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What Does Monetary Policy Reveal about Central Bank's Preferences?

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SUMMARY

The design of monetary policy depends upon the targeting strategy adopted by the central bank. This strategy describes a set of policy preferences, which are actually the structural parameters to analyse monetary policy making. Accordingly, we develop a novel calibration method to identify central bank's preferences from the estimates of an optimal Taylor-type rule. The empirical analysis on US data shows that output stabilization has not been an independent argument in the Fed's objective function during the Greenspan era. This suggests that the output gap has entered the policy rule only as leading indicator for future inflation, therefore being only instrumental (to stabilize inflation) rather than important per se.

Keywords: Central bank's preferences, calibration, inflation targeting, optimal monetary policy

JEL: C61, E52, E58

CONTENTS

1 Introduction

A burgeoning empirical literature has established interest rate rules as a convenient representation of central bank's behaviour. Since the influential paper of John Taylor (1993) numerous specifications of the policy rule have been proposed to describe the response of monetary authorities to the developments in the economy. The main focus has been the evaluation of monetary policy as well as the identification of policy regime shifts from the estimates of alternative Taylor-type reaction functions[1].

From a theoretical point of view, interest rate rules have been modeled as the solution of a constrained optimization problem in which policy makers pursue in a quadratic fashion the stabilization of several goal variables around the relative targets. According to this modeling, the estimated policy rule coefficients can only be interpreted as convolutions of the parameters describing central bank's preferences (i.e. the coefficients in the objective function) and the parameters framing the structure of the economy (i.e. the coefficients in the constraints). It follows that those are reduced form estimates and therefore they cannot be used to analyze the structural features of policy making that characterize a monetary regime.

In contrast, the preference parameters in the central bank's objective function capture those structural features and they are worthy to identify for three main reasons. First, to improve our understanding of policy actions because any decision can be more easily interpreted once the scope is identified. Second, to assess the performance of monetary policy by establishing if the policy outcome is the pursued result of targeted policies rather than the random payoff of favorable macroeconomic conditions. Third, to carry out policy evaluations from the comparison between optimal and observed interest rates, since a sample-specific optimal rule can only be derived once the preference parameters are estimated over that sample.

Accordingly, we develop a novel calibration method to extract central bank's preferences from the estimates of the reaction function that solves the policy makers' optimization problem. In particular, we select among a fairly wide class of alternative targeting policies the set of preference parameters that makes the associated optimal simulated path of policy rate closest to the estimated one. We apply our identification method to US data

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[1] These include Bernanke and Mihov (1998), and Bagliano and Favero (1998) who specify the policy rule as a part of monetary policy vector autoregressions; Judd and Rudebusch (1998), and Clarida, Galì and Gertler (2000) that formulate a simple ad-hoc reaction function; and Rudebusch (2001a), and Muscatelli, Tirelli and Trecroci (2000) who model an optimal state-contingent feedback rule, among many others.

in order to identify the policy preferences of the Federal Reserve during the Greenspan's chairmanship. The empirical analysis shows that the stabilization of output over the cycle has not been a final concern of monetary authorities, although the Fed has set policy rates in response to both inflation and output gap. This implies that any deviation of output from its potential value has been regarded as a *leading indicator* for future inflation, thus being only instrumental to stabilize inflation rather than important *per sè*.

Our work is closely related to several recent studies. Favero and Rovelli (2001) identify central bank's preferences by estimating via GMM the Euler equations for the solution of alternative specifications of the optimization problem. Cecchetti and Ehrmann (2001) capture the dynamics of the economy in a VAR framework and then recover policy makers' preferences from the estimates of the output-inflation variability and those obtained via VAR. Dennis (2001) uses FIML to jointly estimate the policy preferences in the central bank's objective function and the behavioral parameters in the constraints of the economy. While our purpose stands by those of previous studies, we take from them two important departures. First, we use a different sample, which is restricted to a single administration on the reasoning that policy preferences are Chairman-specific. Second, we employ a different identification method as we calibrate rather than estimate those idiosyincratic preferences.

The paper is organized as follows. Section 2 sets up the model and solves the optimization problem relevant to the central bank. Section 3 discusses in details the calibration method, which is applied in section 4 to identify the Fed policy preferences during the Greenspan's tenure. Section 5 concludes, while the appendix provides a guideline to solve numerically the optimal control problem.

2 The model

The central bank faces a dynamic optimal control problem whose solution describes its policy actions. These are the optimal response of monetary authorities to the evolution of the economy as captured by the relationships among the state variables. We describe such a dynamics by means of a simple closed economy-two equation framework made up of an aggregate supply and an aggregate demand, which actually represent the constraints of the policy makers' optimization problem.

2.1 The structure of the economy

The empirical evidence from VAR studies shows that monetary policy affects the economy at different lags (see Christiano, Eichenbaum and Evans, 1996, and Bernanke and Mihov, 1998). Furthermore, if the central bank faces an intertemporal optimization problem, then forecasting the behaviour of the state variables (i.e. inflation and output gap) becomes crucial to set policy rates as the optimal response to the developments in the economy. It follows that for the purpose of monetary policy making, which relies on forecasting method, a backward-looking model is likely to be prefered to a forward-looking one since the former overperforms the latter in fitting the data (see Fuhrer, 1997).

