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Carlo A. Favero, Riccardo Rovelli

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Carlo A. Favero and Riccardo Rovelli
IGIER-Università Bocconi and CEPR; Università di Bologna

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Abstract

The rate of inflation in the US has declined from an average of 4.5% in the period 1960-79 to an average of 3.6% in 1980-98. Between those two periods, the standard deviations of inflation and the output gap have also declined. These facts can be attributed to the interaction of three possible factors: a shift in central bank preferences, a reduction in the variability of aggregate supply shocks and a more efficient conduct of monetary policy. In this paper we identify the relative roles of these factors. Our framework is based on the estimation of a small structural macro model for the US economy jointly with the first order conditions, which solve the intertemporal optimization problem faced by the Fed. Overall, our results indicate that the policy preferences of the Fed, and in particular the (implicit) inflation target, have changed drastically with the advent of the Volcker-Greespan era. In addition, we find that the variance of supply shocks has been lower and also monetary policy has been conducted more efficiently during this period.

JEL classification: C52, E52

Keywords: Interest rate rules, central bank preferences, US monetary policy, GMM estimation of Euler equations.

*Carlo A. Favero is Professor of Economics, Università Bocconi, Milano, Italy (carlo.favero@uni-bocconi.it). Riccardo Rovelli is Professor of Economics, Dipartimento di Scienze Economiche, Università di Bologna, Italy (rovelli@spbo.unibo.it).

Macroeconomic stability and the preferences of the Fed. A formal analysis, 1961-98.

Carlo A. Favero and Riccardo Rovelli [1]

1. Introduction

> "*The trade-off here, to a large extent, is the improvement implied in real productivity and standards of living from lower inflation against increased monetary policy flexibility*" (Alan Greenspan, in: Federal Reserve Bank of Kansas, 1996, p.47)

The rate of inflation in the US has declined from an average of 4.5% in the period 1960-79 to an average of 3.6% in 1980-98. Between those two periods, the standard deviations of inflation and the output gap have also declined, from $\sigma_\pi = 2.56\%$ and σ_y =2.57% in the first period to σ_π =2.24% and σ_y =2.12% in the second.[2] Analyses of US monetary policy generally acknowledge that a shift in policy emphasis occurred between 1979 and 1980. For instance, according to Goodfriend (1995, p.129) "the announcement [by Fed Chairman Paul Volcker] on 6 October 1979 of the switch to non-borrowed reserve targeting officially opened the period of disinflation policy"[3]. This date is generally assumed to be the beginning

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Carlo A. Favero is Professor of Economics, Università Bocconi, Milano, Italy (carlo.favero@uni-bocconi.it). Riccardo Rovelli is Professor of Economics, Dipartimento di Scienze Economiche, Università di Bologna, Italy (rovelli@spbo.unibo.it).

[2] These figures are computed from the data set used for the econometric analysis in Section 3. Inflation is the annual change in the GDP chain-weighted price index and the output gap is the difference between real GDP and potential GDP as computed by the Bureau of Economic Analysis of the US Department of Commerce.

[3] However that first attempt at gaining control over inflation was soon aborted and, following the inflation scare at the beginning of 1980, an aggressive disinflation policy was to be re-inaugurated only in August 1980 (Goodfriend, 1995, pp. 129-133).

of the new policy regime, which later continued under the Chairmanship of Alan Greenspan.

Empirical analyses of the Fed's reaction function confirm this discontinuity. In a recent paper, Clarida, Gali and Gertler (2000) present different estimates of forward-looking Taylor-type monetary policy rules[4] across various sub-samples. Their assessment of the evidence is that "the striking difference in the reaction function across time is the rise in the slope coefficient on inflation from slightly less than unity pre-Volcker to around two in the Volcker-Greenspan era" (p.164). They conclude that "in the pre-Volcker years the Fed typically raised nominal rates by less than any increase in expected inflation, thus letting real short-term rates decline as anticipated inflation rose. On the other hand, during the Volcker-Greenspan era the Fed raised real as well as nominal short-term interest rates in response to higher expected inflation. Thus, our results lend quantitative support to the view that the anti-inflationary stance of the Fed has been stronger in the past two decades"(p.177)[5]. While Taylor rules are an extremely useful tool for policy analysis, we also know that, as it has been shown in particular by Svensson (1996), a Taylor-type interest rate rule (IRR) may be formally derived by solving the intertemporal optimization problem of a central bank, for a suitable loss function. In this framework the coefficients of an IRR are (possibly complicated) convolutions of the parameters describing central bank preferences and of those determining the structure of the economy. Hence a problem of identification arises in all estimated IRR, and until we solve this problem we cannot unequivocally

[4] See Taylor (1993).

