables do not react instantaneously to monetary policy. This restriction is empirically plausible and is now often adopted in VAR models of the monetary transmission mechanism[7]. As a natural way to estimate the model, we suggest implementing GMM on the first order conditions (2.5), choosing as instruments for expected inflation those variables which are consistent with the dynamic specification of (2.1)-(2.2) . We would then test the hypothesis that $E_t\left(\pi_{t+2} - \pi^*\right)$ is orthogonal to all information available at time t by applying the J-statistic suggested by Hansen and Singleton (1982).

In this framework, the minimum lag with which movements in the policy rate affect actual inflation is two periods. Hence, strict inflation targeting implies that the persistence of actual inflation should *not* be reflected in the time-series

[7] See, for example, Bernanke and Mihov (1998).

behavior of expectations taken two periods ahead. To see this point more directly, substitute (2.1)-(2.2) into (2.5) to obtain:

$$\begin{aligned} E_t\pi_{t+2} &= \alpha_\pi E_t\pi_{t+1} + \alpha_w E_t w_{t+2} + \\ &\quad \alpha_x[\beta_x x_t - \beta_r(i_t - E_t\pi_{t+1} - \bar{r})] \end{aligned} \tag{2.6}$$

and then by further substituting from (2.6)in (2.5) and rearranging we obtain:

$$\begin{aligned} i_t &= \bar{r} + \pi^* + \left(\frac{\alpha_\pi + \alpha_x\beta_r}{\alpha_x\beta_r}\right)(E_t\pi_{t+1} - \pi^*) + \\ &\quad + \frac{\beta_x}{\beta_r}x_t + \frac{\alpha_w}{\alpha_x\beta_r}E_t w_{t+2} \end{aligned} \tag{2.7}$$

This shows that the optimal policy rule (2.7) is indeed a forward-looking Taylor rule. Note however that if the rule is estimated as a single equation, the estimated parameters are not "deep" in the sense of Lucas (1976), as they are instead convolutions of the parameters describing central bank preferences (in this simple example, only π^*) together with those describing the structure of the economy $(\alpha_x, \alpha_w, \alpha_\pi, \beta_r, \beta_x, \bar{r})$. This implies that even in this simple case we cannot identify the preference parameters from the unrestricted estimation of a forward looking interest rate rule. Thus, while estimating these rules may be useful as a purely descriptive device, it would still remain impossible on this basis to assess if the estimated response of central bank to output and inflation is consistent with optimal behavior. Also we may note that, under strict inflation targeting, interest rates shoud respond positively to the current output gap. Thus, the simple evidence of a positive relation between policy rates and the output gap does not *per se* reveal any preference for output stabilization.

In fact, only one empirical implication of this rule can be confronted with the data independently from the identification of the parameters of interest. This is whether the parameter describing the reaction of policy rates to the gap between expected and target inflation is larger than one. If monetary policy accommodates changes in inflation, so that $\frac{\partial i_t}{\partial E_t\pi_{t+1}} \leq 1$, it follows that actual inflation will not in general converge to the target rate π^*. Indeed most discussions on estimated monetary policy rules have focused on this empirical prediction (See again Clarida, Gali and Gertler, 1999).

More generally, the derivation and discussion of (2.7) makes it clear that strict inflation targeting imposes two severe restrictions on the data. First, the optimal rule derived above does not account for the observed persistence in policy rates. On the contrary, the available empirical evidence shows that a sluggish adjustment of actual to target rates has to be added to an equation like (2.7) in order to fit the data. For instance, Clarida, Gali and Gertler (1999, p.1697) estimate a persistence parameter equal to 0.79 for the Volcker-Greenspan era (1979:3-1996:4). Second, taking into account the available estimates on the impact of the policy rate on the output gap, and of the output gap on inflation would suggest that the response of policy rates to deviations of expected inflation from its target should be thirty-three times higher than actual estimates.[8]

Summing up, this discussion points toward two different shortcomings in the literature. First, the estimation of Taylor rules is not informative on central bank preferences unless it is implemented in the context of a simultaneous model of the structure of the economy and of the first order conditions for central bank optimization. Second, the rationalization of the observed evidence from the US economy requires a more general structure of central bank preferences than strict inflation targeting.

In the next section we implement this approach.