Accordingly, we let the structure of the economy evolve as follows:

$$\pi_{t+1} = \alpha_1 \pi_t + \alpha_2 \pi_{t-1} + \alpha_3 \pi_{t-2} + \alpha_4 \pi_{t-3} + \alpha_5 y_t + \varepsilon_{t+1} \tag{1}$$

$$y_{t+1} = \beta_1 y_t + \beta_2 y_{t-1} + \beta_3 \left(\bar{\imath}_t - \bar{\pi}_t - \bar{r} \right) + u_{t+1} \tag{2}$$

where π_t is the quarterly inflation in the GDP chain-weighted price index, p_t, calculated at annual rate, that is $4\left(p_t - p_{t-1}\right)$, and $\bar{\pi}_t$ is four-quarter inflation constructed as $\frac{1}{4}\sum\limits_{j=0}^{3}\pi_{t-j}$. The quarterly average federal funds rate, i_t, is expressed in percent per year whereas the four quarter average federal funds rate, $\bar{\imath}_t$, is computed as $\frac{1}{4}\sum\limits_{j=0}^{3} i_{t-j}$. The constant $\bar{r}$ stands for the average real interest rates, and ε_t and u_t are supply and demand iid shocks respectively. All variables but the funds rate are in logs and rescaled upward on a 100 point basis such that the output gap, say, is $y_t = 100 * \left(\log\left(Q_t\right) - \log\left(Q_t^*\right)\right)$ where Q_t and Q_t^* are respectively actual and potential GDP, both in levels. All variables are demeaned, therefore no constants appear in the equations and $\bar{r}$ is set equal to zero.

On the one hand, the aggregate supply equation in (1), AS henceforth, captures the inflation dynamics by relating inflation to its lagged values and to current and lagged output gaps. On the other hand, the aggregate demand equation in (2), AD henceforth, explicitly models the monetary transmission mechanism by relating output gap to its lagged values and most importantly to past real interest rate (see Rudebusch and Svensson, 1999 and 2001).

This empirical model of inflation and output, although parsimonious, embodies the minimal set of variables one may want to include for the analysis of monetary policy (see, for instance, Christiano, Eichenbaum and Evans, 1998), and, as argued in Rudebusch and Svensson (1999), it appears to be broadly in line with the view that policy makers hold about the dynamics of the economy (see the report of the Bank for International Settlements for 11 central bank models, 1995). Moreover, monetary policy affects (through the instrument i_t) aggregate demand with one lag and aggregate supply with two lags, in the spirit of the specifications in Ball (1999) and Svensson (1997). Finally, such a dynamics can be interpreted either as structural relations, as we do, or as a reduced-form restricted VAR with impulse responses that are consistent with those of the FRB-US model.

2.2 The loss function and the optimal monetary policy

We assume that monetary authorities operate by following a *targeting rule* as defined in Svensson (1999a), and Rudebusch and Svensson (1999)[2]. Thus, they use all available information to bring at each point in time the target variables in line with their targets by penalizing any future deviation of the former from the latter. This type of rule seems to be closer than an *instrument rule,* which is a prescribed rule coming from an 'once and for all' decision making (see McCallum, 1999), to the actual practice of policy makers since it embodies some degree of commitment (to a loss function) and some degree of discretion (through a state-contingent rule). Following Rudebusch and Svensson (1999 and 2001), we let the central bank pursue the stabilization of the four-quarter inflation around the inflation target, the stabilization of the output around its potential value and the smoothing of interest rate. The inflation target is assumed to be constant over time and it is normalized to zero because all variables are demeaned[3]. Then, policy rates are set to minimize the following objective function:

$$\lambda_\pi Var\left[\overline{\pi}_t\right] + \lambda_y Var\left[y_t\right] + \lambda_{\Delta i} Var\left[\Delta i_t\right] \qquad (3)$$

The quarterly average short-term interest rate, i_t, is regarded as the instrument under policy makers' control whereas Δi_t represents its first difference. The parameters λ_π and λ_y are the focus of our analysis and unlike in Rudebusch and Svensson (2001), who set them exogenously, they are determined within the model by means of our identification method. They represent the (potentially time-variant) central bank's policy preferences towards inflation and output stabilization respectively. We constrain both parameters to be non negative meaning that the central bank values any deviation of either inflation

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[2] Accordingly, we label 'target variables' the variables in the objective function (and not those in the reaction function). Our terminology lines up with the one in Walsh (1998, Ch. 8), Clarida, Galì and Getler (1999), Rudebusch and Svensson (1999), and Svensson (1999c).

[3] Our analysis is meant to identify the central bank's preferences over the target variables rather than to estimate the targets per sè. A number of papers cover the issue, including Judd and Rudebusch (1998), Sack (2000), Favero and Rovelli (2001) and Dennis (2001).

or output from the target as a *bad*. Finally, we normalize the weights in the objective function to sum to one and in accordance to Rudebusch and Svensson (1999 and 2001) we assume $\lambda_{\Delta i} = 0.2$.

The specification in (3) is empirically attractive since, unlike alternative monetary models as the FRB-US, it is able to predict an interest rate path that exhibits the kind of smoothness observed in the data. (see Clarida, Galì and Gertler, 2000, and Muscatelli, Tirelli and Trecroci, 2000)[4]. A rationale for why interest rate behaviour displays policy inertia is beyond the scope of this paper, although several explanations are provided in the literature[5].

The optimal control problem described in (1)-(3) falls in the class of dynamic programming problems characterized by a quadratic objective function and a linear law of motion. This specification leads to the *stochastic optimal linear regulator problem* according to which the decision rule for interest rates is a linear function of the state variable vector

$$X_t^{'} = \left[\begin{array}{ccccccccc} \pi_t & \pi_{t-1} & \pi_{t-2} & \pi_{t-3} & y_t & y_{t-1} & i_{t-1} & i_{t-2} & i_{t-3} \end{array} \right] \qquad (4)$$

In particular, the central bank minimizes the loss (3) subject to the dynamic constraints (1) and (2). In so doing, it determines an optimal reaction function that can be expressed in the compact form[6]:

$$i_t = f X_t \qquad (5)$$

The coefficients in the vector f represent some convolution of the central bank's preferences, λs, and the behavioral parameters of the economy, αs and βs, such that for any given distribution of weights in (3) there exists a different optimal f in (5).