[5] This is not, of course, the only explanation for the high inflation of the pre-Volcker period. For instance, according to Orphanides (2000), the policy mistake of keeping US interest rates too low in the face of mounting inflationary expectations was 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. Finally, Clarida, Gali and Gertler (2000) discuss at length (but finally reject) the suggestion that inflation in the pre-Volcker era might have been causally linked to the oil shocks in the 1970s.

interpret a change in one of the estimated parameters as a modification of the preferences of the central bank, rather than a modification in 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; Dennis, 2001) have attempted to estimate the *deep* preference parameters.

The identification problem is likely to be quite relevant in practice. In fact, even if we assume that the structural specification of the aggregate demand and supply equations has been stable across time, the empirical observation of increased macroeconomic stability and lower inflation can be attributed to four possible factors: a shift in central bank targets and in their relative weights, a reduction in the variability of aggregate supply shocks and a more efficient conduct of monetary policy[6].

In this paper we propose a framework to identify central bank preferences, and we apply it to a formal analysis of the change in the preference function of the Fed from 1961-79 to 1980-98. The model employs a simple characterization of the US aggregate demand and supply (Rudebusch and Svensson, 1999). We estimate these two equations jointly with the first order conditions, which solve the intertemporal optimization problem faced by the Fed. The estimation of the models allows us to identify the relative roles of changes in central bank preferences, in the efficiency of monetary policy and in the structure of the economy as possible explanatory factors of the improved inflation performance and macroeconomic stability of the US economy.

The paper is organized as follows. In Section 2 we illustrate the problem of identifying central bank preferences in a simplified framework. In Section 3 we

[6]Cecchetti, Flores-Lagunes and Krause (2001) also focus on the last two factors, adopting a similar distinction: they identify the increased efficiency in monetary policy as a movement *toward* the output-inflation variability efficiency frontier, while the reduction in the variability of aggregate supply shocks is interpreted as a movement *of* the efficiency frontier.

discuss the specification and estimation of our three-equation model, and examine the results across two sub-samples. Section 4 concludes.

2. The identification of central bank preferences

We assume that central bank preferences may be described by the following intertemporal loss function:

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

and:

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

where: x_t is the output gap, π_t the inflation rate, i_t the policy instrument (a short-term interest rate), E_t defines expectations taken with respect to information available at time t, λ is the weight attached to output stabilization and μ to interest rate smoothing, π^* is the target level of inflation and δ the intertemporal discount factor. Equation (2.2) is a general characterization of policy objectives and preferences, consistent with the goals of monetary policy as they are laid out in the Federal Reserve Act: "[the Federal Reserve System and the Federal Open Market Committee should seek] *to promote effectively the goals of maximum employment, stable prices and moderate long-term interest rates...*"[7]. The term in the volatility of short-term rates can be rationalized by recalling the link between uncertainty in the policy rates and a higher term premium in long rates

[7] The notion of stable prices is indeed a vague one, although the Fed is on record for having supported the Neal Resolution, which would have required it to reduce inflation to the point where *"the expected rate of change of the general level of prices ceases to be a factor in individual and business decisionmaking"*. See Goodfriend (1995, p. 122). That Resolution, however, was not passed by Congress.

(See Favero and Mosca, 2001)[8]. Finally, note that the assumed specification also accommodates as special cases that of strict ($\lambda = \mu = 0$) and flexible inflation targeting ($\mu = 0$) (Svensson, 1997).

