On the Fed's Interest Rate Smoothing

Ph.D. Thesis by Efrem Castelnuovo

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A mia mamma, mio papà, e mio fratello,
per tutto quello che mi hanno dato.

Contents of my Thesis

Introduction

My Ph.D. thesis regards the observed and widely documented gradualism associated to most of the Central Banks' policy conducts. The reasons why many monetary authorities have implemented such a smooth policy rate are only partly understood, and much research is still needed in order to deepen our knowledge in this sense. With my three empirical exercises I have just tried to shed a little bit of light on this issue, focussing on the American Monetary Policy Authority, i.e. the Fed. Particularly, in my first chapter, i.e. **Model Uncertainty, Optimal Monetary Policy, and the Preferences of the Fed**, I empirically investigated the impact that the ignorance about the real world's dynamics exerts on the Policy Maker's decisions. The idea is that this ignorance should call for a degree of cautiousness in implementing monetary policy moves. In fact, it turns out that the observed federal funds rate smoothness may find its rationale in the above mentioned ignorance. Then, model uncertainty is something a researcher should bear in mind when trying to understand the Fed's moves.

Let me spend a few more words about this paper. First of all, this is joint work with Paolo Surico, a friend of mine also enrolled in Bocconi's Ph.D. in Economics. I had the fortune to meet Paolo in Barcelona, where both of us spent one year as students enrolled in the Master of Science in Economics at Universitat Pompeu Fabra. We have been discussing economic issues (not our main argument of discussion, though ...) for many years now, and I have always found our exchanges quite stimulating. I guess this joint work is just a starting point for us, and I hope many other co-authored papers will follow. Secondly, we received a prize for this paper, namely the *Scottish Economic Society's Sir Alex Cairncross Prize* (year 2002): A great intellectual satisfaction, indeed!

Going back to my Ph.D. thesis, another key-element in deciding which monetary policy to implement is private sector's expectations. The ability of influencing private sector's expectations may dramatically reduce the cost related to the short-run trade off existing between inflation volatility and output gap volatility. In a discretionary environment, a smooth interest rate may be explained by the willingness of the monetary authority to influence agents' expectations. In my second paper, i.e. **Squeezing the Interest Rate Smoothing Weight with a Hybrid New-Keynesian Model**, I empirically show that the explicit formalization of forward looking agents may very much explain why we observe such an interest rate smoothing. Indeed, the quantitative impact of the forward looking agents component is striking.

Interestingly enough, not all the researchers involved into the monetary policy arena are sympathetic with the idea of interest rate smoothing at quarterly frequencies, i.e. the frequency typically employed for performing monetary policy analysis. In a stimulating paper published in the Journal of Monetary Economics on September 2002, Glenn D. Rudebusch claims that the interest rate smoothing we believe we are observing in the real world is *de facto* an illusion. His reasoning is based on an indirect proof, i.e. if the interest rate smoothing were indeed so high, then it should be pretty easy to predict the federal funds rate behavior, which is in fact not true. Actually, some comments have been written on Rudebusch's contribution. In the third chapter of my Ph.D. thesis, i.e. **Describing the Fed's Conduct with Taylor Rules: Is Interest Rate Smoothing Important?**, I basically combine and extend all these contributions to test if the interest rate smoothing typically estimated in the literature is indeed an illusion or not. My work supports the idea of monetary policy gradualism also at quarterly frequencies.

Model Uncertainty, Optimal Monetary Policy, and the Preferences of the Fed*

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Abstract

US monetary policy is characterized by a substantial degree of inertia. While in principle this may well be the outcome of an optimizing central bank behaviour, the ability of any derived policy rule to match the data relies on so large weights for interest rate smoothing into policy makers' preferences as to be theoretically flawed. In this paper we investigate whether such a puzzle can be interpreted as resulting from the concern of monetary authorities for potential misspecifications of the macroeconomic dynamics. Accordingly, we use a novel *thick modeling* approach to incorporate model uncertainty into the identification of central bank's preferences. The robust *thick* policy rule shows the kind of smoothness observed in the data without resorting to implausible values for the preference parameters.

JEL classification: C61, E52, E58.

Keywords: Model uncertainty, interest rate smoothing, Fed policy preferences, robust optimal monetary policy.

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1 Introduction

The US Federal Reserve tends to change short-term interest rates by small steps that move in a particular direction over sustained periods and reverse only infrequently (see Rudebusch, 1995, and Goodhart, 1997). This prominent feature of policy rates, which is interchangeably referred to as interest rate smoothing, policy gradualism or policy inertia, characterizes the Fed response to inflation and output gaps as having been more moderate than an optimizing central bank behavior would predict.

In a recent survey of evidence, Sack and Wieland (2000) interestingly discuss several explanations to reconcile historical and optimal policy rules. A number of empirical studies find that uncertainty creates incentives to smooth policy rates, in the form of either parameter uncertainty or measurement error for inflation and output gap. Parameter uncertainty, which is the uncertainty on the monetary transmission mechanism, alters the knowledge of decision makers about the impact of policy action on the economy. Accordingly, a central bank that adjusted aggressively policy rates to the developments in the economy would be more likely to have unpredictable and therefore undesirable movements of output and inflation. Then, as shown in the VAR analyses by Sack (2000), Salmon and Martin (1999), and Söderström (1999), policy gradualism may be the optimal strategy to bring the relevant macroeconomic variables in line with the targets.

Another source of uncertainty comes from the measurement errors on inflation and output gap. Indeed, the evaluation of monetary policy in most empirical studies relies on the unrealistic assumption that policy makers know the state of the economy without error. However, monetary policy mainly involves decisions that are based on real-time available information, which are subject to frequent revisions after the initial release. Interestingly, Orphanides (1998) shows that whenever policy makers take data uncertainty into account the estimated policy response to inflation and output gaps is more moderate, thereby preventing the possibility of wide interest rate fluctuations due to measurement errors. This attenuation turns out to be particularly relevant under simple policy rules, although it also emerges for optimal policy rules.

These explanations have each proved to be statistically significant, although none alone has resulted to be quantitatively satisfactory (see Sack and Wieland, 2000). Moreover, interest rate smoothing is derived as the optimal policy rule of a central bank whose only concerns are to stabilize output and inflation and the possibility that policy makers have an explicit preference to penalize policy rate fluctuations is ruled out by assumption.

On the positive side, the inclusion of interest rate changes in the policy makers' loss function can be justified on several grounds (see Woodford, 2002, Ch. 7; Goodfriend, 1991 and Lowe and Ellis, 1997). The empirical model proposed by Rudebusch and Svensson (1999), which includes an explicit interest rate smoothing goal, has become by now a popular framework to analyze monetary policy under uncertainty (see Stock, 1999; Smets, 1999; Onatski and Stock, 2002; Rudebusch, 2001 and Favero and Milani, 2001). For example, Rudebusch (2001) argues that the interaction of several forms of uncertainty rather than a single one is likely to generate the kind of smoothness observed in the data and points towards measurement errors and model misspecifications as the most relevant candidates. In particular, the perturbation of some key structural relations such as the inflation dynamics and the output sensitivity to interest rate are shown, everything equals, to make smoother an otherwise volatile policy rate behavior, thereby being an excellent starting point for the present analysis.

On the negative side, the ability of any optimal policy rule to match the data badly relies on so large weights for the policy makers' aversion to interest rate changes as the theory cannot easily motivate. This suggests the potential for a strictly related issue, namely the identification of the Fed policy preferences. Indeed, several pioneering studies have proposed alternative strategies to estimate the structural parameters in a small empirical model à la Rudebusch and Svensson (see Favero and Rovelli, 2002; Dennis, 2001; Ozlale, 2001). While extremely promising, these estimates have left the *interest rate smoothing puzzle* unsolved in that any plausible set of preferences implies an optimal path for policy rates much more volatile than the observed one.

In this paper we bring together the literature on model uncertainty and the one on central bank's preferences by using the progresses made in the former to solve the puzzle emerged in the latter. To this end, we incorporate model uncertainty in the simple calibration method we propose to identify the Fed policy preferences. In so doing, we investigate whether the concern for model misspecifications can explain the inertial behavior of policy rates without resorting to implausible weights, if any, for an interest rate smoothing goal.

The intuition for having more moderate policy responses when the model is misspecified comes from the policy makers' agnosticism about what model provides the most accurate description of the economy. Accordingly, a policy rule, which is optimal under a single specification, may turn out to perform quite poorly if that model does not capture properly the 'true' macroeconomic dynamics. Then, the observation of smooth policy rates can simply reflect the choice of a policy rule that would perform reasonably well over various alternative policy scenarios.

A general strategy to take model uncertainty into account is to calculate a global optimal policy as some combination of the policy rules derived separately for each of the relevant specifications (see Stock, 1999). It is worthy to note that the *robust* rule we are interested in differs in scope from the one derived with robust control techniques. Indeed, here robustness has to be understood as a form of hedging against potential misspecifications of the macroeconomic dynamics rather than as a way of guarding against worst case scenarios. To this end, we follow the *thick* modeling proposed by Granger and Jeon (2001) to pool into a single policy rule a large number of specifications in a given class of nested models. In particular, we first let policy makers implement, at each point in time, some average of the optimal rates for each of the relevant specifications. Then, we identify among a large number of targeting policies the set of preference parameters that makes such a *robust* rule matching the data.

Our results shed new lights as well as confirm conventional wisdoms on the conduct of US monetary policy in the last decade. First, potential misspecifications of the macroeconomic dynamics is an important concern of the Fed such as to explain alone most of the observed inertial behavior of policy rates. Second, any identification method that did neglect model uncertainty would deliver a set of policy preferences that cannot be readily interpreted. Third, the stabilization of output over the cycle has not been a final concern of US monetary authorities whereas the stabilization of inflation has been a superior goal.