3. Identifying central bank preferences

In this section, we discuss the identification of central bank preferences in a more general framework than the one discussed so far. We consider a more general description of the central bank's preferences, which nests a number of specific hypotheses. As we did in the previous section, we then minimize the loss function over time with respect to the policy instrument, subject to the constraints given by the structure of the economy.

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

$$E_t \sum_{i=0}^{\tau} \delta^i L_{t+i} \tag{3.1}$$

where, differently from (2.4), we arbitrarily limit the planning horizon to a finite length, τ [9]. The loss function L is now specified as:

[8] For instance, point estimates in Rudebusch and Svensson (1999, p. 208) are: $\alpha_\pi = 1$, $\beta_x = 0.14$, $\beta_r = 0.10$. Substituing these values into our reaction function would imply $\frac{\partial i_t}{\partial E_t \pi_{t+1}} \simeq 72$. On the other hand Clarida, Gali and Gertler (1999) estimate this parameter equal to 2.15.

[9] We motivate below in the text the empirical choice of a value for τ.

$$L=\frac{1}{2}\left[(\pi_t-\pi^*)^2+\lambda x_t^2+\mu\left(i_t-i_{t-1}\right)^2\right] \quad (3.2)$$

where λ is the weight attached to output stabilization[10] and μ to interest rate smoothing[11]. Note that the interaction between the structure of the economy and the policy reaction function would generate an identification problem which - similarly to the previous section - may be solved by assuming the absence of a contemporaneous feedback between the macroeconomy and monetary policy.

The complete model to be estimated now includes the first order conditions derived from the minimization of (3.1) and (3.2) , subject to the constraint given by the relevant aggregate demand and supply equations. Allowing for a more general lag structure in aggregate demand and supply than the one embodied in equations(2.1) and(2.2), and also adopting the backward-looking structure for the IS curve employed by Rudebusch and Svensson (1999), we may write the complete model as:

$$\begin{aligned}
x_t &= C_1(L)\,x_{t-1}-C_2(L)\left(i_{t-1}-\pi_{t-1}-\bar{r}\right)+u_t^d && (3.3)\\
\pi_t &= C_3(L)\,\pi_{t-1}+C_4(L)\,x_{t-1}+C_5(L)\,w_t+u_t^s && (3.4)\\
E_t f\left(i_{t+i+j},\pi_{t+i+j},x_{t+i+j}\right) &= 0 && (3.5)\\
f\left(i_{t+i+j},\pi_{t+i+j},x_{t+i+j}\right) &= \sum_{i=0}^{\tau}\delta^i E_t\left(\pi_{t+i+j}-\pi^*\right)\frac{\partial \pi_{t+i+j}}{\partial i_{t+j}}+\\
&\quad +E_t\sum_{i=0}^{\tau}\delta^i\lambda E_t x_{t+i+j}\frac{\partial x_{t+i+j}}{\partial i_{t+j}}+\\
&\quad +\mu\left(i_{t+j}-i_{t+j-1}\right)-\mu\delta E_t\left(i_{t+j+1}-i_{t+j}\right)+u_t^m
\end{aligned}$$

As (3.5) are the first order conditions for the solution of the intertemporal optimization problem, they imply some testable cross-equation restrictions between the parameters of the backward and forward-looking blocks.

[10] As x_t measures the output gap, the relevant stabilisation concept clearly extends only to aggregate demand shocks. As supply shocks enter directly into the aggregate supply equation (2.2) or (3.4) below, this is equivalent to the assumption that the central bank does not react to them other than for the purpose of stabilising inflation.

[11] Goodfriend (1987), Svensson (1998b) and Walsh (1998, ch.10) discuss why the central bank might attach a positive value to the smoothing of interest rates. Empirically, this choice is motivated by the desire to account for the observed persistence or graduality in the setting of the Federal Funds rate.