In general, a central bank would solve the above intertemporal optimization problem subject to the specification of aggregate demand and supply. To examine the identification problem discussed in the Introduction, however, it is sufficient to analyze the case of flexible inflation targeting, and to consider a stylized description of aggregate demand and supply:

$$x_{t+1} = c_1 x_t - c_2 \left(i_t - \pi_t \right) + u^d_{t+1} \tag{2.3}$$

$$\pi_{t+1} = \pi_t + c_3 x_t + u^s_{t+1} \tag{2.4}$$

where we assume that real activity responds to movements in the monetary policy instrument and that inflation responds to the output gap[9]. u^d and u^s are i.i.d. demand and supply shocks and all the parameters $\mathbf{c} = (c_1, c_2, c_3)$ are positive.

The intertemporal optimization problem is then to minimize 2.1-2.2 subject to the constraints (2.3) and (2.4) and to the restriction $\mu = 0$. As shown by Svensson

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

[9] This simple structure embodies the main features of well-known simple empirical models of the US economy, as in Christiano, Eichenbaum and Evans (1998) and Rudebusch and Svensson (1999). Apart from adding a more realistic lag structure, 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 the model without altering its fundamental structure.

(1997, p.1133), the Euler equation which solves this problem can be written in terms of a conventional Taylor rule:

$$i_t = \pi_t + B\left(\pi_t - \pi^*\right) + Cx_t \tag{2.5}$$

where: $B = \frac{1-\Gamma}{c_2 c_3}$; $C = \frac{1-\Gamma+c_1}{c_2}$; $0 \leq \Gamma = \frac{\lambda}{\lambda+\delta k(c_3)^2} < 1$ and $k = k(\lambda, \delta, c_3) \geq 1$.

It is clear that, even in this simple case, a single-equation approach to the estimation of the interest rate rule would not allow to identify the policy preferences parameters: π^*, δ, λ . More complicated models of the economy or more general specifications of the loss function (allowing for $\mu \geq 0$) would imply that more terms would be added to the optimal IRR and the estimated coefficients would become even more convoluted. Moreover, note that even if we assume $\lambda = 0$, i.e. no preference for output stabilization, the term in the output gap would still be included in the optimal IRR.

The example just presented is sufficient to illustrate the shortcomings of a single-equation approach to the estimation of Taylor rules. On the other hand, it may also suggest that the specification and estimation of an optimal Taylor rule, derived under the conditions of equations(2.2) (i.e. allowing for a preference for both output and interest-rate stabilization) and subject to a richer specification of the aggregate demand and supply equations, may become too complicated to be feasible or identifiable. In the Appendix we show how, under suitable and plausible assumptions, an estimable and identifiable IRR consistent with optimal monetary policy choices can be derived.

3. The policy preferences of the Fed

In this Section we apply the framework proposed above to identify the preference parameters of the Fed. In particular, we want to understand whether the decline in the level and variability of inflation in the Volcker-Greenspan period may be attributed to a change in the implicit inflation target assumed by the Fed, or also, and to what extent, to a change in the relative weights of inflation, output, and interest rate stabilization in the loss function(2.2), to an increased efficiency in the conduct of monetary policy, or to a change in the size and persistence of macroeconomic shocks, or in some other characteristic of the macro-transmission mechanism.

We estimate a three-equation model, obtained by minimizing the loss-function (2.2) under the assumption of a finite-time horizon, and subject to a general, distributed lag specification of the aggregate demand and supply, derived from the stylized specification proposed in equations (2.3)-(2.4). The full derivation of the model is discussed in the Appendix. By imposing appropriate restrictions on the structure of leads and lags, we obtain the following empirical specification:

$$\begin{aligned} x_t &= c_1 + c_2 x_{t-1} + c_3 x_{t-2} + c_4 \left(i_{t-2} - \bar{\pi}_{t-2}\right) + \\ &\quad + c_5 \left(i_{t-3} - \bar{\pi}_{t-3}\right) + u_t^d \end{aligned} \tag{3.1}$$

$$\begin{aligned} \pi_t &= c_6 \pi_{t-1} + c_7 \pi_{t-2} + c_8 x_{t-1} + \\ &\quad + c_9 \Delta_4 lpcm_{t-1} + u_t^s \end{aligned} \tag{3.2}$$