The paper is organized as follows. Section 2 sets up the model and presents the relative estimates. Section 3 identifies the preference parameters for the Greenspan's tenure and defines the *interest rate smoothing puzzle* from the comparison between our results and those obtained in several recent studies. The *thick* modeling approach to model uncertainty is introduced in section 4 and then it is used in the following section to re-identify the Fed policy preferences. The last section concludes while the appendix provides a guideline to solve numerically the optimal control problem.

2 A small empirical model of the US economy

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 relations 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, 1998, and Bernanke and Mihov, 1998). Furthermore, if the central bank faces an intertemporal optimization problem, then forecasting the behavior of the state variables 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 methods, a backward-looking model may be a suitable characterization of the macroeconomic dynamics (see Fuhrer, 1997).

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

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

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

where π_t is the quarterly inflation in the GDP chain-weighted price index, p_t, calculated at annual rate, that is $4(p_t - p_{t-1})$, and $\bar{\pi}_t$ is four-quarter inflation constructed as $\frac{1}{4}\sum_{j=0}^{3} \pi_{t-j}$. 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 $\frac{1}{4}\sum_{j=0}^{3} i_{t-j}$; Supply and demand iid shocks are denoted by ε_t and u_t respectively. All variables are demeaned. All variables but the funds rate are in logs and rescaled upward on a 100 point basis such that the output gap, say, is $y_t = 100 * (\log(Q_t) - \log(Q_t^*))$ where Q_t and Q_t^* are respectively actual and potential GDP, both in levels. Therefore, no constants appear in the equations.

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).

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 a structural relation or as a reduced-form restricted VAR with impulse responses that are consistent with those of the FRB-US model.

The AD-AS system is backward-looking and therefore it is subject to the Lucas critique (1976). It follows that the selection of an inappropriate sample may undermine the stability of the behavioral parameters of the economy, which is an important condition for drawing inference. For instance, Muscatelli and Trecroci (2001) show evidence that while the response of output to interest rate shocks has not significantly changed, the short-run correlation between output and inflation has shifted during the last two decades. To the extent that this can be ascribed to the productivity growth that has characterized the US economy since the late 80s, focusing on the sample 1987:3 - 2001:1, which corresponds to the tenure of Alan Greenspan as Fed chairman, it turns out to be beneficial to limit parameter variation. Indeed, one may argue that this period has been marked not only by an increasing macroeconomic stability and a lower inflation but also by the expectations of some form of inflation targeting (see Bernanke and Mihov, 1998), thereby reducing the significance of the Lucas critique.

We estimate individually equations (1) and (2) by OLS. 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 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:

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

$$y_{t+1} = \underset{(0.136)}{1.229}y_t - \underset{(0.149)}{0.244}y_{t-1} - \underset{(0.078)}{0.073}\left(\bar{i}_t - \bar{\pi}_t\right) + \hat{u}_{t+1} \tag{4}$$

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.[1] 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 Muscatelli and Trecroci, 2001, and 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.

2.2 The loss function and the optimal monetary policy

We assume that monetary authorities operate according to a *targeting rule* as defined in Svensson (1999). This corresponds to set the instrument rate so as to bring at each point in time the target variables in line with the targets by penalizing any future deviation of the former from the latter. Following Rudebusch and Svensson (1999), 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 potentially 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.[2] Then, policy rates are set to minimize the following objective function:

$$Var\left[\bar{\pi}_t\right] + \lambda Var\left[y_t\right] + \mu Var\left[\Delta i_t\right] \tag{5}$$

The quarterly average short-term interest rate, i_t, is regarded as the instrument under policy makers' control whereas Δi_t stands for its first difference. The parameters λ and μ represent

[1] Moreover, the cross-correlation of the errors is 0.137, implying that the parameter estimates are not affected by the estimation method. Lastly, the Andrews' test (1993) cannot reject the null of stability for both equations.

[2] As argued in Dennis (2000), demeaning all variables does not affect the derivation of policy makers' preferences. Furthermore, our analysis is meant to identify the central bank parameters 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).

the central bank's policy preferences towards output stabilization and interest rate smoothing respectively and unlike in Rudebusch and Svensson (1999), who set them exogenously, they will be determined within the model. The coefficient on inflation stabilization is normalized to one such that λ and μ are expressed in relative terms. Finally, we constrain both parameters to be non negative meaning that the central bank values both any deviation of output from its potential and any jump in interest rates as a *bad*.

On the positive side, the specification in (5) 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 inertia observed in the data. On the negative side, the desire for smoothing policy rates has little theoretical justification beyond the optimal delegation argument according to which the appointment of a central banker who pursues an alternative objective relative to the true social one may be welfare improving (see Woodford, 2002, Ch. 7).[3] However, it can be argued that high variability and frequent reversals in interest rate movements may lead to financial instability (see Goodfriend, 1991) as well as they may be interpreted by the private sector as an admission of earlier policy mistakes (see Lowe and Ellis, 1997), thereby being undesirable.

The optimal control problem described in (1), (2) and (5) has a convenient state space representation that is characterized by a quadratic objective and a linear transition law. 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:

$$X_t' = \left[\begin{array}{ccccccccc} \pi_t & \pi_{t-1} & \pi_{t-2} & \pi_{t-3} & y_t & y_{t-1} & i_{t-1} & i_{t-2} & i_{t-3} \end{array} \right] \tag{6}$$

In particular, the central bank minimizes the loss (5) 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[4]:

$$i_t = fX_t \tag{7}$$

The coefficients in the vector f represent some convolution of the central bank's preferences, λ and μ, and the behavioral parameters of the economy, αs and βs, such that for any given distribution of weights in (5) there exists a different optimal f in (7).

[3] Alternatively, monetary authority may wish to stabilize the level, rather than the change, of policy rates. Then, the presence of transaction frictions and/or a zero nominal interest-rate lower bound result in an utility-based loss function with an interest rate term which enhances social welfare (see Woodford, 2002, Ch. 6)

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

Then, we make the model consistent with our implementation by the timing assumption that the Fed sets policy rates after the realization of the state variables, which occurs at the beginning of the period. Hence, we estimate by OLS the stochastic version of the optimal rule derived in (7). The estimates yield the following results:

$$\begin{aligned} i_t &= \underset{(0.07)}{0.212}\pi_t + \underset{(0.03)}{0.043}\pi_{t-1} + \underset{(0.08)}{0.151}\pi_{t-2} - \underset{(0.09)}{0.177}\pi_{t-3} + \underset{(0.10)}{0.346}y_t + \\ & \quad - \underset{(0.11)}{0.265}y_{t-1} + \underset{(0.14)}{1.259}i_{t-1} - \underset{(0.20)}{0.398}i_{t-2} - \underset{(0.12)}{0.008}i_{t-3} + \hat{v}_t \end{aligned} \tag{8}$$

with an Adjusted R^2 of 0.96.[5] The significant parameters show that the monetary authorities operate in a gradual manner by changing the funds rates in response to both inflation and output gaps. In particular, the first lag of the policy rate implies that the Fed tends to move its instrument in a particular direction over sustained periods, while the second lag confirms the potential for few reversals (see Rudebusch, 1995, and Goodhart, 1997). Finally, the coefficients on the interest rate lags sum up to 0.85 consistently with much of the literature on partial adjustment policy rules. This suggests that the observed policy inertia is greater than systematic responses to output and inflation fluctuations would imply.

3 The Fed policy preferences with no model uncertainty

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 that characterize the aversion of monetary authorities towards inflation, output and potentially interest rate volatility. Then, a simple way to recover these preferences is to assume that policy makers are acting optimally and, as a kind of revelation principle, to extract the relevant information from the observed policy decisions. The control problem described above shows that the reaction function estimates can be interpreted as convolutions of the behavioral parameters of the economy and those describing the central bank's preferences and therefore they are natural candidates for the purpose at hand.[6] Accordingly, given the point estimates in (3) and (4), we calibrate the preference parameters $[\lambda, \mu]$ such as to minimize the distance between the optimal policy and the fitted path of interest rates in (8),

[5] McCallum and Nelson (1999) argue that in operational policy making the central bank does not observe (and respond to) the current state of the economy. Using four lags of funds rate, GDP inflation and CBO output gap as instruments does not change significantly neither the point estimates nor the standard errors of the feedback coefficients.

[6] Moreover, our optimal control problem satisfies the three necessary and sufficient conditions derived in Dennis (2000) to identify central bank policy preferences .

where the distance is measured by the sum of squared deviations over time.[7] The optimal policy describes the path that the funds rates would have followed if the Fed had historically implemented the optimal rule and therefore, given the actual values of state variables at the beginning of the sample, it is derived by substituting, period by period, the simulated dynamics of the X into the reaction function (7). Our identification method applied to the sample 1987:3 - 2001:1, which corresponds to the Greenspan chairmanship, returns values of $\lambda = 1.00$ and $\mu = 8.00$ for the preferences on output stabilization and interest rate smoothing respectively. One may be tempted to conclude that while output and inflation stabilizations have received an equal concern, interest rate smoothing has been the major objective of the Fed. However, we show below that these results can be highly misleading in that they miss an important feature of actual monetary policy making.

At this point, it is useful to relate our results to several recent studies since there exists interesting differences and similarities. Favero and Rovelli (2002) 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 (1999) capture the dynamics of the economy in a VAR framework and then recover policy makers' preferences from the estimates of the output-inflation variability frontier and those obtained via VAR. Dennis (2001) and Ozlale (2001) use respectively a full information approach and the Kalman filtering to jointly estimate with maximum likelihood the structural model of the economy and the loss function. These studies but the ones by Cecchetti and Ehrmann (1999) are built upon a common empirical model of inflation and output, namely the one by Rudebusch and Svensson (1999), and therefore their findings turn out to be directly comparable to ours. Table 1 brings together our revealed preferences and the estimates from the different contributions. The reported values refer to the Greenspan's tenure, although Favero and Rovelli (2002) do not distinguish between the Volcker's and the Greenspan's chairmanship.[8] In particular, Panel A shows the first two moments of the fitted policy rates whereas Panel B displays in columns the

[7] By defining our measure of distance upon fitted rather than actual rates we restrict our attention to the systematic component of policy rate behaviour, that is, to the component we can explain within an optimal control framework. Moreover, our results do not change significantly when actual rates enter the calibration because of the good empirical fit of the feedback estimates.