On the basis of optimal lag selection criteria we have chosen four lags for the backward looking block. We also selected four leads for the forward looking block. 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.[12] We select the best fitting empirical model by omitting non-significant lags and leads from the general model. The resulting model, reported in detail in Table 1, has the following specification:

$$\begin{aligned} x_t &= c_1 + c_2 x_{t-1} + c_3 x_{t-2} + c_4 \left(i_{t-2} - \bar{\pi}_{t-2}\right) + \qquad (3.6) \\ &\quad + c_5 \left(i_{t-3} - \bar{\pi}_{t-3}\right) + u_t^d \\ \pi_t &= c_6 \pi_{t-1} + c_7 \pi_{t-2} + c_8 x_{t-1} + \qquad (3.7) \\ &\quad + c_9 \Delta_4 lpcm_{t-1} + u_t^s \\ E_t f\left(i_{t+i+j}, \pi_{t+i+j}, x_{t+i+j}\right) &= 0 \qquad (3.8) \\ f\left(i_{t+i+j}, \pi_{t+i+j}, x_{t+i+j}\right) &= i_t - c_{10} - c_{11} i_{t+1} - c_{12} \pi_{t+1} - c_{13} \pi_{t+2} \\ &\quad - c_{14} x_{t+1} - c_{15} x_{t+2} - c_{16} x_{t+3} + u_t^m \end{aligned}$$

where x is the relative gap between actual and potential GDP in percentage points , π is annual inflation $(100 * (\ln p_t - \ln p_{t-4}))$ in the GDP chain-weighted price index in percentage points,[13] the real rate of interest is defined by subtracting to the nominal rate, i_t,[14] the average annualized quarterly inflation over the previous four quarters, $\bar{\pi}$.[15] $\Delta_4 lcpm_t$ is the IMF commodity price index (annual growth rate). The model is estimated on quarterly data, from 1980:3 to 1998:3. The sample covers the Volcker-Greenspan era, as defined in Clarida, Gali and Gertler (1999, 2000). We have tested the strong exogeneity of the commodity price index for the estimation of the parameters of interest and could not reject it. The estimated parameters in the backward-looking demand and supply block are consistent with the results reported by Rudebusch and Svensson (1999). Note that the inclusion of the commodity price index as a leading indicator for

[12] We have checked the robustness of our choice of the horizon 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 $\tau = 5$ and found support for the choice $\tau = 4$.

[13] Source: U.S. Department of Commerce, Bureau of Economic Analysis. Available from FRED (http://www.stls.frb.org/fred/data/gdp.html).

[14] i_t is the average value of the Federal Funds rate in the last month of each quarter (Source: Datastream).

[15] See Rudebusch and Svensson (1999).

inflation, as suggested by the VAR literature on the monetary transmission mechanism (see, for example, Christiano, Eichenbaum and Evans, 1998), implies small modifications in the estimated parameters of the supply equation.

The unrestricted model reported in Table 1 does not allow the identification of the structural parameters of interest. We then proceed to identify them by rewriting the Euler equation consistent with the selected specification for demand and supply :

$$\begin{aligned} & \lambda E_t x_{t+1} \frac{\partial x_{t+1}}{\partial i_t} + \delta \lambda E_t x_{t+2} \left(\frac{\partial x_{t+2}}{\partial x_{t+1}} \frac{\partial x_{t+1}}{\partial i_t} \right) \\ & + \delta^2 \lambda E_t x_{t+3} \left(\frac{\partial x_{t+3}}{\partial x_{t+2}} \frac{\partial x_{t+2}}{\partial i_t} + \frac{\partial x_{t+3}}{\partial x_{t+1}} \frac{\partial x_{t+1}}{\partial i_t} \right) \\ & + \delta E_t \left(\pi_{t+2} - \pi^* \right) \left(\frac{\partial \pi_{t+2}}{\partial x_{t+1}} \frac{\partial x_{t+1}}{\partial i_t} \right) + \delta E_t \left(\pi_{t+3} - \pi^* \right) \left(\frac{\partial \pi_{t+3}}{\partial \pi_{t+2}} \frac{\partial \pi_{t+2}}{\partial x_{t+1}} \frac{\partial x_{t+1}}{\partial i_t} \right) \\ & + \delta E_t \left(\pi_{t+4} - \pi^* \right) \left(\frac{\partial \pi_{t+4}}{\partial \pi_{t+3}} \frac{\partial \pi_{t+3}}{\partial \pi_{t+2}} \frac{\partial \pi_{t+2}}{\partial x_{t+1}} \frac{\partial x_{t+1}}{\partial i_t} \right) \\ & + \mu E_t \left(i_{t+1} - i_t \right) - \mu \delta E_t \left(i_{t+2} - i_{t+1} \right) \\ = & \; 0 \end{aligned} \tag{3.9}$$