$$\begin{aligned} 0 &= \mu \left(i_t - i_{t-1}\right) - \mu\delta E_{t-1}\left(i_{t+1} - i_t\right) \\ &\quad + \delta^3 E_{t-1}\left[c_8 c_4 \left(\pi_{t+3} - \pi^*\right) + \delta\left(c_6 c_8 c_4 + c_8\left(c_5 + c_2 c_4\right)\right)\left(\pi_{t+4} - \pi^*\right)\right] \\ &\quad + \lambda\delta^2 E_{t-1}\left[c_4 x_{t+2} + \delta\left(c_5 + c_2 c_4\right) x_{t+3} + \delta^2\left(c_2\left(c_5 + c_2 c_4\right) + c_3 c_4\right) x_{t+4}\right] \\ &\quad + u_t^m \end{aligned} \tag{3.3}$$

where: x_t is the relative gap between actual and potential GDP in percentage points , π_t is annual inflation $(100 * (\ln p_t - \ln p_{t-4}))$ in the GDP chain-weighted price index[10], the real rate of interest, $i_t - \bar{\pi}$, is defined by subtracting to the

[10] Source: U.S. Department of Commerce, Bureau of Economic Analysis. Available from

nominal rate[11] the average annualized quarterly inflation over the previous four quarters[12]. $\Delta_4 lcpm_t$ is the IMF commodity price index (annual growth rate, percentage points).

As a natural way to estimate the model, we implement GMM on the first order conditions (3.3), choosing as instruments for expected inflation those variables which are consistent with the dynamic specification of equations (3.1)-(3.2). We tested the strong exogeneity of the commodity price index for the estimation of the parameters of interest and could not reject it. The model has been estimated for the two sub-samples 1961:1-1979:3 and 1980:3-1998:3. We report estimates of the relevant parameters in Table 1.

The sign and size of the parameters in the backward-looking demand and supply block are consistent with the results reported by Rudebusch and Svensson (1999). We observe that the inclusion of the commodity price index as a leading indicator for inflation, as suggested by the VAR literature on the monetary transmission mechanism (see, for example, Christiano, Eichenbaum and Evans, 1998), induces only small modifications in the estimated parameters of the supply equation. It is apparent from the reported estimates that changes in the structure of the economy were not very pronounced between the two sub-samples, as the estimated parameters in the demand and supply block are very similar in size and significance. However, we also note that macroeconomic conditions have been more favorable in the second sub-period, as the standard deviation of the supply shocks is approximately 73% of that in the first period.

Turning our attention to the preference parameters, we have restricted the discount factor to $\delta = 0.975$, as the unrestricted estimate is very imprecise. This

FRED (http://www.stls.frb.org/fred/data/gdp.html).

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

[12] This specification of the real rate follows that in Rudebusch and Svensson (1999).

seems a plausible assumption, and also allows a meaningful interpretation of the remaining preference parameters, without affecting the overall fit of the model. The weights on interest rate smoothing and on output stabilization (having normalized at unity the weight on inflation) are small but clearly significant in both sub-periods. The parameter on interest rate smoothing, μ, increases from 0.0051 to 0.0085; while λ decreases from 0.00153 to 0.00125 . The most relevant change in preferences occurs in π^*, the implicit inflation target, which falls from 5.8% to 2.6%. This is mirrored in an estimate of the implicit equilibrium real interest rate, which increases from 1.9% to 3.7%.

While the estimated values of λ and μ are very small, it would not be correct to assume that they are irrelevant. In particular, if $\mu = 0$, the Fed would have used interest rates much more actively, in order to reach its goals. This is clearly illustrated in Figure 1, where we compare the observed policy rates during 1982-98 with the optimal policy rates generated within our model, and with the optimal policy rates *conditional* on setting either λ or μ to zero. The results clearly show that an implausibly large volatility of interest rates would have emerged in the case of $\mu = 0$, whereas the implications of setting $\lambda = 0$ do not appear equally dramatic.