[8] Understanding whether the two periods may be described by a single set of policy preferences is beyond the scope of this paper. However, to the extent that no monetary regime shifts have occured in the post-Volcker period (see Clarida, Gali and Gertler, 2000), the preference parameters in Favero and Rovelli (2002) can be taken as a rough approximation of those in the restricted sample for Alan Greenspan only. As we are interested only in a qualitative comparison between our optimal policy rule and those from other studies, we consider such an approximation only as a minor in the interpretation of the results.

Fed policy preferences, the first two moments of the optimal paths and the average distance between optimal and fitted rates. Figure 1 plots the optimal and the fitted path of policy rates for the four studies.

The first two lines of Panel B in Table 1 refer to the present work and the one by Dennis (2001).[9] On the one hand, these sets of policy preferences predict a path for policy rates capable to replicate the kind of smoothness observed in the data (see the top panels of Figure 1). Indeed, the first two moments are broadly consistent in both cases with those of the fitted path in Panel A and the average distance, which is computed on squared values, is fairly low. On the other hand, they rely upon extremely large parameters for interest rate smoothing which cannot be easily motivated within the optimal monetary policy literature.[10]

By contrast, the last two lines of Table 1, which refer to the works by Favero and Rovelli (2002) and Ozlale (2001), return more plausible weights for the inertial coefficient in the loss function. However, the bottom panels of Figure 1 show that this can be done only at the cost of an optimal policy rule that is so volatile as to contradict the evidence on the funds rates.

The results at this stage seem to call for a sort of *interest rate-smoothing puzzle*. A trade-off between an inertial behavior of policy rates and a plausible value for the relative preference parameter seems to emerge, thereby suggesting that the source of interest rate smoothing has to be found elsewhere.

The structure of the economy proposed by Rudebusch and Svensson (1999), while empirically attractive, is indeed very simple and the omission of any relevant variable may turn out to be an issue for the results obtained so far. Moreover, as discussed in the introduction, the lack of knowledge about the 'true' model of the economy may lead policy makers to consider various alternative policy scenarios, each one corresponding to a different specification of the underlying macroeconomic dynamics. We explore such an alternative in the next section to assess the potential of model uncertainty to account for the observed interest rate smoothing.

4 Model uncertainty

A common observation across central banks is that interest rates are moved in a more moderate fashion than certain equivalent optimal monetary policies predict. The difficulty of

[9] We thank Richard Dennis for having kindly offered the FIML estimates for the Greenspan's period.

[10] For instance, the utility based loss function in Woodford (2002, Ch. 6 and 7), albeit derived in a different class of models, implies a theoretical value of μ no greater than 0.28, which is based on stuctural estimates for the US economy.

standard models to rationalize policy inertia has led to incorporate various forms of model uncertainty into the policy makers' optimization problem. In practice, monetary authorities know far less about the dynamics of the economy than simple policy experiments presume and model parameters are likely to be better viewed as random. In particular, suppose that monetary authorities know the distribution of parameters but not the realization; then, uncertainty can be introduced at different levels. A Brainard-style multiplicative uncertainty (1967) considers parameter distributions that are centered around the estimates of a specific model. This means that policy makers know the parameter first moments on an ex ante basis, although they do not know the values that realize in any given quarter. Rudebusch (2001), Estrella and Mishkin (1999), and Peersman and Smets (1999) find that parsimonious structural models and simple policy rules predict only negligible attenuations of policy action in the context of such an uncertainty. By contrast, Sack (2000), Salmon and Martin (1999) and Söderström (1999) show using unrestricted VARs and unrestricted policy rules that the response of monetary authorities may result quantitatively more moderate, although they conclude that multiplicative parameter uncertainty alone is not enough to replicate the kind of smoothness observed in the data.

Another way to think of model uncertainty is to regard also the parameter mean as unknown. In fact, if policy makers fear that a small structural model is misspecified, they would have no reason to believe that the 'true' parameters coincide, even on average, with the least square estimates. A valuable robustness check is then to vary the values of some key model parameter to understand whether this is the relevant form of uncertainty that central banks face. Rudebusch (2001) shows that the slope coefficients on inflation and output gap are indeed crucial as the perturbation of each of them, everything equals, results in a significant, but not exhaustive, attenuation of the policy stance.

These results altogether are very promising in that they point towards model uncertainty, in a *broad* sense, as the relevant source of the observed policy gradualism. Moreover, they suggest that the policy preference reported above may be 'misleading' as no identification method takes such an uncertainty into account and only the point estimates of the model parameters enter the analyses. By contrast, this section incorporates model specification uncertainty into the calibration of the Fed policy preferences. In so doing, we attempt to solve for the *interest rate smoothing puzzle* by assessing the potential of a *broad* type of uncertainty for explaining the inertial behavior of policy rates.

Our approach departures from previous studies along three lines. First, we regard the point estimates of our benchmark model only as one set of possible realizations. In other words, we allow the average value of the distributions to be different from the estimated parameters. Moreover, rather than assuming that these distributions are known ex-ante, we let them be shaped ex-post by the point estimates obtained for each of the possible models. Lastly, in addition to the kind of slope coefficient uncertainty in Rudebusch (2001), we also allow for simultaneous perturbations of all parameters as potentially omitted variables are likely to affect each of the point estimates in the model.

In practise, we follow Granger and Jeon (2001) and we label this approach to model uncertainty *thick modeling*. We keep all close specifications according to some statistical criterion, find their outputs that relate to the design of optimal monetary policy and pool these values. The label 'thick', as opposed to 'thin', reflects the fact that if one estimates and plots each model-specification she will get a 'thick' representation of the optimal monetary policy, that is, a curve whose width is made up of as many 'thin' curves as the number of specifications that survive the trimming of the outliers.

Before discussing our 'thick' strategy, we consider worthwhile to describe how model uncertainty has been traditionally approached.

4.1 Traditional approaches

The robustness of monetary policy to model uncertainty has been the focus of a number of recent empirical studies. The goal has been to assess the performance of optimal rules moving from the model in which they are derived to a set of alternative specifications as well as to establish the efficiency of simple policy rules (see Taylor, 1999). For example, McCallum (1998) shows that monetary-based instrument rules overperform optimal ones over a range of possible macroeconomic dynamics. Moreover, simple partial adjustment policy mechanisms and simple forecast-based instrument rules responding to an inflation horizon no longer than one year are found to efficiently stabilize inflation and output in a variety of forward-looking models (see Levine, Wieland and Williams,1999 and 2001). Essentially, these rules set the change in the funds rate rather than the level as the optimal value of the lagged policy rate coefficient is close to one. The intuition is that the central bank, which has established a reputation of conducting monetary policy in a gradual manner, can achieve its goals while maintaining a low level of interest rate volatility through the expectations of policy inertia (see also Goodfriend, 1991 and Woodford, 2002, Ch. 7).

An alternative approach to solve for model uncertainty is provided by the techniques of robust control (see Hansen and Sargent, 2001, chapters 6 and 8). This method specifies a risk function and a minimax criterion that serve to form a non-parametric set of perturbations around the policy makers' model. The latter is assumed to be an approximation that belongs to a potentially time varying and state dependent bounded neighborhood of the 'true' model of the economy. Then, given the least favorable scenario, that is roughly speaking the maximum value that the loss function can take in that neighborhood, the robust optimal rule is chosen so as to minimize the maximum value function. Interestingly, Stock (1999), Onatski and Stock (2002), and Tetlow and von zur Muehlen (2001) show that model uncertainty may call for a more activist policy stance, although the worst possible models for the kind of historical Fed policy rule may not describe plausible structures of the economy (see Onatski, 2000). The intuition for this result comes from the fact that the central bank plays a game against a malevolent nature in which only worst case scenarios matter for policy making. This implies that an aggressive rule may be the optimal response of monetary authorities to large departures of inflation and output from the target values.

4.2 A novel approach: 'thick modeling'

The standard practice of econometric modelling is to choose among a set of relevant specifications the best according to some model selection criterion like *adjusted* R^2, *Akaike* or *Schwarz*, discarding any information in the alternative specifications. In practical policy making, however, it is not clear that this may be a good strategy and policy makers, who are uncertain about the future state of the economy, may find retaining and combining all information in a number of close specifications a superior strategy. The reason for that mirrors the results in the literature of optimal forecasting (and portfolio allocation) which demonstrate that the combination of forecasts (assets) is often a better procedure than using the best single forecast (asset). Then, *mutatis mutandis*, the monetary authority may prefer to consider the range of a wide number of optimal monetary policies, each one corresponding to the solution of the control problem associated to a different structure of the economy, rather than to come up with a single policy rule which is optimal only within the model specification in which it has been derived. In so doing, they may end up with as many policy prescritions as the number of relevant macroeconomic scenarios. To the extent that the latter differ in the lag specification of the monetary transmission mechanism and that policy makers have no strong *a priori* on the future state of the economy, the *thick* modelling of combining those prescriptions comes as a simple strategy for the design of a global optimal policy without requiring any restrictive decision about what model will provide the best description of the economy.