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[4] Goodfriend (1987), Walsh (1998, Ch. 10), Miskin (1999), Svensson (1999b) and Woodford (2001) interestingly discuss why interest rate smoothing may be an explicit objective into policy makers' preferences. Alternatively, the observed policy inertia can be rationalized either by imposing some form of partial adjustment of actual interest rates towards the equilibrium value or by introducing strong serial correlation and long lags in monetary policy effects throught the economic dynamics. However, to remain consistent with other empirical studies, we take the first view and we let interest rate smoothing enter the central bank's objective function.

[5] These include, *inter alia*, persistence in the structure of the economy (Sack, 2000 and Rudebusch, 2001a), serially correlated shocks rule (Rudebusch, 2001b), commitment of the authorities which want to have a quick and strong impact on the economy by simply reverting the direction of policy rate changes (Woodford, 1999), fear of disruption of financial markets (Goodfriend, 1991), and concern of policy makers about potential misspecifications of the macroeconomic dynamics (Castelnuovo and Surico, 2001).

[6] The appendix provides a full derivation of the feedback rule that solves the stochastic optimal linear regulator problem.

3 Identifying central bank's preferences

Once defined the object of our analysis, we have to search for a strategy to move from the reduced form parameters in the policy rule to the structural ones in the objective function. In this section we propose a calibration method to extract the policy preferences, λs, from the vector of feedback coefficients, f.

We estimate the reaction function in (5) and we solve numerically the stochastic optimal linear regulator problem for alternative targeting policies (i.e. for alternative distribution of weights λs in the loss function). Among those, we select the pair $[\lambda_\pi,\ \lambda_y]$ that makes the associated optimal interest rate path closest to the fitted path, which comes from the estimation of the optimal state-contingent rule derived in (5). In so doing, *de facto* we are calibrating the central bank's preferences relevant for the period under analysis. Notice that by defining our measure of distance upon the *fitted* rather than the *actual* rate we are restricting our attention to the systematic component of policy rate behaviour, that is, to the component that we can explain within an optimal control framework.

Our calibration strategy can be seized in five steps:

i) *constraint estimates*: we estimate the AD-AS system as specified in (1) and (2). The estimates roughly summarize the structure of the economy over a given sample and they will enter the recursive formulation of our simulated economy.

ii) *reaction function estimates*: we estimate the reduced form reaction function derived in (5) and we call $\hat{\imath}_t = \hat{f} X_t$ the fitted value of policy rate at time t, where $\hat{f}$ is the vector of feedback coefficient estimates.

iii) *optimal control problem solution*: since a variation of the set of policy makers' preferences $[\lambda_\pi,\ \lambda_y]$ implies a modification of the feedback coefficients in the optimal rule, we solve the stochastic optimal linear regulator problem for many different targeting policies. In other words, we compute numerically as many vectors of optimal feedback coefficients f in (5) as the number of possible permutations of the λs over the range $[0, 1 - \lambda_{\Delta i}]$, where steps are one percent point basis.

iv) *implied optimal interest rate path*: we first substitute, period by period, the actual values of the state variables into the derived rules, and then we compute for each optimal f the interest rate path implied by the relative control problem. We define it as $i_t = f\left(\lambda_\pi, \lambda_y\right) X_t$ to stress that any optimal path depends upon the specification of a set of central bank's preferences.

v) *policy preference calibration*: finally, we select the set of policy preferences capable to deliver the minimum distance between fitted and optimal interest rate according to a canonical measure of the type proposed in Sack(2000), and Cecchetti, McConnell and Perez-Quiros (1999):

$$\sum_t \left[i_t\left(\lambda_\pi, \lambda_y\right) - \hat{i}_t\right]^2 \tag{6}$$

With this identification strategy at hand, we can evaluate the monetary policy making over a specific sample. This is the focus of the next section.

4 The conduct of monetary policy in the US

In this section we apply our identification method to US data. Our goal is to identify the Federal Reserve policy preferences over a given period and to establish the sensitivity of these results to robustness and stability analyses. A natural time-break candidate for sample selection is the appointment of Paul Volker in the October 1979 since it has represented the watershed for the US economy from an high to a low inflation era. However, with a backward looking model, the selection of a long time-horizon may undermine the stability of the behavioral parameters, which is an important condition for drawing inference and surviving the Lucas critique (1976). This consideration motivates our focus on a single tenure, namely the one of Alan Greenspan. Indeed, one may argue that this period has been characterized not only by an increasing macroeconomic stability and a lower inflation but also by the expectations of some form of inflation targeting, thereby being particularly suited for our kind of analysis.

4.1 A small empirical model of the US economy

We capture the dynamics of the US economy from 1987:3 to 2001:1 by applying OLS method to the AD-AS system described in (1) and (2). The potential output is obtained from the Congressional Budget Office whereas all other data are taken from the web-site of the Federal Reserve Bank of St. Louis. In particular, we collect monthly time-series for the Fed funds rate, quarterly data for the GDP chain-weighted 1996 commodity price index and quarterly data for the potential output. All series are seasonally adjusted. We then convert monthly data in quarterly data by taking end-of-quarter observations. Lastly, we de-mean all variables.