Finally, we evaluate the improvements in the efficiency of monetary policy by comparing over time the volatility of actual interest rates around their estimated optimal path. Volatility is measured by the standard deviation of the estimated residuals of the Euler equation (i.e., the interest rate-setting regression). This has decreased by 20%, from 0.0110 to 0.0088, between the two samples[13]. We thus conclude that also the conduct of monetary policy has indeed become more efficient in the Volcker-Greenspan period.

[13] See the last row of Table 1.

4. Conclusions

In this paper we developed an approach to the identification of 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" preference parameters with those describing the structure of the economy, it is not possible to identify the former 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 aggregate demand and supply equations together with the forward-looking, first order conditions for the solution of the optimization problem. The "deep" preference parameters are identified and estimated after imposing the cross-equation restrictions implied by optimization.

We used our approach to evaluate to what extent the improved performance of the US economy in terms of inflation, its volatility and the volatility of the output gap could be attributed to a shift in central bank preferences, to an increase in the efficiency of monetary policy or to a more favorable economic environment. Our results indicate that the policy preferences of the Fed, and in particular the implicit inflation target, have changed drastically with the advent of the Volcker-Greenspan era. To a large extent, this was to be expected, and confirms the earlier results of Clarida, Gali and Gertler (CGG, 2000), who had found that "the Federal Reserve [had been] highly 'accommodative' in the pre-Volcker years" (*id.*, p.148). However, CGG attribute the improved inflation performance essentially to the more "proactive stance" against inflation, which had been adopted by Volcker and Greenspan. In their view, the most relevant change has been the *atti-*

tude towards inflation, rather than the inflation target itself. Their point estimate of the target declines only from 3.58% (in the period 60:1-79:2) to 3.16% (82:4-96:4[14]), a change which they consider economically not significant. On the other hand, our estimates point to a more dramatic change in the inflation target, from 5.79% (61:1-79:2) to 2.63% (80:3-98:3), whereas the change in the relative preference for output stabilization declines only marginally, from 0.00153 to 0.00125, i.e. by 18%[15].

However we may intepret them, changes in policy preferences are not sufficient to tell the whole story, according to our results. Two additional factors contribute to explain the improved macroeconomic performance of the second period, relatively to the first one: the standard deviation of supply shocks has been reduced after 1980 to approximately 73% of that in the first period, and also the efficiency of monetary policy - that is, the extent to which observed policy rates have been close to the estimated optimal path - has increased by 20%.[16]

[14] To reduce the differences due to the different sample size and model specification, we quote the estimates obtained by CGG for the periods which they indicate respectively as *Pre-Volcker* and *Post-1982.* Also, we refer to their estimates computed with an inflation forecasting horizon of 4 quarters ahead (see their Tables IV and V respectively), which is close to the horizon suggested by our structural estimates.

[15] A decrease in the preference for output stabilization, λ, increases the degree of "proactiveness" of the Fed (β, in the terminology of CGG, which is analogous to the coefficient B in equation (2.5) in our paper). Although the two sets of estimates are strictly not comparable, to mirror the 3.5 times increase in β computed by CGG (from 0.86 to 3.13), our estimate of λ would have to decrease by more than 50%.

[16] See footnote 13. In a similar vein, Cecchetti, Flores-Lagunes and Krause (2001) observe, albeit in the context of a somewhat different identifying framework, that also in the course of the Volcker-Greenspan period (i.e., comparing 82-89 to 90-97) the macroeconomic performance of the US economy has continued to improve. They attribute this improvement in almost equal parts to the reduced variance of supply shocks and to the increased policy efficiency (see Table 2 in their paper).

5. Appendix: From theory to the empirical model

We derived our empirical model starting from the assumption that central bank preferences are described by the following intertemporal loss function:

$$E_t \sum_{i=0}^{\tau} \delta^i L_{t+i} \tag{5.1}$$

where the loss function L is specified as in Equation (2.2). The assumption of a finite horizon in the optimal problem, while arbitrary, is preferable to the maintained assumption of an infinite horizon. In fact, while apparently more elegant, the infinite horizon model in fact resorts to a backward-looking empirical specification, as implemented recently by Dennis (2001). Thus the forward-looking characteristic of monetary policy would be lost. Moreover, as we show below, the weight of the variables in the forward-looking equation (in the case of a finite horizon) naturally declines as the time-lead increases (this is true even if the discount factor is unity), implying that more distant expected variables carry less information for current policy decisions. Hence a natural cutting point for the future horizon would emerge in any case. We thus assumed that the monetary policy maker minimizes (5.1) and (2.2), subject to the constraints given by the relevant aggregate demand and supply equations. Allowing for a more general lag structure than the one embodied in equations (2.3) and (2.4), and also adopting the backward-looking specification for the IS curve employed by Rudebusch and Svensson (1999), we may write the complete model as:

$$\begin{aligned} x_{t+j} &= C_1(L)\, x_{t+j-1} - C_2(L)\left(i_{t+j-1} - \pi_{t+j-1} - \bar{r}\right) \qquad (5.2)\\ &\quad + u^d_{t+j} \\ \pi_{t+j} &= C_3(L)\, \pi_{t+j-1} + C_4(L)\, x_{t+j-1} + C_5(L)\, w_{t+j} \qquad (5.3) \end{aligned}$$

$$
\begin{aligned}
& +u^s_{t+j} \\
E_t f\left(i_{t+i+j}, \pi_{t+i+j}, x_{t+i+j}\right) &= 0 \qquad (5.4) \\
f\left(i_{t+i+j}, \pi_{t+i+j}, x_{t+i+j}\right) &= \sum_{i=0}^{\tau} \delta^i E_t \left(\pi_{t+i+j} - \pi^*\right) \frac{\partial \pi_{t+i+j}}{\partial i_{t+j}} + \\
&+ \sum_{i=0}^{\tau} \delta^i \lambda E_t x_{t+i+j} \frac{\partial x_{t+i+j}}{\partial i_{t+j}} + \\
&+ \mu \left(i_{t+j} - i_{t+j-1}\right) - \mu \delta E_t \left(i_{t+j+1} - i_{t+j}\right) + u^m_{t+j}
\end{aligned}
$$

Note that the interaction between the structure of the economy and the policy reaction function would generate an identification problem, which we solved by assuming the absence of a contemporaneous feedback between the macroeconomic variables and monetary policy, i.e. by ruling out the effect of contemporaneous monetary policy in the aggregate demand equation. This restriction is empirically plausible and is now often adopted in VAR models of the monetary transmission mechanism[17].

As (5.4) 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.

Empirical estimation of the model requires truncation of the relevant lag and leads. On the basis of optimal lag selection criteria we chose four lags for the backward looking block. We then selected four leads for the forward looking block. We checked the robustness of this choice by extending the horizon by one period, and testing if the additional variables involved in the Euler equation attract significant coefficients. We did so by setting $\tau = 5$ and found support for the choice $\tau = 4$. Notice that the choice of a finite horizon is also consistent with the description of the policy process presented in the "Greenbook", which publishes (with a five-year delay) real-time Fed forecasts for inflation and unemployment up to four quarters

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

ahead. Also note that the stationarity of the system implies that the weight of future variables declines with the horizon, even in the case $\delta = 1$. This result is reinforced if $\delta < 1$.

We then selected the best fitting empirical model by omitting non-significant lags and leads from the general model. The resulting model, written for j=1, has the following specification:

$$
\begin{aligned}
x_{t+1} &= c_1 + c_2 x_t + c_3 x_{t-1} + c_4 \left(i_{t-1} - \bar{\pi}_{t-1}\right) + \\
&\quad + c_5 \left(i_{t-2} - \bar{\pi}_{t-2}\right) + u_{t+1}^d && (5.5) \\
\pi_{t+1} &= c_6 \pi_t + c_7 \pi_{t-1} + c_8 x_t + \\
&\quad + c_9 \Delta_4 lpcm_t + u_{t+1}^s && (5.6) \\
E_t f\left(i_{t+i+1}, \pi_{t+i+1}, x_{t+i+1}\right) &= 0 && (5.7) \\
f\left(i_{t+i+1}, \pi_{t+i+1}, x_{t+i+1}\right) &= i_t - c_{10} - c_{11} i_{t+1} - c_{12} i_{t+2} - \sum_{i=1}^{4} c_{12+i} \pi_{t+i} \\
&\quad - \sum_{i=1}^{4} c_{16+i} x_{t+i} + u_{t+1}^m
\end{aligned}
$$