We rearrange (3.9) in terms of interest rates and substitute derivatives with coefficients from (3.6) and (3.7) to obtain:

$$\begin{aligned} E_t \left(i_t - i_{t+1} \right) = & \; \delta E_t \left(i_t - i_{t+1} \right) + \\ & + \delta \left(1/\mu \right) E_t \left[c_8 c_4 \left(\pi_{t+3} - \pi^* \right) + \delta \left(c_6 c_8 c_4 + c_8 \left(c_5 + c_2 c_4 \right) \right) \left(\pi_{t+4} - \pi^* \right) \right] \\ & + \left(\lambda/\mu \right) E_t \left[c_4 x_{t+2} + \delta \left(c_5 + c_2 c_4 \right) x_{t+3} + \delta^2 \left(c_2 \left(c_5 + c_2 c_4 \right) + c_3 c_4 \right) x_{t+4} \right] \end{aligned} \tag{3.10}$$

The model to be estimated now consists of equations (3.6) and (3.7) together with (3.10).

Note that a structural estimate of the real equilibrium interest rate is given by $\frac{-c_1}{c_4+c_5}$. We report estimates of the parameters from the three equations in Table 2, where, in addition to the cross-equation restrictions, we have also imposed that the coefficients on lagged inflation sum to one, which is consistent with the estimates from the unrestricted model.[16] The parameters in the backward-looking

[16] See Table 1, coefficients c_6 and c_7.

block are substantially unaltered when these restrictions are imposed. Turning our attention to the preference parameters, we also restricted the discount factor equal to .975, as the unrestricted estimate is very imprecise. This seems a plausible assumption, and also allows a meaningful interpretation of the remaining preference parameters, without affecting the overall fit of the model. The reported estimates imply that the weight placed on inflation stabilization was about fifty times larger than the weight on interest rate smoothing, and more than one hundred times larger than the weight on output stabilization. However, both λ and μ still differ significantly from zero. Moreover, the inflation target is estimated at 2.4 per cent[17], while the long-run equilibrium real rate stands at 3.3 per cent.

To assess the performance of our specification, we compare the actual path of policy rates, respectively, with the path dynamically simulated from the unrestricted forward-looking model (3.6)-(3.8) (Figure 1) and from the restricted forward-looking model (3.6) , (3.7) and (3.10) (Figure 2). Note that the rates simulated from the restricted model are smoother and closer to the actual rates than those simulated form the unrestricted model. In Figure 3 we compare the simulated path from the restricted model with the 95 per cent confidence interval from the unrestricted model. Here we may note that interest rates simulated from the restricted model always lie within the unrestricted confidence interval. However, we must observe that the latter interval is quite wide, which makes a considerable range of different interest rate policies potentially compatible with the optimal policy.

We conclude this discussion comparing our results, and especially our methodology, to those in the closely related paper of Cecchetti, McConnell and Perez-Quiros (1999). Their results on the revealed preferences of several central banks are quite comparable to ours, in terms of the estimated relative weights on in-

[17] Note that, if the central bank were to pursue a policy of attempting to raise output beyond the equilibrium level, this would be reflected in the adoption of an alternative loss function:

$$L = \frac{1}{2}\left[(\pi_t - \pi^*)^2 + \lambda(x_t + \kappa)^2 + \mu\,(i_t - i_{t-1})^2\right] \tag{3.11}$$

where κ would be the (positive) incremental output target. A positive value of κ would be reflected in the constant in the Euler equation. Since the constant term in our restricted estimates captures the inflation target, we may conclude that our estimates do not provide any evidence against the null that κ does not differ from zero. Notice however that this finding provides evidence against a positive *average* inflation bias (in the teminology of Svensson, 1997a). On the other hand, our framework does not allow to detect the relevance of Svensson's *state-contingent* bias.

flation and output stabilization and on interest rate smoothing. However, their methodology is quite different. They proceed from the assumption that central banks behaved optimally, and then estimate the loss function that implies the policy path effectively undertaken, given the structure of the economy. In practice, having identified aggregate demand and supply shocks, they impose cross-equation restrictions on the moving-average representations of the structure of the economy and for the optimal policy rates, to derive preference parameters. Our approach differs form theirs since we consider a VAR representation for the structure of the economy,[18] and in this framework then compare both unrestricted and restricted models, adopting only those identifying restrictions which are necessary to pin down the monetary policy rules. It may be argued that in an optimal control framework it is more natural to write the evolution of the control in terms of the forcing processes, i.e. the aggregate demand and supply shocks. This approach however requires the identification of demand and supply shocks. In turn, this implies the need to impose some additional restrictions, which may not be necessary in this case. In fact, following a forward-looking interest rate rule automatically discriminates between aggregate supply and demand shocks, since aggregate demand shocks have the same effect on the output gap and on the deviation of inflation from the target, while supply shocks have opposite effects on the two variables. On the positive side, we feel that in principle the estimation of both the restricted and unrestricted versions of the model offers the opportunity to test whether the behavior of central bank has been optimal.