The estimates are as follows, standard errors in parenthesis:

$$\pi_{t+1} = \underset{(0.133)}{0.282}\pi_t - \underset{(0.134)}{0.025}\pi_{t-1} + \underset{(0.134)}{0.292}\pi_{t-2} + \underset{(0.136)}{0.385}\pi_{t-3} + \underset{(0.054)}{0.141}y_t + \hat{\varepsilon}_{t+1} \qquad (7)$$

$$y_{t+1} = \underset{(0.136)}{1.229}y_t - \underset{(0.149)}{0.244}y_{t-1} - \underset{(0.078)}{0.073}\left(\bar{\imath}_t - \bar{\pi}_t\right) + \hat{u}_{t+1} \qquad (8)$$

The system displays a reasonably good empirical fit with an Adjusted R^2 equal to 0.58 for the AS and 0.93 for the AD[7]. All estimates have the expected sign but the second lag of inflation in the AS, although it has not explanatory power. Furthermore, the coefficient for the real interest rate is not statistically significant. While undesirable, this result confirms the evidence from several studies for the US and the UK over recent samples (see for instance Neiss and Nelson, 2001). Finally, although these estimates suggest a minor initial role for monetary policy, the impact of the lagged values of the output gap in the AD is large implying that the response of aggregate demand to policy rates is much greater in the long-run.

Given the backward-looking nature of the problem, the derivation of the optimal policy rule in (5) relies on the assumption that the structure of the economy is invariant to monetary policy, and therefore it is subject to the Lucas critique (1976). However, we show below not only that the policy preference parameters are stable over the sample but also that the associated optimal path of interest rates displays substantial policy inertia and limited deviations from the estimated one. It follows that one may reasonably expect the behavioral parameters to be stable as well, thereby reducing the significance of the Lucas critique[8].

Notice the timing assumption in our model. At the beginning of each period t the Central Bank observes all the state variables up to time t included (i.e. the policy maker knows the value of the variables in the vector (4)). On the basis of these values the Central Bank sets the optimal policy rate; then, nominal and real shocks hit the economy, so that at the beginning of period t+1 a new vector of state variables influences the Central Bank's decisions.

That is why, consistently with our set-up, we may exploit all the information available at time t to estimate by OLS the stochastic version of the optimal rule derived in (5). The

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[7] The cross-correlation of the errors is 0.137, implying that the parameter estimates are barely the same when a SUR estimation is performed.

[8] Moreover, the Andrews' test (1993) cannot reject the null of stability for both equations.

estimates yield the following results:

$$\begin{aligned} i_t \;=\; & \underset{(0.07)}{0.212}\pi_t + \underset{(0.08)}{0.043}\pi_{t-1} + \underset{(0.08)}{0.151}\pi_{t-2} - \underset{(0.09)}{0.177}\pi_{t-3} + \underset{(0.10)}{0.346}y_t + \\ & -\underset{(0.11)}{0.265}y_{t-1} + \underset{(0.14)}{1.259}i_{t-1} - \underset{(0.20)}{0.398}i_{t-2} - \underset{(0.12)}{0.008}i_{t-3} + \hat{v}_t \end{aligned} \tag{9}$$

with an Adjusted R^2 of 0.96[9]. The coefficients show that monetary authorities adjust gradually funds rates in response to both inflation and output gaps since the relevant parameters are significantly different from zero. In particular, the first lag of the funds rate implies that the Fed tends to move its instrument in a particular direction over several periods, while the second lag confirms the potential for few reversals in the policy rate path (see Rudebusch, 1995 and Goodhart, 1997).

The reduced form estimates of the feedback coefficients are convolutions of the very structural parameters described above, then they are not well-suited to address structural issues as the characterization of a monetary regime. Conversely, our method serves to extract from those feedback estimates the component that refer to central bank's preferences.

4.2 The Fed policy preferences

The behaviour of policy rates in our framework can be determined by three factors: the (variability of) supply and demand shocks, the dynamics of the economy and the policy preferences of the central bank. In a linear model with a quadratic loss function the certainty equivalence principle holds, and hence the solution to the control problem is unaffected by the additive uncertainty in the constraints. Furthermore, we assume that the Fed knows with certainty the dynamics of the economy as described by the point estimates in the AS and AD. It follows that our identification strategy, which selects the optimal interest rate path closest to the observed path, turns out to be particularly well-suited to recover policy makers' preferences as these remain the main determinant of interest rate movements.

The optimal path of policy rates is derived given the actual history of the economy at each point in time, that is, it is obtained by substituting the vector of actual state variables, period by period, into the optimal policy rule. Since the optimal path depends upon the specification of a set of policy preferences, we use our calibration method to identify the preferences of the US Federal Reserve over the sample. Then, we compute for

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[9] Neither the point estimates nor the standard errors change significatively when GMM method is applied.

any quarter the optimal level of funds rate, given that the Fed has behaved in accordance to the calibrated policy preferences and that it has previously implemented the actual level of interest rates. Figure 1 plots the optimal values of policy rates associated to the preference parameters coming from the calibration whereas Figure 2 plots the actual series of inflation. In particular, the first graph displays the optimal policy rule associated to the values $\lambda_\pi = 0.80$ and $\lambda_y = 0.00$, after having imposed $\lambda_{\Delta i} = 0.20$.

Insert Figure 1 and 2 about here

The optimal policy effectively captures the main features of funds rate movements under the Greenspan's chairmanship, although it predicts an higher level of interest rates both at the beginning and at the end of the sample. Since inflation is found to be the only final concern of the Fed and since it is affected by interest rates with two lags, we look at the relationship between forwarded inflation and current interest rates. Interestingly, a comparison between Figures 1 and 2 shows that whenever observed policy rates are lower (higher) than those predicted by the optimal rule, inflation is high (low) and above (below) its target, which is zero by construction[10]. This seems to call for a time-varying inflation target over the sample. However, to be consistent with other empirical analyses, we keep a constant inflation target. Our findings line up with those in Sack (2000), although we use a different specification of the economic structure and most importantly a different set of policy preferences.