In practice, we specify a class of nested models for the structure of the economy and propose some *a priori* criterion to pool into a single robust *thick* policy rule the information that relate to the design of monetary policy. To this end, we estimate by OLS the dynamics generated by the relevant combinations of a base set of eight regressors for the AS and nine for the AD whose richest specification takes the following form:

$$\pi_{t+1} = \alpha_1\pi_t + \alpha_2\pi_{t-1} + \alpha_3\pi_{t-2} + \alpha_4\pi_{t-3} + \alpha_5 y_t + \alpha_6 y_{t-1} + \alpha_7 y_{t-2} + \alpha_8 y_{t-3} + \xi_{t+1} \tag{9}$$

$$y_{t+1} = \beta_1 y_t + \beta_2 y_{t-1} + \beta_3 y_{t-2} + \beta_4 y_{t-3} + \beta_5\pi_t + \beta_6\pi_{t-1} + \beta_7\pi_{t-2} + \beta_8\pi_{t-3} + \beta_9\left(\bar{\imath}_t - \bar{\pi}_t\right) + \eta_{t+1} \tag{10}$$

The selection of the relevant models is based on both empirical and theoretical arguments. First, we keep fixed across specifications the first lag of inflation and output gap in the AS and AD respectively. In so doing, we end up with those models displaying a fairly good empirical fit. Moreover, we discard the specifications that do not allow monetary policy to have a direct impact on the economy through both equations. In particular, we take the real interest rate, $\bar{\imath}_t - \bar{\pi}_t$, as a further fixed regressor and we constraint the AS to be dependent from, at least, one of the lagged values of the output gap. The latter amounts to cut off approximately the five percent of the 2^7x2^7 models specified in this class. Finally, we derive the optimal policy rules for each of the retained AD-AS specifications and we let policy makers implement, at each point in time, the average of the optimal rates associated to those specifications.

A number of alternative weighting schemes may be appropriated for computing the average optimal policy. Instead of using a simple statistical pooling, Granger and Jeon (2001) argues that a simple averaging may serve for the purpose at hand, corresponding to what in the literature is usually refered to as a non-informative prior with equal weights given to different monetary policies. An alternative somewhat in the spirit of Bayesian econometrics is to weight the OLS estimates across models by some statistical criterion corrected for the degrees of freedom. Doppelhofer, Miller and Sala-i-Martin (2000) propose a weighting criterion analogous to the Schwarz in the context of the so-called Bayesian averaging of classical estimates (BACE), which has the advantage over the Bayesian model averaging of not requiring any specification of prior distributions for the model parameters.

These alternative weighting schemes describe the robust policy rules that we use in the next section to evaluate the ability of model uncertainty to account for the observed interest rate smoothing. Our *thick* strategy is in the spirit of Favero and Milani (2001), although we take three important departures. First, we analyze a different sample according to the reasoning that policy preferences are Chairman-specific. Second, we endogenously determine these preferences rather than simply imposing them. Lastly, we evaluate the robustness of our results to different weighting schemes for averaging the optimal policies obtained under the alternative policy scenarios.

5 The Fed policy preferences under model uncertainty

In this section, we use our identification method to recover the preference parameters for the Greenspan's tenure in the presence of model uncertainty. In order to gauge the merits of the robust *thick* policy rule we compare our results with those obtained under a multiplicative parameter uncertainty which a number of researchers have advocated as an important, although not exhaustive, source of policy attenuation (see Sack, 2000, Sack and Wieland, 2000, and Rudebusch, 2001 among others).

It is worthy to note that in contrast to the analysis in section 3, which considers a single specification of the economy and thus a single optimal rule, the calibration is based here on the distance between fitted and *thick* policy rates, where the latter are computed as some average of the optimal rules for each of the relevant models. In so doing, we incorporate model uncertainty into the identification of policy preferences. In other words, we investigate whether the Fed cares about model misspecification by assessing the ability of a *robust* rule to match the data without resorting to implausibly high values for the interest rate smoothing parameter.

5.1 The robust thick policy rule

The third row of table 2 reports some descriptive statistics of the optimal rule under model uncertainty as well as the corresponding calibrated policy parameters. The revealed preferences for the Greenspan's chairmanship write now $\lambda = 0.00$ and $\mu = 0.11$ while the first two moments of the associated optimal path are consistent with the historical policy (first row). Moreover, the average distance is still fairly low and the standard deviation of the interest rate changes, which actually defines interest rate smoothing, remains virtually identical moving from the historical rule to the robust *thick* rule. While the statistics and the following figures on model uncertainty refer to the simple average case, the picture does not change, both qualitatively and quantitatively, weighting each optimal policy with the relative *adjusted* R^2, *Akaike* and *Schwarz* criterion respectively. In the light of our trimming strategy, this result does not come as a surprise since the closer are the retained specifications the more the weighted average tends to the simple average, that is the grater is the likelihood that similar weights are attached to each specification.

Figure 2 compares the two optimal paths associated to the preferences $\lambda = 0.00$ and $\mu = 0.11$ in the absence and under model uncertainty respectively. The robust *thick* policy rule effectively describes the main features of funds rate movements throughout the sample, although there are some differences in magnitude. While this suggests that other source of uncertainty such as measurement errors for inflation and output gap may also be relevant, we find that by considering model misspecifications most of the *interest rate smoothing puzzle* seems to vanish, as the relative preference parameter take now only a modest value. Model uncertainty is eventually crucial because whenever neglected the optimal policy rule looses its ability to match the data. Hence, any identification method that did not take this form of uncertainty into account would miss an important part of the story, thereby delivering a set of policy preferences that cannot be sensibly interpreted.

The revealed policy preferences computed under model uncertainty show that the conduct of monetary policy in the US is successfully described by a *strict inflation targeting* as defined by Svensson (1999), and Rudebusch and Svensson (1999). According to it, the stabilization of output around potential has not been a final concern of the Federal Reserve (i.e. $\lambda = 0.00$). However, we do not mean that the output gap has been unimportant in policy actions. Indeed, as argued by Favero and Rovelli (2002) and Dennis (2001), it may well be that the output gap has been regarded as a leading indicator for future inflation rather than as a goal variable per sè (i.e. as an argument in the reaction function rather than in the loss). An alternative, in the spirit of the evidence in Smets (1999), Estrella and Mishkin (1999), and Wieland (1998) on output gap uncertainty, is that monetary authorities have placed less weight on the most poorly measured target, or yet, that the marked productivity growth of the 90s has drastically reduced any concern towards output stabilization.

5.2 Model uncertainty vs. parameter uncertainty

The result that uncertainty makes smoother an otherwise volatile path of policy rates does not come as new in the literature and a number of empirical studies have recently shown that multiplicative parameter uncertainty limits the responsiveness of the interest rate (see Sack, 2000 and the references therein). A relevant question at this point is the extent to which parameter uncertainty would be capable alone to replicate the observed path or rather there exists room for other forms of uncertainty. To this end, we bring together in the last two rows of table 2 some descriptive statistics for the robust policy rules obtained under model and parameter uncertainty respectively. We take as given the revealed policy preferences $\lambda = 0.00$ and $\mu = 0.11$, which assigns a very limited role to an interest rate smoothing goal, so that the performance of the robust rules can be readily compared. The computational difference between the two robust rules stems from the distribution of the AS-AD coefficients which only under parameter uncertainty are centered around our estimates of the Rudebusch and Svensson (1999) model and shaped by the relative estimated standard errors. By contrast, the robust *thick* approach does not impose any mean value to the parameter distributions whose support reflects a model specification uncertainty rather than the classical estimation uncertainty due to sampling.

The last row of table 2 shows that multiplicative parameter uncertainty attenuates the policy response of monetary authorities such that the relative robust descriptive statistics come closer to the data than the single specification counterparts. Nevertheless, the robust optimal policy seems to reduce but not to close the gap with the observed monetary policy confirming the conclusions in Sack (2000) and Rudebusch (2001). In addition, taking model uncertainty into account makes the robust *thick* policy rule more successful at describing the policy rate dynamics than the parameter uncertainty robust rule. This can be seen not only from the first two moments and the average distances but also, more importantly, from the standard deviations of the interest rate changes. Consistent with these findings, Figure 3 shows that the behavior of policy rates is considerably smoother under model uncertainty than under parameter uncertainty as the robust *thick* policy rule shows more limited deviations from the historical rule.

We interpret these results as the evidence that model misspecification has been an important concern of the Fed such that its ability to limit the responsiveness of the fed funds rate goes beyond the ability of a multiplicative parameter uncertainty.[11]

6 Conclusions

Actual policy rates appear to be smoother than optimal monetary policies predict. An obvious way to reconcile the historical evidence with an optimizing central bank behavior is to model the aversion to interest rate fluctuations as an independent argument in the central bank's loss function. However, the relative parameter should be imposed at values so high as they cannot be easily motivated by the theory, thereby making this choice alone unsatisfactory.

This paper contributes to the literature of optimal monetary policy by presenting a novel method to solve for a relevant form of uncertainty in practical policy making, namely uncertainty about the structure of the economy. While there may well be also other rationales such as data uncertainty or a minor goal to avoid interest rate variability, it is shown that the concern for potential misspecifications of the macroeconomic dynamics creates incentives for monetary authorities to move policy rates in a gradual manner. Indeed, a thich approach to model uncertainty appears to solve most of the observed *interest rate smoothing puzzle* as the preference calibration based on a robust policy rule returns values which are more readily interpretable. Moreover, the preference parameters 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.

We take these results as a promising deal for future research and the calibration exercise we propose proves these potentialities. Intriguing identification strategies for the preference parameters have returned unattractive results in that they display either implausible values for the inertial coefficient or extremely volatile paths for the policy rates whenever model uncertainty is neglected. By contrast, our revealed preferences move to sensible values when the calibration incorporates a wide number of possible specifications. This seems to suggest that most of the observed policy inertia can be better interpreted as a consequence of mone-

[11] It should be noticed that we have modelled parameter uncertainty as the perturbation of the slope coefficient of inflation and the interest rate sensitivity on output only. While varying all parameters produces only limited changes, an alternative would be to consider a richer macroeconomics dynamics as the one in a VAR specification of the economy. However, Sack (2000) shows that even involving very persistent interest rate movements, the optimal policy derived within a VAR dynamics is still more aggressive than the observed policy.

tary policy making under uncertainty rather than as an objective in itself and that omitted model uncertainty may lead to the spurious finding of an independent goal for interest rate smoothing.