Given the specification of the unrestricted model we proceeded to identify the structural parameters of interest by imposing the cross-equation restrictions on the Euler equation:

$$
\begin{aligned}
&\lambda \delta^2 E_t x_{t+3} \frac{\partial x_{t+3}}{\partial i_{t+1}} + \delta^3 \lambda E_t x_{t+4} \left(\frac{\partial x_{t+4}}{\partial i_{t+1}}\right) + \delta^4 \lambda E_t x_{t+5} \left(\frac{\partial x_{t+5}}{\partial i_{t+1}}\right) \qquad (5.8) \\
&+ \delta^3 E_t \left(\pi_{t+4} - \pi^*\right) \left(\frac{\partial \pi_{t+4}}{\partial i_{t+1}}\right) + \delta^4 E_t \left(\pi_{t+5} - \pi^*\right) \left(\frac{\partial \pi_{t+5}}{\partial i_{t+1}}\right) \\
&+ \mu E_t \left(i_{t+1} - i_t\right) - \mu \delta E_t \left(i_{t+2} - i_{t+1}\right) \\
= \; & 0
\end{aligned}
$$

We rearranged (5.8) and substituted derivatives with coefficients from (5.5) and (5.6) to obtain:

$$\begin{aligned} 0 &= \mu E_t \left(i_{t+1} - i_t\right) - \mu\delta E_t \left(i_{t+2} - i_{t+1}\right) \\ &\quad +\delta^3 E_t \left[c_8 c_4 \left(\pi_{t+4} - \pi^*\right) + \delta \left(c_6 c_8 c_4 + c_8 \left(c_5 + c_2 c_4\right)\right) \left(\pi_{t+5} - \pi^*\right)\right] \\ &\quad +\lambda\delta^2 E_t \left[c_4 x_{t+3} + \delta \left(c_5 + c_2 c_4\right) x_{t+4} + \delta^2 \left(c_2 \left(c_5 + c_2 c_4\right) + c_3 c_4\right) x_{t+5}\right] \end{aligned} \tag{5.9}$$

Joint estimation of equations (5.5) and (5.6) together with (5.9) allows the identification of the parameters δ, λ, μ and π^*, which fully describe the preferences of the central bank. The system has been 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. Results of the estimation are presented in Section 3 and Table 1.