The values of the preference parameters are not affected by imposing other values for the interest rate-smoothing weight, $\lambda_{\Delta i}$, since the value of λ_π turns out to be always the complement to one of any $\lambda_{\Delta i}$ value. Furthermore, the higher the preference parameter on inflation stabilization, the better is the match between optimal and fitted rates for any given value of the interest rate-smoothing coefficient. This suggests that the conduct of monetary policy in the US is successfully described by a *strict inflation targeting* as defined in Rudebusch and Svensson (2001) and Ball (1999), and according to which the stabilization of output around its potential value has not been a final concern of monetary authorities (i.e. $\lambda_y = 0.00$). However, we do not mean that the output gap has not been important in policy actions. Indeed, the feedback rule estimates show that it has been regarded as a leading indicator for future inflation rather than as a goal variable (i.e. it is

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[10] It can be shown in our set up that demeaning all variables corresponds to targeting inflation to its sample mean. In particular, such a mean is 2.49, which seems to be a reasonable value for the inflation target over the sample.

an argument in the reaction function rather than in the loss); this finding is in line with those in Favero and Rovelli (2001), and Dennis (2001).

4.3 Sensitivity analysis

The calibration of the central bank's policy preferences relies on the assumption that the AD-AS system specified in (1) and (2) is actually the macroeconometric model that policy makers have in mind. Indeed, researchers are uncertain about what it is, along both the parameter and the model dimension. In particular, monetary authorities may use sub-sample windows to capture the changing of the economic structure or may employ a different dynamics specification of their empirical model. For this reason, we relax in turn the assumptions that both the behavioral parameters and the model specification are time-invariant in order to assess the robustness of our results. First, given the model (1)-(2), we perform rolling sub-sample estimates to identify the associated values of the US policy makers' preferences for five-year moving windows. The values that the inflation stabilization coefficient, λ_π, takes over time are plotted in Figure 3 for the benchmark case (i.e. $\lambda_{\Delta i} = 0.2$).

Insert Figure 3 about here

The results are overwhelming and more general than those shown in the graph. For any value of $\lambda_{\Delta i}$, the parameter on inflation stabilization turns out to be fairly stable. Moreover, once we eliminate for the outlayer in the first quarter of 1999, its full sample mean is virtually equal to 0.8, implying that the monetary policy of the Fed can be evaluated within a single policy regime.

We turn now the attention on alternative specifications of the economic structure that might as well be relevant to monetary authorities. The goal is to identify of a set of policy preferences robust to model mis-specifications[11]. To this end, we apply our calibration method to a number of empirical models that display a reasonably good fit in a given class of specifications. This class is made up of all combinations of a base set of eight regressors for the AS and nine for the AD whose richest specification takes the following form:

$$\begin{aligned} \pi_{t+1} = {} & \alpha_1\pi_t + \alpha_2\pi_{t-1} + \alpha_3\pi_{t-2} + \alpha_4\pi_{t-3} + \\ & \alpha_5 y_t + \alpha_6 y_{t-1} + \alpha_7 y_{t-2} + \alpha_8 y_{t-3} + \xi_{t+1} \end{aligned} \tag{10}$$

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[11] We stress that the source of uncertainty here is the unknown view that Greenspan has about the economy rather than the unknown 'true' dynamics of the world.

$$\begin{aligned} y_{t+1} = \beta_1 y_t + \beta_2 y_{t-1} + \beta_3 y_{t-2} + \beta_4 y_{t-3} + \beta_5 \pi_t + \\ \beta_6 \pi_{t-1} + \beta_7 \pi_{t-2} + \beta_8 \pi_{t-3} + \beta_9 \left(\bar{\imath}_t - \bar{\pi}_t \right) + \eta_{t+1} \end{aligned} \qquad (11)$$

Among these, we first select and then combine the top ten AS with the top ten AD where the ranking is based on the Akaike model selection criterion. In ninety out of one hundred cases, a *strict inflation targeting* overperforms any other targeting strategy and not surprisingly the outlayers are the specifications combining the alternative AS equations with the only 'theoretically not plausible' AD, namely the one in which the Aggregate Demand positively depends on interest rate.

This evidence shows that our findings seem to be stable and robust to both model and parameter uncertainty, and therefore they may fairly describe the Fed policy preferences under the Greenspan's chairmanship.

5 Conclusions

Monetary policy reflects central bank's preferences, thus to evaluate the former it is crucial to identify the latter. A simple way to do this is to go backward and, as a kind of revelation principle, to extract the relevant information from observed policy decisions. Since the estimated coefficients in a feedback rule are convolutions of the 'deep' parameters of the economy and those describing the policy makers' preferences, they are natural candidates for the purpose at hand. This paper develops a novel calibration method to recover the central bank's policy preferences from the reduced form estimates of a Taylor-type reaction function. To this end, we solve the intertemporal optimization of monetary authorities under the constraints provided by a small empirical model of the US economy. Then, we select among a fairly wide class of alternative targeting policies, the one that minimizes the sum of squared deviations between the associated optimal rule and the estimated one.

Our findings show that the Greenspan's tenure as Fed chairman is effectively described by a *strict inflation targeting* policy according to which the stabilization of inflation around its target has been the only concern of monetary authorities. Indeed, the feedback estimates show that the output gap has been important in policy making. However, since it is found to enter the policy rule but not the objective function, it can only be interpreted as a leading indicator for future inflation. Furthermore, our results are pretty stable over the Greenspan's era and particularly robust to alternative specifications of the relevant structure of the economy.