Furthermore, our robust *thick* modeling can be extended to alternative formulations of the inflation dynamics and the output gap dynamics in order to evaluate the empirical relevance of model uncertainty within a class of non-nested specifications. Lansing and Trehan (2001), for instance, show that by introducing some degree of forward-looking behavior in output, the responses to inflation and output gap recommended by an optimizing Taylor rule are less pronounced. In particular, they show that private sector expectations may be an important channel through which monetary policy can be effectively conducted by means of small interest rate changes (see also Levin, Wieland and Williams, 1999, Sack and Wieland, 2000, and Castelnuovo, 2003). However, Söderlind, Söderström and Vredin (2002), who calibrate the preferences of the Fed within a New-Keynesian model of output and inflation, still find a large value for the policy parameter on interest rate smoothing. This suggests that model uncertainty about the relevant macroeconomic dynamics may turn out to be an issue also in such a framework and therefore further work can be usefully done along these lines.

7 Appendix: the optimal control problem

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

$$E_t \sum_{\tau=0}^{\infty} \delta^{\tau} LOSS_{t+\tau} \tag{11}$$

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

$$LOSS_t = \bar{\pi}_t^2 + \lambda y_t^2 + \mu (i_t - i_{t-1})^2 \tag{12}$$

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 and μ represent the relative policy preferences of the central bank towards output stabilization and interest rate smoothing respectively. The inflation stabilization weight in the objective function is normalized to one.

When the discount factor, δ, approaches unity, the intertemporal loss function in (11) approaches the unconditional mean of the period loss function:

$$E[LOSS_t] = Var[\bar{\pi}_t] + \lambda Var[y_t] + \mu Var[\Delta i_t] \tag{13}$$

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:

$$X_{t+1} = AX_t + Bi_t + \eta_{t+1} \tag{14}$$

where the elements of (14) are given by:

$$X_t' = \begin{bmatrix} \pi_t & \pi_{t-1} & \pi_{t-2} & \pi_{t-3} & y_t & y_{t-1} & i_{t-1} & i_{t-2} & i_{t-3} \end{bmatrix} \tag{15}$$

$$A = \begin{bmatrix} \alpha_1 & \alpha_2 & \alpha_3 & \alpha_4 & \alpha_5 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ \frac{-\beta_3}{4} & \frac{-\beta_3}{4} & \frac{-\beta_3}{4} & \frac{-\beta_3}{4} & \beta_1 & \beta_2 & \frac{\beta_3}{4} & \frac{\beta_3}{4} & \frac{\beta_3}{4} \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \end{bmatrix}, \quad B = \begin{bmatrix} 0 \\ 0 \\ 0 \\ 0 \\ \frac{\beta_3}{4} \\ 0 \\ 1 \\ 0 \\ 0 \end{bmatrix} \tag{16}$$

$$\eta_t' = \begin{bmatrix} \varepsilon_t & 0 & 0 & 0 & u_t & 0 & 0 & 0 & 0 \end{bmatrix} \tag{17}$$

X_{t+1} is the $9x1$ vector of state variables, i_t is the policy control (i.e. the federal funds rate) and η_{t+1} is a $9x1$ vector of supply and demand iid normally distributed shocks with mean vector zero and covariance matrix $E\eta_t\eta_t' = \Omega$. Lastly, A and B are the matrices of behavioral parameters.

The loss function in (12) can be represented in a more compact form by defining the $3x1$ vector Y_t of goal variables. This vector reads:

$$Y_t = CX_t + Di_t \tag{18}$$

where the elements of (18) are given by:

$$Y_t = \begin{bmatrix} \bar{\pi}_t \\ y_t \\ i_t - i_{t-1} \end{bmatrix}, \quad C = \begin{bmatrix} \frac{1}{4} & \frac{1}{4} & \frac{1}{4} & \frac{1}{4} & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & -1 & 0 \end{bmatrix}, \quad D = \begin{bmatrix} 0 \\ 0 \\ 1 \end{bmatrix} \tag{19}$$

Accordingly, the loss function can be rewritten as:

$$LOSS_t = Y_t'RY_t \tag{20}$$

where R is a negative semidefinite symmetric $3x3$ matrix characterized by the weight 1, λ and μ on the main diagonal and zeros elsewhere. Then, the central bank optimal control problem is to minimize over choice of $\{i_t\}_{t=0}^{\infty}$ the criterion:

$$\sum_{\tau=0}^{\infty} \delta^{\tau} \left\{ Y_{t+\tau}' R Y_{t+\tau} \right\} \tag{21}$$

subject to the dynamic evolution of the economy described in (14) 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 convenient 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, Ω, as the certainty equivalence holds. Then, the first-order necessary condition turns out to be:

$$\left(S + \delta B'PB\right) i = -(V' + \delta B'PA)X \tag{22}$$

This implies the following feedback rule for the policy instrument

$$i = fX \tag{23}$$

where f is given by:

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

The $9x9$ matrix P is the solution of the algebraic Riccati equation:

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

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

The reaction function (23) 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.

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 $9x9$ matrix M is equal to $A + Bf$.

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Table 1 - Historical policy rule vs. optimal policy rules: a quantitative comparison of empirical evidence

Panel A: Descriptive statistics of the fitted policy rule, 1987:3 – 2001:1

Mean	*Standard deviation*
0.000	1.7307

Panel B: Descriptive statistics, policy preferences and average distance of the optimal rules

Author/s	*Estimates*	*Mean*	*Standard deviation*	*Average distance*
Castelnuovo and Surico (present paper)	λ = 1.000 μ = 8.000	0.4913	1.9100	1.4459
Dennis (2001)	λ = 0.815 μ = 6.181	0.4888	1.9797	1.4894
*Favero and Rovelli (2002)**	λ = 0.00125 μ = 0.00850	0.3564	16.9932	41.5373
Ozlale (2001)	λ = 0.525 μ = 0.975	0.5563	2.4752	2.8621

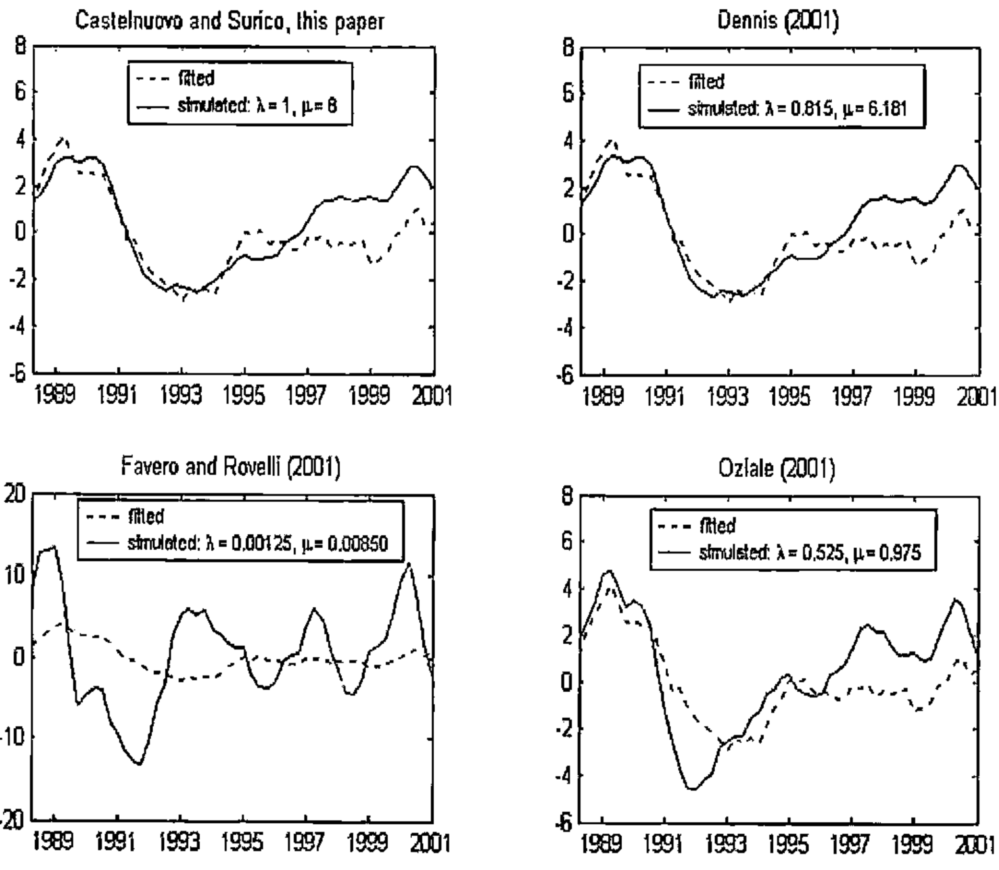
* The estimates in Favero and Rovelli are based on the Volcker-Greenspan period, 1980:3 1998:3, rather than on the Greenspan tenure only, from the 1987:3 onwards. As discussed in the main text, this does not affect our conclusions.
Note: the preference parameter on inflation stabilization is normalized to one. The parameter on output stabilization is denoted by λ while the one on interest rate smoothing is μ. The average distance is measured as the mean of the sum of the squared deviations between optimal and fitted policy rates at each point in time.