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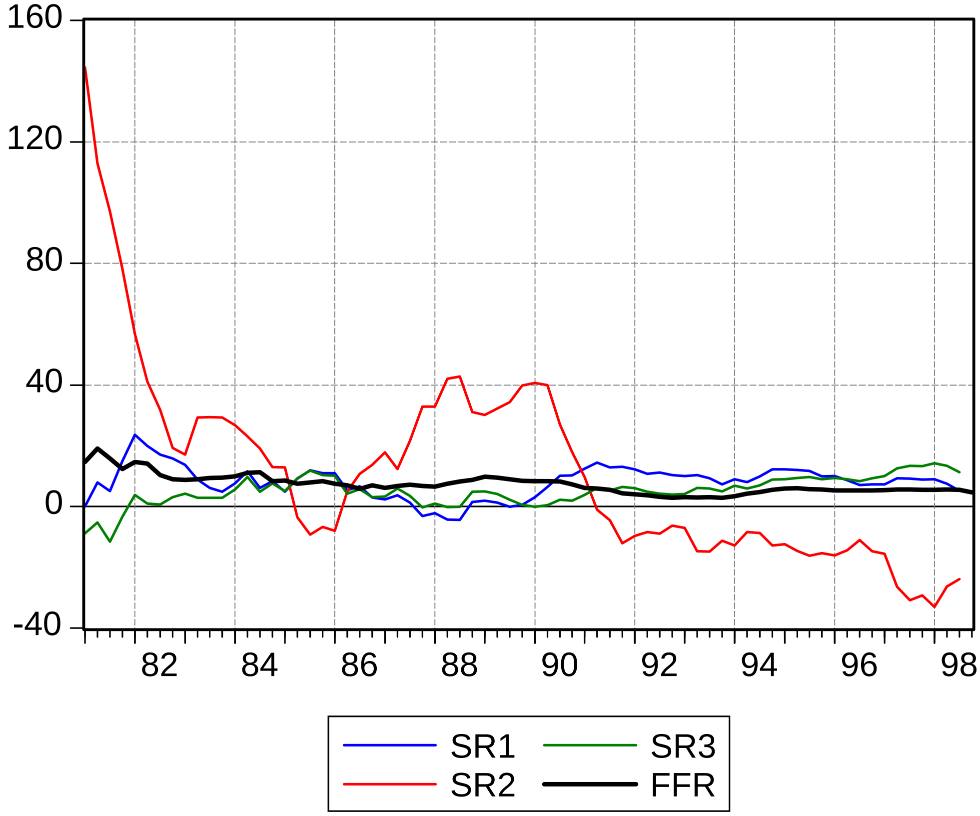
Table 1: **Structural and preference parameters (Eqs. 3.1. 3.2, 3.3)**						
$x_t = c_1 + c_2 x_{t-1} + c_3 x_{t-2} + c_4 (i_{t-2} - \bar{\pi}_{t-2}) + c_5 (i_{t-3} - \bar{\pi}_{t-3}) + u_t^d$ $\pi_t = c_6 \pi_{t-1} + (1 - c_6) \pi_{t-2} + c_8 x_{t-1} + c_9 \Delta_4 lpcm_{t-1} + u_t^s$ $0 = \mu (i_t - i_{t-1}) - \mu\delta E_{t-1} (i_t - i_{t+1}) +$ $+\delta^3 E_{t-1} [c_8 c_4 (\pi_{t+3} - \pi^*) + \delta (c_6 c_8 c_4 + c_8 (c_5 + c_2 c_4)) (\pi_{t+4} - \pi^*)]$ $+\lambda\delta^2 E_{t-1} \left[c_4 x_{t+2} + \delta (c_5 + c_2 c_4) x_{t+3} + \delta^2 (c_2 (c_5 + c_2 c_4) + c_3 c_4) x_{t+4}\right]$ $+u_t^m$						
	1961:1-1979:2			1980:3-1998:3		
	Coeff	**S. E.**	**t-ratio**	**Coeff**	**S. E.**	**t-ratio**
c_1	0.279	0.03	9.34	0.282	0.04	7.04
c_2	1.113	0.04	30.95	1.353	0.02	65.63
c_3	-0.158	0.03	-4.70	-0.411	0.02	-16.70
c_4	-0.108	0.01	-8.40	-0.187	0.05	-39.33
c_5	-0.038	0.02	-1.88	0.111	0.01	12.15
c_6	1.371	0.03	41.88	1.33	0.01	93.28
c_8	0.033	0.004	8.19	0.040	0.001	26.92
c_9	0.011	0.001	12.20	0.009	0.001	12.19
δ	0.975	-	-	0.975	-	-
π^*	5.795	0.07	86.44	2.628	0.06	46.79
λ	0.00153	0.0003	4.92	0.00125	0.0002	6.82
μ	0.0051	0.0006	7.95	0.0085	0.0006	14.42
$(i - \bar{\pi}) = \frac{-c_1}{c_4 + c_5} = 1.92$				$(i - \bar{\pi}) = \frac{-c_1}{c_4 + c_5} = 3.71$		
$\sigma\left(u^d\right) = 0.913$				$\sigma\left(u^d\right) = 0.587$		
$\sigma(u^s) = 0.360$				$\sigma(u^s) = 0.261$		
$\sigma(u^m) = 0.011$				$\sigma(u^m) = 0.0088$		

FIGURE 1: **The effects of alternative policy preferences on the path of interest rates, 1982-98**



FFR: 3 months Federal Funds Rate (see footnote 11). SR1: Simulated interest rates from the estimated model (Table 1). SR2: Simulated rates allowing only for output smoothing ($\lambda = 0.00125; \mu = 0.0$). SR3: Simulated rates allowing only for interest rate smoothing ($\lambda = 0.0; \mu = 0.0085$).