4. Conclusions

In this paper we developed an approach to identify central bank 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 the "deep" parameters describing central bank preferences with those describing the structure of the economy, it is not possible to identify central bank preferences from the direct estimation of monetary policy rules. However, preferences can be naturally identified from the first order conditions of the intertemporal optimization problem faced by central banks, for a given structure of the economy. We implement this approach by simultaneous GMM estimation of a three-equation model including both the forward-looking, first order conditions

[18] Clearly the VAR and MA representation are equivalent, even if a finite VAR implies infinite order lag-polynomials in the MA representation.

for the solution of the optimization problem and aggregate demand and supply equations. The "deep" preference parameters are identified and estimated after imposing the cross-equation restrictions implied by optimization.

The model is estimated on US quarterly data, for the Volcker-Greenspan period (1980:3-1998:3).The reported estimates imply that the Fed placed a weight on inflation stabilization which was about fifty times larger than the weight on interest rate smoothing, and more than one hundred times larger than the weight on output stabilization. Nevertheless, also the weights on interest rate smoothing and output stabilization in the central bank loss function differ significantly from zero. The inflation target is estimated at 2.4 per cent, while the long-run equilibrium real rate stands at 3.3 per cent. Due to the uncertain estimates of the parameters describing the structure of the economy, confidence intervals around the estimated policy rates are rather wide. Since this implies that a wide range of policy rules (and interest rate paths) are empirically compatible with optimal behavior, we conclude that it may be quite difficult to assess empirically to what extent interest rates have been set in accord with an optimal rule. Overall, however, our results suggest that direct estimation of the Euler equation is an appropriate approach to identify the preferences of central banks. Hopefully, the framework used in this paper can be extended to accommodate more complex structural models and also alternative hypotheses on central bank behavior.

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TABLE 1: The unrestricted system, sample 1980:3-1998:3

$$x_t = c_1 + c_2 x_{t-1} + c_3 x_{t-2} + c_4 \left(i_{t-2} - \pi_{t-2}\right) + c_5 \left(i_{t-2} - \pi_{t-2}\right) + u_t^d$$

$$\pi_t = c_6 \pi_{t-1} + c_7 \pi_{t-2} + c_8 x_{t-1} + c_9 \Delta_4 lpcm_{t-1} + u_t^s$$

$$E_t f\left(i_{t+i+j}, \pi_{t+i+j}, x_{t+i+j}\right) = 0$$

$$f\left(i_{t+i+j}, \pi_{t+i+j}, x_{t+i+j}\right) = i_t - c_{10} - c_{11} i_{t+1} - c_{12} \pi_{t+1} - c_{13} \pi_{t+2} + -c_{14} x_{t+1} - c_{15} x_{t+2} - c_{16} x_{t+3} + u_t^m$$

	Coefficient	**Std. Error**	**t-ratio**	**Prob.**
c_1	0.244	0.06	4.18	0.00
c_2	1.353	0.03	40.29	0.00
c_3	-0.408	0.04	-10.02	0.00
c_4	-0.181	0.01	-18.54	0.00
c_5	0.114	0.01	11.10	0.00
c_6	1.307	0.04	33.50	0.00
c_7	-0.320	0.04	-8.57	0.00
c_8	0.029	0.005	5.60	0.00
c_9	0.009	0.001	8.25	0.00
c_{10}	0.378	0.18	2.14	0.03
c_{11}	1.116	0.05	24.85	0.00
c_{12}	2.158	0.39	5.57	0.00
c_{13}	-2.656	0.43	-6.25	0.00
c_{14}	1.619	0.12	13.58	0.00
c_{15}	-2.851	0.24	-11.76	0.00
c_{16}	1.253	0.15	8.12	0.00

The system is estimated by GMM, with a four lag Newey-West estimate of the covariance matrix. Instruments used include four lags of inflation, output gap, commodity price inflation and the nominal interest rate.