Table 2 – Optimal monetary policy rules and uncertainty: descriptive statistics

Optimal Rules	*Estimates*	*Mean*	*Standard deviation of interest rate levels*	*Standard deviation of interest rate changes*	*Average distance*
Fitted policy rule	- -	0.000	1.7307	0.5207	-
Thin policy rule	λ = 0.000 μ = 0.111	0.4635	4.2493	1.2980	11.4717
Thick model uncertainty robust policy rule	λ = 0.000 μ = 0.111	0.0087	1.8024	0.5165	2.0385
Parameter uncertainty robust policy rule	λ = 0.000 μ = 0.111	0.3051	2.9353	0.8439	3.5341

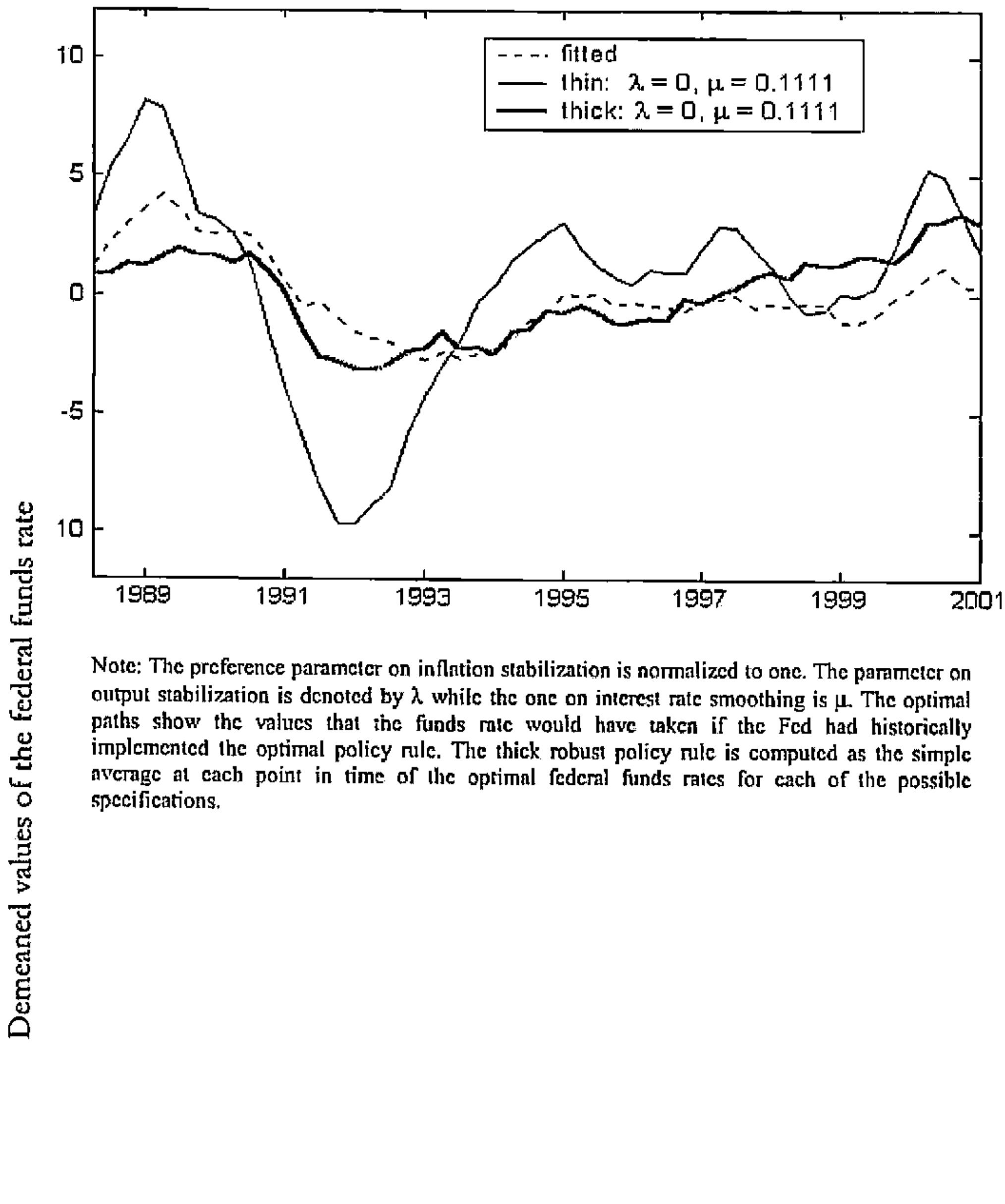
Note: the preference parameter on inflation stabilization is normalized to one. The parameter on output stabilization is denoted by λ while the one on interest rate smoothing is μ. The average distance is measured as the mean of sum of the squared deviations between optimal and fitted policy rates at each point in time. The thick robust policy rule is computed as the simple average at each point in time of the optimal rates for each of the possible specifications. The parameter uncertainty robust policy rule is computed as multiplicative uncertainty on the key coefficients α_3 (slope of the Phillips curve, equation (1) in the main text) and β_3 (semi-elasticity of the output-gap with respect to the real interest rate, equation (2) in the main text). The uncertainty is determined upon the Variance-Covariance matrix of the OLS estimators.

Figure 1 - Historical policy rule vs. optimal policy rules: a graphical comparison of empirical evidence



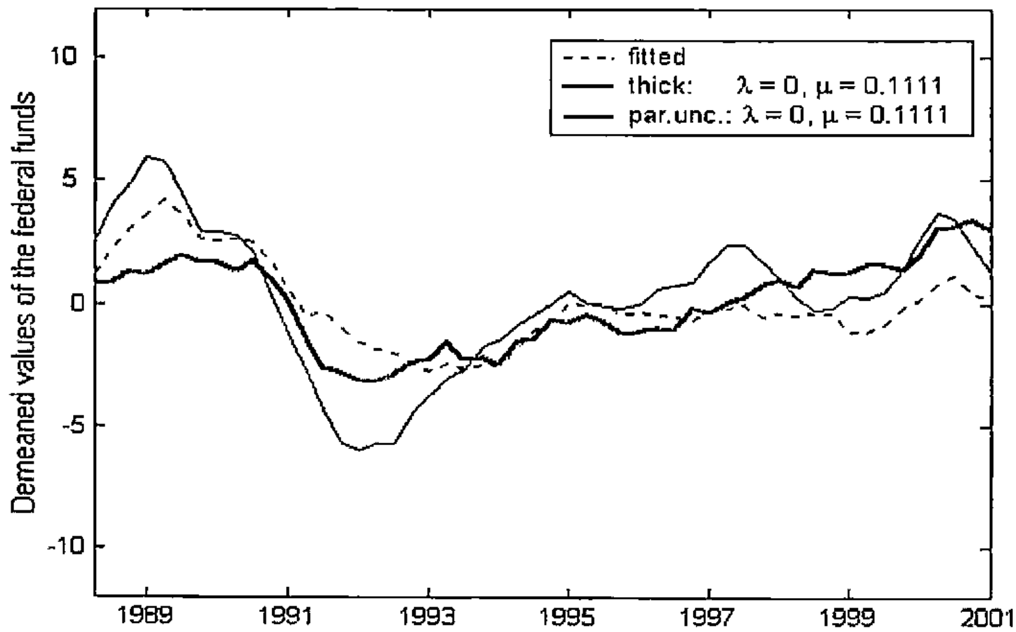
Note: the preference parameter on inflation stabilization is normalized to one. The parameter on output stabilization is denoted by λ while the one on interest rate smoothing is μ. Each optimal path shows the values that the funds rate would have taken if the Fed had historically implemented that optimal policy rule. Demeaned values of the federal funds rate are on the vertical axis.

Figure 2 - Thick robust policy rule vs. thin policy rule



Note: The preference parameter on inflation stabilization is normalized to one. The parameter on output stabilization is denoted by λ while the one on interest rate smoothing is μ. The optimal paths show the values that the funds rate would have taken if the Fed had historically implemented the optimal policy rule. The thick robust policy rule is computed as the simple average at each point in time of the optimal federal funds rates for each of the possible specifications.

Figure 3 - Model vs. parameter uncertainty



Note: The preference parameter on inflation stabilization is normalized to one. The parameter on output stabilization is denoted by λ while the one on interest rate smoothing is μ. The optimal paths show the values that the funds rate would have taken if the Fed had historically implemented the optimal policy rule. The thick model uncertainty robust policy rule is computed as the simple average at each point in time of the optimal federal funds rates for each of the possible specifications. The parameter uncertainty robust policy rule is computed as multiplicative uncertainty on the key coefficients α_j (slope of the Phillips curve, equation (1) in the main text) and β_j (semi-elasticity of the output-gap with respect to the real interest rate, equation (2) in the main text). The uncertainty is determined upon the Variance-Covariance matrix of the OLS estimators.

Squeezing the Interest Rate Smoothing Weight with a Hybrid New-Keynesian Model*

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Abstract

How to replicate the observed federal funds rate *smooth* behavior with a small scale macroeconomic model? In this paper we compare the descriptive performance of a calibrated fully backward looking model with that of a calibrated hybrid representation of the economy. It turns out that the Fed's monetary policy conduct can be very well described with a hybrid New-Keynesian model which allows for the presence of a small but positive fraction of forward looking agents. In fact, the explicit formalization of forward looking agents dramatically reduces the large interest rate smoothing weight otherwise needed to track the observed federal funds rate pattern. Together with a measurement of this reduction, we also provide some calibrated/estimated values regarding the Fed's preferences and the structural parameters of our economic model for the sample 1987Q3-2001Q1.

Keywords: Central Banker, interest rate smoothing, forward looking agents, hybrid Phillips curve, hybrid IS curve.

JEL Classification System: C51, E52.

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1 Introduction

In the recent applied monetary policy literature, a simple framework representing the Central Banker (CB hereafter)'s problem has been extensively exploited. In this framework, the CB's loss function considers variables such as the inflation rate and the output gap (or the unemployment rate), while the economy is formalized via a Phillips curve and an IS schedule.[1] Interestingly enough, with this framework the solution of the CB's optimal control problem turns out to be an interest rate path featured by frequent reversals, reversals due to the willingness of the CB to tackle the various shocks affecting the economy. In fact, in the real world we observe smooth paths of the policy rates; this tendency has been labeled as *interest rate smoothing*.[2] To capture this feature of the policy rate the CB's loss function has typically been enriched with a penalty for the interest rate change, i.e. the interest rate smoothing argument.