Appendix: the optimal control problem

For a discount factor δ, $0 < \delta < 1$, the central bank faces an intertemporal optimization problem of the form:

$$E_t \sum_{\tau=0}^{\infty} \delta^{\tau} LOSS_{t+\tau} \tag{12}$$

according to which it minimizes the expected discounted sum of future loss values. In particular, the objective function reads in each period:

$$LOSS_t = \lambda_{\pi} \bar{\pi}_t^2 + \lambda_y y_t^2 + \lambda_{\Delta i} \left(i_t - i_{t-1} \right)^2 \tag{13}$$

The loss function is quadratic in the deviations of output and inflation from their target values and embodies an additional term that is meant to penalize for an excessive volatility of the policy instrument, i_t. The parameters λ_{π} and λ_y represent the (potentially time-variant) central bank's policy preferences towards inflation and output stabilization respectively. The weights in the objective function are normalized to sum to one.

When the discount factor, δ, approaches unity, the intertemporal loss function in (12) approaches the unconditional mean of the period loss function:

$$E\left[LOSS_t\right] = \lambda_{\pi} Var\left[\bar{\pi}_t\right] + \lambda_y Var\left[y_t\right] + \lambda_{\Delta i} Var\left[\Delta i_t\right] \tag{14}$$

The constraints of the optimization problem describe the structure of the economy, and they are specified by the AD-AS system in (1) and (2). This has a convenient state-space representation of the form:

$$X_{t+1} = AX_t + Bi_t + \eta_{t+1} \tag{15}$$

where the elements of (15) are given by:

$$X_t' = \left[\begin{array}{ccccccccc} \pi_t & \pi_{t-1} & \pi_{t-2} & \pi_{t-3} & y_t & y_{t-1} & i_{t-1} & i_{t-2} & i_{t-3} \end{array} \right] \tag{16}$$

$$A = \left[\begin{array}{ccccccccc} \alpha_1 & \alpha_2 & \alpha_3 & \alpha_4 & \alpha_5 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ \frac{-\beta_3}{4} & \frac{-\beta_3}{4} & \frac{-\beta_3}{4} & \frac{-\beta_3}{4} & \beta_1 & \beta_2 & \frac{\beta_3}{4} & \frac{\beta_3}{4} & \frac{\beta_3}{4} \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \end{array} \right], B = \left[\begin{array}{c} 0 \\ 0 \\ 0 \\ 0 \\ \frac{\beta_3}{4} \\ 0 \\ 1 \\ 0 \\ 0 \end{array} \right] \tag{17}$$

$$\eta_t' = \left[\begin{array}{ccccccccc} \varepsilon_t & 0 & 0 & 0 & u_t & 0 & 0 & 0 & 0 \end{array} \right] \tag{18}$$

X_{t+1} is the 9 x 1 vector of state variables, i_t is the policy control (i.e. the federal funds rate) and η_{t+1} is a 9 x 1 vector of supply and demand iid normally distributed shocks with mean vector zero and covariance matrix $E\eta_t\eta_t' =$. Lastly, A and B are the matrices of behavioral parameters.

The loss function in (13) can be represented in a more compact form by defining the 3 x 1 vector Y_t of goal variables. This vector reads:

$$Y_t = CX_t + Di_t \tag{19}$$

where the elements of (19) are given by:

$$Y_t = \begin{bmatrix} \bar{\pi}_t \\ y_t \\ i_i - i_{t-1} \end{bmatrix}, C = \begin{bmatrix} \frac{1}{4} & \frac{1}{4} & \frac{1}{4} & \frac{1}{4} & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & -1 & 0 \end{bmatrix}, D = \begin{bmatrix} 0 \\ 0 \\ 1 \end{bmatrix} \tag{20}$$

Accordingly, the loss function can be rewritten as:

$$LOSS_t = Y_t'RY_t \tag{21}$$

where R is a negative semidefinite symmetric 3 x 3 matrix characterized by the weight λ_π, λ_y and $\lambda_{\Delta i}$ on the diagonal and zeros elsewhere.

The central bank's optimal control problem is to minimize over choice of $\{i_t\}_{t=0}^{\infty}$ the criterion:

$$\sum_{\tau=0}^{\infty} \delta^\tau \left\{ Y_{t+\tau}' R Y_{t+\tau} \right\} \tag{22}$$

subject to the dynamic evolution of the economy described in (15) and given the current state of the economy X_t.

The quadratic objective function, the linear transition equation and the property $E\left(\eta_{t+1} \mid X_t\right) = 0$ are convinient forms for the stochastic optimal linear regulator problem (see Ljungqvist and Sargent, Ch. 4, 2000). It follows that the feedback rule that solves the optimization is linear and independent from the problem's noise statistics, , as the certainty equivalence holds. Then, the first-order necessary condition turns out to be:

$$\left(S + \delta B'PB\right) i = -(V' + \delta B'PA)X \tag{23}$$

which implies the following feedback rule for the policy instrument $i = fX$ where f is given by:

$$f = -\left(S + \delta B'PB\right)^{-1}(V' + \delta B'PA)$$

The 9 x 9 matrix P is the solution of the algebraic Riccati equation:

$$P = Q + \delta\,(A + Bf)'\,P\,(A + Bf) + f'Sf + Vf + f'V' \tag{24}$$

where Q, V and S are defined as $C'RC$, $C'RD$ and $D'RD$ respectively.

Such a reaction function resembles an augmented Taylor's rule according to which monetary authorities set the federal funds rate in every period as the optimal response to movements in the current and lagged values of the state variables as well as lagged values of the fed funds rate itself.