TABLE 2: Identifying central bank preferences, sample 1980:1-1998:3

$$x_t = c_1 + c_2 x_{t-1} + c_3 x_{t-2} + c_4 \left(i_{t-2} - \bar{\pi}_{t-2}\right) + c_5 \left(i_{t-3} - \bar{\pi}_{t-3}\right) + u_t^d$$

$$\pi_t = c_6 \pi_{t-1} + (1 - c_6) \pi_{t-2} + c_8 x_{t-1} + c_9 \Delta_4 lpcm_{t-1} + u_t^s$$

$$E_t \left(i_t - i_{t+1}\right) = \delta E_t \left(i_t - i_{t+1}\right) + $$
$$+\delta \left(1/\mu\right) E_t \left[c_8 c_4 \left(\pi_{t+3} - \pi^*\right) + \delta \left(c_6 c_8 c_4 + c_8 \left(c_5 + c_2 c_4\right)\right) \left(\pi_{t+4} - \pi^*\right)\right]$$
$$+ \left(\lambda/\mu\right) E_t \left[c_4 x_{t+2} + \delta \left(c_5 + c_2 c_4\right) x_{t+3} + \delta^2 \left(c_2 \left(c_5 + c_2 c_4\right) + c_3 c_4\right) x_{t+4}\right]$$

	Coefficient	**Std. Error**	**t-ratio**	**Prob.**
c_1	0.194	0.04	4.51	0.00
c_2	1.345	0.02	64.42	0.00
c_3	-0.400	0.03	-15.59	0.00
c_4	-0.182	0.01	-25.30	0.00
c_5	0.126	0.01	14.55	0.00
c_6	1.328	0.01	104.18	0.00
c_8	0.040	0.002	16.52	0.00
c_9	0.009	0.001	8.63	0.00
δ	0.975	-	-	-
π^*	2.413	0.13	18.14	0.00
$1/\mu$	49.317	9.72	5.08	0.00
λ/μ	0.411	0.10	4.32	0.00
$(i - \bar{\pi}) = \frac{-c_1}{c_4 + c_5} = 3.29$				

The system is estimated by GMM, with a four lag Newey-West estimate of the covariance matrix. Instruments used include four lags of inflation, output gap, commodity price inflation and the nominal interest rate

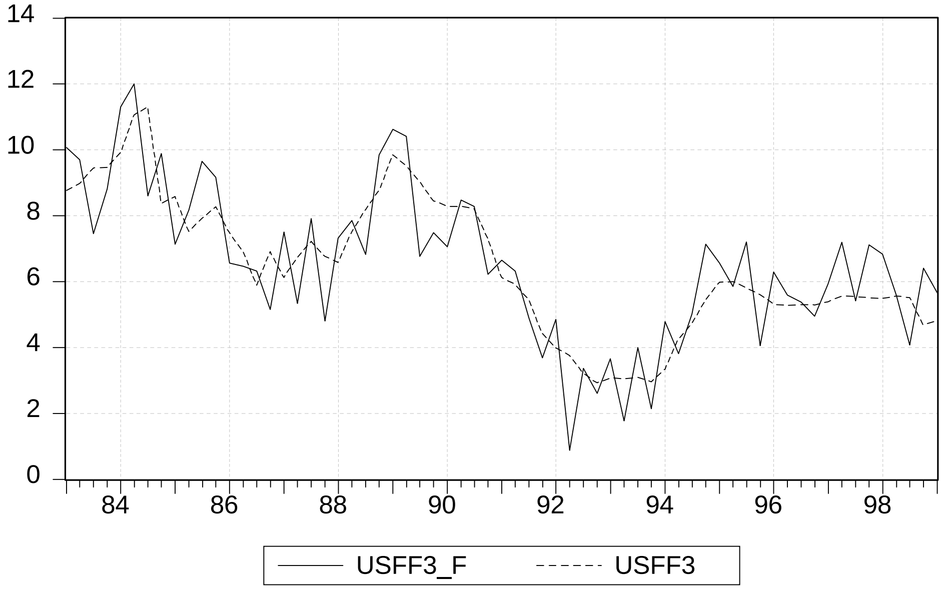

Figure 1: Actual (USFF3) and Simulated (USFF3_F) US Federal Funds rate. Simulated rates are generated by dynamic simulation of the unrestricted forward looking model.