Indeed, there seems to exist a *trade-off* between economic plausibility (of the relative weight μ attributed to the interest rate smoothing volatility in the loss function) and goodness-of-fit (associated to the small-macro scale model in use). Castelnuovo and Surico (2003) consider different studies (i.e. Dennis, 2002; Ozlale, 2003; Favero and Rovelli, 2003) in which researchers have estimated the Fed's relative preferences. In these empirical efforts, there is a common economic model (i.e. Rudebusch and Svensson, 1999,2002), but different econometric techniques are employed. It turns out that when economically sensible (i.e. relatively low) values of the μ parameter are estimated, the optimal simulated interest rate (in first differences) shows a much larger volatility than the historical one. Furthermore, authors such as Goodhart (1999), Sack (2000), Sack and Wieland (2000), and Cecchetti (2000) claim that a smooth interest rate may very well be the solution of a problem in which there is *not* any interest rate smoothing targeting. In particular, Sack and Wieland (2000)

[1] A very incomplete list of contributions built up on this simple framework includes Ball (1999), Rudebusch and Svensson (1999,2002), Nessen and Vestin (2000), Dennis (2002,2003), Söderlind, Söderström, and Vredin (2002), Favero and Rovelli (2003), Rudebusch (2001,2002a,b,c), Smets (2002), Masuch, Nicoletti Altimari, Pill, and Rostagno (2002), Aksoy, De Grauwe, Dewachter (2002), Ozlale (2003), and Castelnuovo and Surico (2003).

[2] Rudebusch (1995), Goodhart (1997), Lowe and Ellis (1998), Sack and Wieland (2000), and Srour (2001) are examples of studies focused on the interest rate smoothing evidence. Interestingly, in a recent contribution Rudebusch (2002a) claims that the monetary policy inertia observed at a quarterly frequency is just an *illusion*. Nevertheless, English, Nelson, and Sack (2003) and Castelnuovo (2003a,b) run a direct test on the existence of the CB's sluggish adjustment strategy, finding it statistically relevant.

conjecture that forward looking agents, uncertainties regarding the dynamics of the economy, and measurement-errors problems might induce monetary authorities to implement a cautious policy. From this standpoint, the interest rate smoothing element embedded into the loss function is just a *residual* capturing what it is left out of the model.

Sack and Wieland (2000)'s considerations motivate this research. In particular, in this paper we focus our attention on the relationship between interest rate smoothing and *forward looking agents* (FLA hereafter). In fact, private sector's expectations may play a key role in monetary policy making. Prices and production primarily react to long-term interest rates, which are in turn influenced by expectations on future movements of the short-term ones. Then, the announcement of a small change in the short term policy rate's reference value may trigger important nominal and real effects if private agents *expect* this change to be followed by a sequence of others. Of course, these expectations are formed only if agents *believe* this is going to happen, e.g. if the CB has historically implemented *smooth* patterns of the policy rates. To support this reasoning, Sack and Wieland (2000) report a statement by Otmar Issing (1997), current member of the Executive Board of the European Central Bank and former Chief Economist at the Bundesbank:

> *"If changes in official rates in a certain direction that are confirmed by repetition and not expected to be reversed soon have most influence on longer-term rates, it would seem appropriate for the Bundesbank to adjust its official rates in the smoothest manner."*

Many researchers (e.g. Amato and Laubach, 1999; Levin, Wieland, and Williams, 1999,2002; Rotemberg and Woodford, 1999; Williams, 1999; Woodford, 1999) have investigated this issue from a *normative* standpoint, e.g. they have replied to a question like "Can a credible, inertial policy be beneficial when the private sector is forward looking?". The answer coming from these studies has been unanimously positive. In fact, if agents expect future gradual moves by the CB, they will adjust their inflation and output gap expectations toward the CB's targets, so helping policy-makers to stabilize the economy.

Somewhat surprisingly, the *quantitative* importance of the FLA ingredient in the context of the trade-off pointed out above has not been assessed yet in the literature. How large is the impact of the FLA component on the interest rate smoothing weight in the CB's penalty function? Is the FLA chunk helpful for tracking the observed federal funds rate path? In this study, we aim at understanding *how much descriptive power* a small macro model may gain when passing from a backward looking formalization of the economy to a representation in which there is room for forward looking agents. In our study, we use an encompassing AD-AS model à la Rudebusch (2002b) that, under some identifying restrictions, may collapse to a backward looking, hybrid, or fully forward looking illustration of the linkages existing among inflation, output gap, and the policy rate. For each different vector of 'structural' parameters identifying the economic framework, we calibrate the weight to be attributed to the interest rate smoothing argument in order to fit the actual federal funds rate at best. The lower the weight, the better the model performance from a positive standpoint. To our knowledge, this the first effort oriented at quantitatively assessing the role of FLA in designing these small macro models.

In performing our exercise we concentrate on the American federal funds rate along most of Greenspan's regime. Our comparison of the results obtained with a fully backward looking model with those stemming from our hybrid version of the economy allows us to state that the presence of the FLA element guarantees significant gains in terms of data-fitting.

Notice that we reach this result under discretion. In fact, in our framework agents know that the CB aims at minimizing a loss function featured by the presence of a penalty for the short-run nominal interest rate volatility. Then, even if the CB re-optimizes in each period, its optimal choice will be history-dependent (Woodford, 1999). Therefore, the interest rate smoothing penalty is to be interpreted as a proxy for CB's concerns such as credibility, uncertainties, and learning; these concerns are understood by private agents, and provide a *rationale* for private agents' expectations of an inertial rate under discretion.

Overall, our calibration exercises suggest that a hybrid new-Keynesian may very well fit the data. In particular, a low relative concern for output gap volatility, a low degree of 'forward lookingness' in both the Phillips curve and the IS curve, and a high weight the expected real-interest rate are the features of our best positive model. In this sense, our findings are fairly in line with those contained in recent works by Söderlind, Söderström, and Vredin (2002), Dennis

(2003), and Mayer (2003). Implicitly, our empirical evidence suggests that much more should be done in order to better understand the role of adjustment costs and habit formation in shaping the dynamics of variables such as inflation and the output gap (as done by e.g. Fuhrer and Moore 1995, Fuhrer 2000, and Estrella and Fuhrer 2002).

The map of the paper is the following. Section 2 describes the modeling framework we employ for performing our exercise. In Section 3 we discuss our strategy for evaluating the importance of the FLA ingredient. In Section 4 we show and comment our findings. Section 5 discusses the importance of FLA. In Section 6 we deepen our analysis with a robustness check. Section 7 reviews some other possible ingredients potentially capable to ulteriorly reduce the interest rate smoothing weight in the loss function. Section 8 concludes. References follow.

2 Modeling the Central Banker's problem

We assume that the CB determines the optimal path of its control variable, i.e. the short term nominal interest rate, in order to minimize a penalty function. The period loss function reads as follows:

$$L_t = (\overline{\pi}_t)^2 + \lambda(y_t)^2 + \mu(i_t - i_{t-1})^2 \qquad (1)$$

where π_t represents the inflation rate, y_t is the output gap, and i_t is the short-term nominal interest rate (e.g. the federal funds rate).[3] A few comments on this definition of the loss function are needed. The target level for inflation is normalized to zero, while our definition of the output gap implies that the target for the level of output set by the CB is the potential output, as plausibly done by the Fed (Blinder, 1997).[4] Finally, in (1) the weight λ represents the

[3] The variables used in our study have been constructed as follows: π_t is the four-quarter inflation rate computed on the basis of the GDP chain-weighted price index P_t, i.e. $\pi_t \equiv 4(p_t - p_{t-1})$, where $p_t = 100 \ln P_t$. y_t is the output gap, i.e. $y_t \equiv q_t - q_t^*$, where $q_t \equiv 100 lnQ_t$, while $q_t^* \equiv 100 lnQ_t^*$. Q_t is the real GDP level, while Q_t^* is the potential output. Finally, upper-barred variables indicate simple averages taken over the contemporaneous observation and the previous three lags of the variable in consideration. All the series used in our analysis are downloadable from the Federal Reserve Bank of St. Louis' web-site, i.e. http://research.stlouisfed.org/fred2/. The potential output series is the one estimated by the Congressional Budget Office.

[4] Indeed, the monopoly-power held by firms in the underlying structure of the economy might lead to think about a CB willing to set a higher target level, given that the equilibrium production in case of monopolistic competition is lower than the socially desirable one.

preference of the CB over the output gap relative to inflation. Instead, given our interpretation of the interest rate smoothing argument, the weight μ should be seen as a residual, or a necessary proxy for replicating the observed path of the federal funds rate.

We assume that the CB solves an *intertemporal* optimization problem. We shape the CB's loss function as follows:

$$\underset{\{i_t\}}{Min}\ E_t \sum_{j=0}^{\infty} \delta^j L_{t+j} \tag{2}$$

As shown by Rudebusch and Svensson (1999), when the discount rate $\delta \rightarrow 1$, equations (1) and (2) can be rewritten as follows:

$$\underset{\{i_t\}}{Min}\ E(L_t) = Var(\overline{\pi}_t) + \lambda Var(y_t) + \mu Var(i_t - i_{t-1}) \tag{3}$$

So, the conditional mean (2) collapses to its unconditional counterpart, which is equal to the weighted sum of the unconditional variances of the loss function's arguments. Hereafter, we will consider equation (3) as the CB's objective function.

We now turn to the representation of the economic environment. We adopt a model à la Rudebusch (2002b), which reads as follows:

$$\pi_{t+1} = \gamma_\pi E_t\ \overline{\pi}_{t+4} + (1-\gamma_\pi) \sum_{j=1}^{4} \alpha_{\pi j}\pi_{t-j+1} + \alpha_y y_t + \varepsilon_{t+1} \tag{4}$$

$$\begin{aligned} y_{t+1} \quad = \quad & \gamma_y E_t y_{t+2} + (1-\gamma_y) \sum_{j=1}^{2} \beta_{yj} y_{t-j+1} \\ & -\gamma_r \beta_r (i_t - E_t\ \overline{\pi}_{t+4}) - (1-\gamma_r)\beta_r(\overline{i}_t - \overline{\pi}_t) + \eta_{t+1} \end{aligned} \tag{5}$$

where γ_π represent the 'degree of forwardness' of the dynamic Phillips curve (4), while γ_y and γ_r are the weights of the FLA elements of the expected demand and the expected real interest rate in the IS equation (5). A few comments are due here. First, following some researchers' example (e.g. Fuhrer and Moore,

However, by introducing a target greater than the potential output, the CB would face an inflation bias problem (Barro and Gordon, 1983). That is why in our study the output gap target is equal to zero. However, under discretion the optimal policy implies a larger volatility for inflation and the interest rate and a lower volatility for the output gap than the one we would observe under commitment. This inefficiency has been labelled as "stabilization bias".