Finally, given this optimal feedback rule the transition law of the economy can be rewritten as $X_{t+1} = MX_t + \eta_{t+1}$, where the 9 x 9 matrix M is equal to $A + Bf$.

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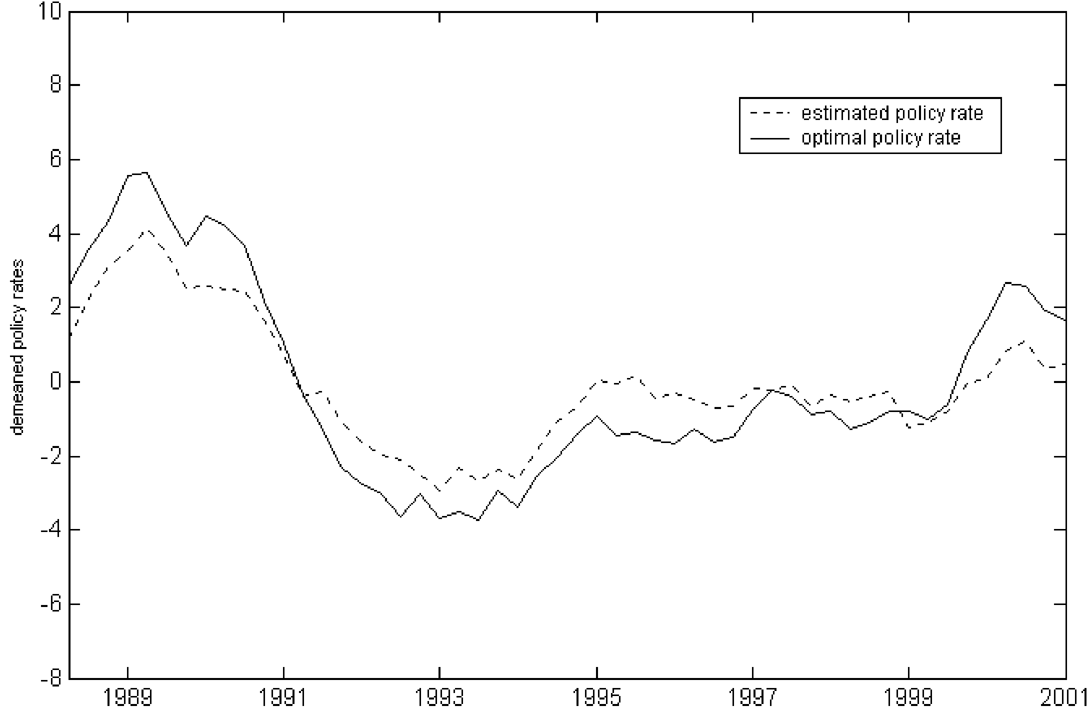
Figure 1: estimated and optimal policy rates



Note: the optimal policy rate is computed given the actual history of the economy at each point in time.

Figure 2: actual path of inflation

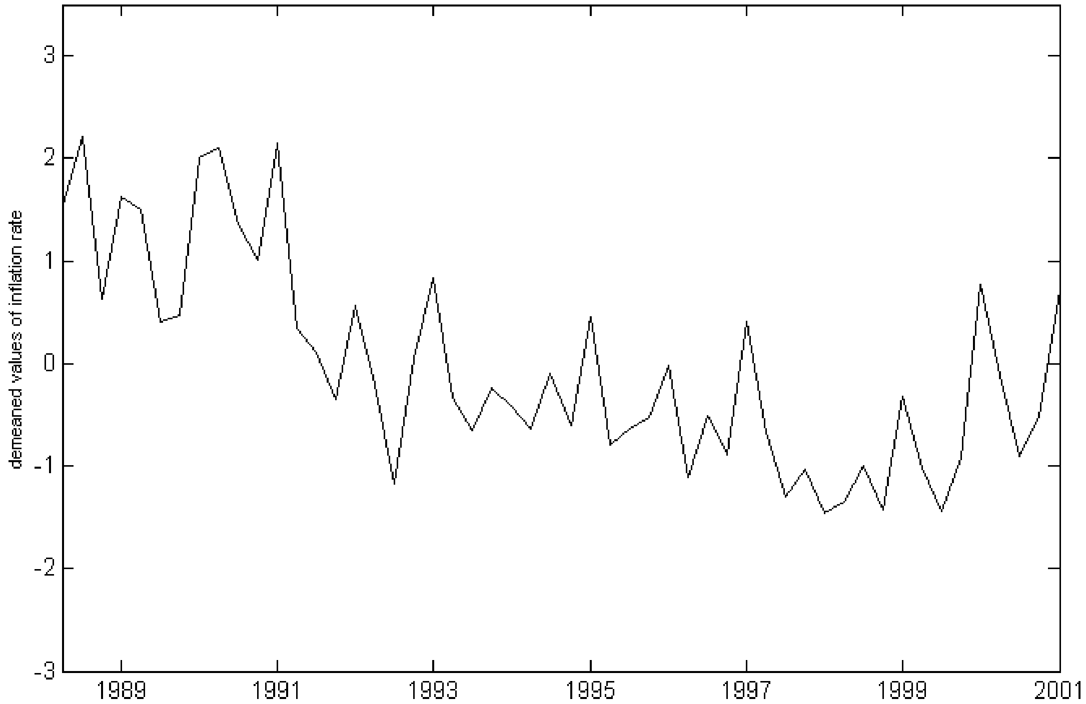
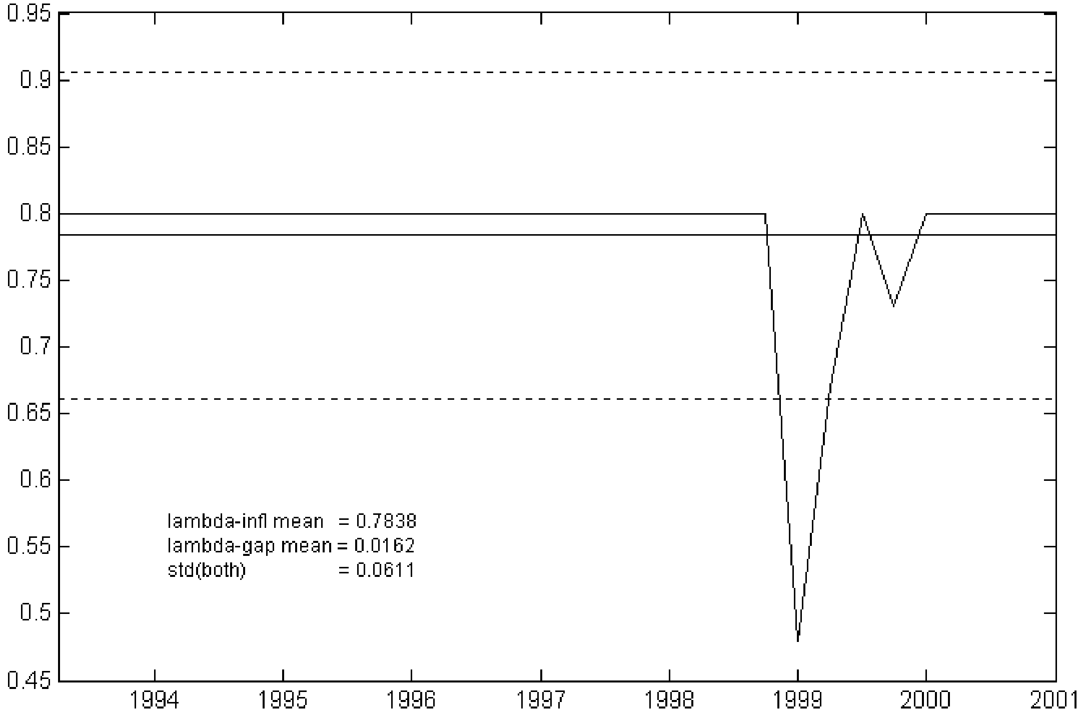