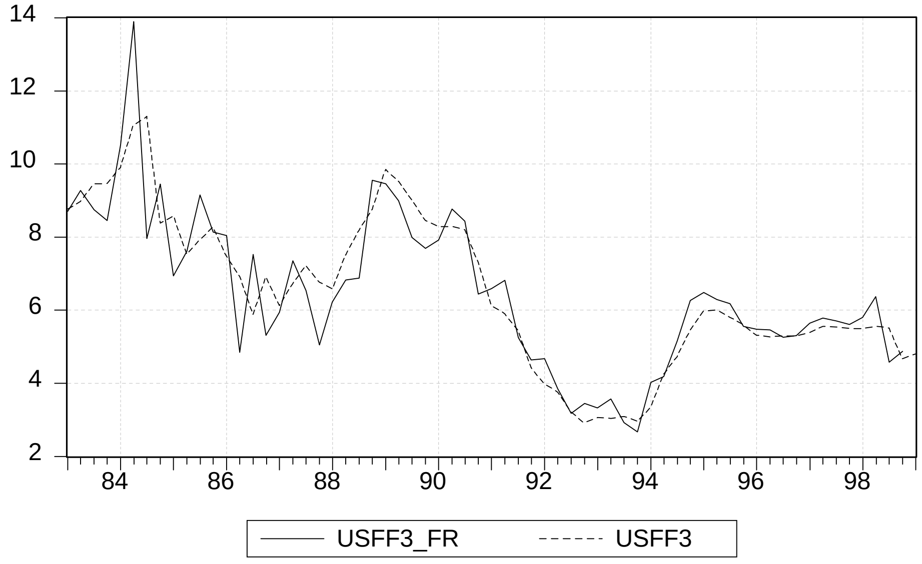

Figure 2: Actual (USFF3) and Simulated (USFF3_FR) US Federal Funds rate. Simulated rates are generated by dynamic simulation of the restricted forward looking model.

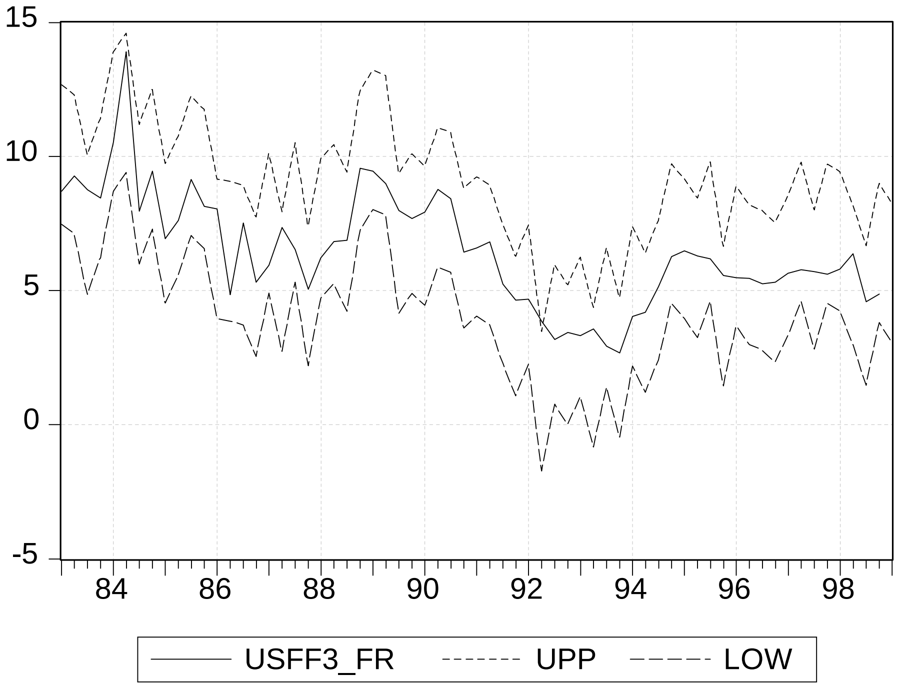

Figure 3: Simulated Federal Funds rate from the restricted model (USFF3_FR) and upper (UPP) and lower (LOW) bounds of the 95 per cent confidence interval of the simulated rates from the unrestricted model.