Figure 3: the preference parameter on inflation stabilization over time



Note: each parameter estimate is obtained from a five-year rolling sub-sample regression that ends in the quarter in which the parameter estimante is plotted.

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ETA	2.2002	*Efrem CASTELNUOVO and Paolo SURICO*: What Does Monetary Policy Reveal about Central Bank's Preferences?

(xlii) This paper was presented at the International Workshop on "Climate Change and Mediterranean Coastal Systems: Regional Scenarios and Vulnerability Assessment" organised by the Fondazione Eni Enrico Mattei in co-operation with the Istituto Veneto di Scienze, Lettere ed Arti, Venice, December 9-10, 1999.
(xliii)This paper was presented at the International Workshop on "Voluntary Approaches, Competition and Competitiveness" organised by the Fondazione Eni Enrico Mattei within the research activities of the CAVA Network, Milan, May 25-26,2000.
(xliv) This paper was presented at the International Workshop on "Green National Accounting in Europe: Comparison of Methods and Experiences" organised by the Fondazione Eni Enrico Mattei within the Concerted Action of Environmental Valuation in Europe (EVE), Milan, March 4-7, 2000
(xlv) This paper was presented at the International Workshop on "New Ports and Urban and Regional Development. The Dynamics of Sustainability" organised by the Fondazione Eni Enrico Mattei, Venice, May 5-6, 2000.
(xlvi) This paper was presented at the Sixth Meeting of the Coalition Theory Network organised by the Fondazione Eni Enrico Mattei and the CORE, Université Catholique de Louvain, Louvain-la-Neuve, Belgium, January 26-27, 2001
(xlvii) This paper was presented at the RICAMARE Workshop "Socioeconomic Assessments of Climate Change in the Mediterranean: Impact, Adaptation and Mitigation Co-benefits", organised by the Fondazione Eni Enrico Mattei, Milan, February 9-10, 2001
(xlviii) This paper was presented at the International Workshop "Trade and the Environment in the Perspective of the EU Enlargement ", organised by the Fondazione Eni Enrico Mattei, Milan, May 17-18, 2001
(xlix) This paper was presented at the International Conference "Knowledge as an Economic Good", organised by Fondazione Eni Enrico Mattei and The Beijer International Institute of Environmental Economics, Palermo, April 20-21, 2001
(l) This paper was presented at the Workshop "Growth, Environmental Policies and + Sustainability" organised by the Fondazione Eni Enrico Mattei, Venice, June 1, 2001
(li) This paper was presented at the Fourth Toulouse Conference on Environment and Resource Economics on "Property Rights, Institutions and Management of Environmental and Natural Resources", organised by Fondazione Eni Enrico Mattei, IDEI and INRA and sponsored by MATE, Toulouse, May 3-4, 2001
(lii) This paper was presented at the International Conference on "Economic Valuation of Environmental Goods", organised by Fondazione Eni Enrico Mattei in cooperation with CORILA, Venice, May 11, 2001
(liii) This paper was circulated at the International Conference on "Climate Policy – Do We Need a New Approach?", jointly organised by Fondazione Eni Enrico Mattei, Stanford University and Venice International University, Isola di San Servolo, Venice, September 6-8, 2001

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