1995; Clarida, Galí and Gertler, 1999; Rudebusch and Svensson, 1999, 2002), we admit a stochastic element in the Phillips curve, the *cost-push* shock ε_t, which is responsible for the short-run trade-off existing between inflation and output gap. We also admit a demand shock in the IS curve, namely η_t. In this latter curve, we consider the possibility of having a 'hybrid' representation of the short-term real interest rate; we do so to be consistent with the overall 'hybrid' economic set up we want to take into account performing our exercises. Finally, notice that, when $\gamma_\pi = \gamma_y = \gamma_r = 1$, this model collapses to the well-known 'New Neoclassical Synthesis' model by Goodfriend and King (1997).

The model (4)-(5) may be re-written in its state space form as follows:

$$A_0 \begin{bmatrix} x_{1t+1} \\ E_t x_{2t+1} \end{bmatrix} = A_1 \begin{bmatrix} x_{1t} \\ x_{2t} \end{bmatrix} + B_1 i_t + v_{t+1} \tag{6}$$

where A_0 and A_1 are squared matrices of size $(n1+n2)$, B_1 is a $((n1+n2)\times 1)$ columns vector, x_{1t} is the $(n1\times 1)$ column vector of predetermined state variables (with $n1 = 9$), i.e. $x_{1t} = [\pi_t\ \pi_{t-1}\ \pi_{t-2}\ \pi_{t-3}\ y_t\ y_{t-1}\ i_{t-1}\ i_{t-2}\ i_{t-3}]'$, and x_{2t} is the $(n2 \times 1)$ column vector of forward-looking jump variables (with $n2 = 4$), i.e. $x_{2t} = [E_t\pi_{t+3}\ E_t\pi_{t+2}\ E_t\pi_{t+1}\ E_t y_{t+1}]'$.[5]

The CB's aim is that of optimally setting the path of the interest rate i_t in order to minimize the expected loss (3) subject to the law of motion (6). The timing of the game is the following: At the beginning of each period private agents form their expectations; then, the interest rate level is optimally fixed by the Central Bank; finally, demand and supply shocks strike the economy. Söderlind (1999) proves the optimality of the linear feedback rule

$$i_t = -F x_{1t} \tag{7}$$

where F is the $(1 \times n1)$ row vector whose elements are convolutions of the structural parameters in (6) and the coefficients attached to the arguments in the objective function (3).

In our positive exercises we compute the optimal monetary policy under discretion. We do so because we believe that this set up may well approximate Greenspan's monetary policy conduct. Our choice is supported both by some

[5] A description on how to conveniently set up and solve the optimal control problem proposed in this paper is provided in Söderlind (1999). The Technical appendix related to our exercise is available upon request.

academics' opinion (e.g. Jensen, 2002; Söderlind, Södeström, and Vredin, 2002) and by some Governors' official declarations (e.g. Bernanke, 2003).[6]

The model (6)-(7) fairly replicates the dynamics featuring the American economy.[7] In this framework the transmission of the monetary policy action happens with some lags. This is in line with what the observation of the real economy seems to suggest, i.e. a change in the interest rate level affects the output gap with a certain delay, and the inflation rate even with a larger delay, as underlined in Christiano, Eichembaum and Evans (1998, 2001). Indeed, the presence of the backward looking part of the model enables us to introduce the FLA component without inducing counterfactual dynamics in the system; for a contribution about this point, see Estrella and Fuhrer (2002).

With this model at hand, we can calibrate the value of the weight μ in order to find the optimal simulated interest rate that most closely replicate Greenspan's federal funds rate. In the next section we describe our econometric strategy.

3 Econometric strategy

The aim of our exercise is to fit the policy rate set by Alan Greenspan in the sample 1987Q3-2001Q1.[8] In doing so, we consider two different set of identification restrictions on equations (4)-(5). The first one - our benchmark model, i.e. our fully backward looking specification - is featured by $\gamma_\pi = \gamma_y = \gamma_r = 0$.[9] This benchmark model will deliver us with the value that we have to assign to the parameter μ in order to replicate the historical path of the federal funds rate while neglecting the FLA component. The second set of restrictions identify our Hybrid version of the model, featured by the presence of an explicit

[6] To be precise, Bernanke (2003) defines the concept of 'constrained discretion', which is approximated by the policy framework we adopt in our work, i.e. inflation targeting under discretion.

[7] A plot of some impulse response functions under our benchmark parametrization is available upon request.

[8] The choice of Greenspan's period is suggested both by sample-length considerations (he has been in charge since the third quarter of 1987, a sample longer than those of the other chairmen) and by our willingness to compare our findings with the available literature, which mostly concentrates on the post-Volcker era. Also, we think it is plausible to consider the Fed's preferences as being chairman-specific.

[9] A fully backward looking framework like this has been used for monetary policy analyses by Ball (1999), Rudebusch and Svensson (1999, 2002), Peersman and Smets (1999), Favero and Milani (2001), Rudebusch (2001), Masuch *et al* (2002), Aksoy *et al* (2002), Ozlale (2003), Favero and Rovelli (2003), and Castelnuovo and Surico (2003), among the others.

formalization of the FLA component. Referring once more to equations (4)-(5), we are in this case allowing for the presence of strictly positive values for the parameters γ_π, γ_y, and γ_r. Notice that we are not exogenously fixing those weights; instead, we want to calibrate them to get the best possible fit of the federal fund rate. So, when the Hybrid version of the model is considered, we will *jointly* calibrate the weight μ and the parameters γ_π, γ_y, and γ_r.

Our choice of performing a calibration exercise deserves an explanation. Indeed, the optimal stochastic regulator problem offers the possibility of estimating the parameters of the economy and those in the CB's loss function via Maximum Likelihood, both in case of a fully backward looking representation (e.g. Ozlale, 2003) and when a hybrid economy is taken into account (e.g. Dennis, 2003). In fact, Dennis (2003) shows that both the backward and the hybrid economic framework may satisfy familiar rank and order conditions for their parameters to be identified. Of course, Maximum Likelihood estimates have the plus of allowing for formal tests on the estimated coefficients. However, this possibility does not come for free. In fact, with Maximum Likelihood one need to make an assumption on the distribution of the errors, something that we are not required to do when performing our calibration exercise. Moreover, as pointed out by Söderlind, Söderström, and Vredin (2002), Maximum Likelihood is quite sensitive to sample selection and outliers. Finally, our focus is that of understanding the impact of FLA on the interest rate smoothing parameter μ in the loss function. Then, we do want to keep all the other parameters of the model constant when moving from the fully backward looking representation of the economy to the hybrid one. Clearly, this would heavily limit the benefits deriving from the use of Maximum Likelihood.

In order to assign values to the parameters of the model (3) and (6), i.e. λ, μ, γ_π, γ_y, γ_r, α_s, and β_s, we implement the following calibration strategy:

1) We OLS estimate the parameters α_s and β_s of our backward looking specification, i.e. we estimate equations (4)-(5) subject to the constraint $\gamma_\pi = \gamma_y = \gamma_r = 0$. Our estimates are reported in Table 1.

A key parameter for the transmission of the monetary policy is the interest rate elasticity β_r. Notably, our point estimate - 0.073 - is statistically in line with that of Rudebusch (2002b).[10]

[10] Instead, probably due to the different samples considered, it is much lower than those provided by Clark, Laxton and Rose (1996) - 0.16 - and Smets (2002) - 0.9.

Phillips curve: $\pi_{t+1} = \alpha_{\pi 1}\pi_t + \alpha_{\pi 2}\pi_{t-1} + \alpha_{\pi 3}\pi_{t-2} + \alpha_{\pi 4}\pi_{t-3} + \alpha_y y_t + \varepsilon_{t+1}$					
Parameter	$\alpha_{\pi 1}$	$\alpha_{\pi 2}$	$\alpha_{\pi 3}$	$\alpha_{\pi 4}$	α_y
Point Estimate	0.282	-0.025	0.292	0.385	0.141
Standard Deviation	0.133	0.134	0.134	0.136	0.054
Adjusted R^2: 0.58; σ_ε=0.66.					
AD curve: $y_{t+1} = \beta_{y1} y_t + \beta_{y2} y_{t-1} + \beta_r(\bar{i}_t - \bar{\pi}_t) + \eta_{t+1}$					
Parameter	β_{y1}	β_{y2}	β_r		
Point Estimate	1.229	-0.244	-0.073		
Standard Deviation	0.136	0.149	0.078		
Adjusted R^2: 0.93; σ_η=0.51.					
Variables demeaned before estimation, so no constants appear.					
Sample: 1987Q3-2001Q1.					

Table 1: Estimates of the AD-AS backward looking structure

2) We exogenously fix a value for the relative preference λ. We do so to concentrate our attention on the parameters playing a key-role in our story, i.e. μ, γ_π, γ_y, and γ_r. Notice that λ is a structural preference of our set-up, i.e. the relative weight that Alan Greenspan has attributed to the volatility of the output gap versus the volatility of the average inflation rate in deviations from the target. Therefore, the choice of a sensible value for this parameter is essential in our analysis. Indeed, it is possible to find many different estimates of Greenspan's λ in the literature. Focusing on backward representations of the economy à la Rudebusch and Svensson (1999,2002), Favero and Rovelli (2003) estimate with GMM the Euler conditions of the CB's problem, finding a (statistically insignificant) value of 0.00125. Ozlale (2001) exploits Kalman-filtering and estimates a value of 0.525, Dennis (2002) gets 0.815 with a FIML approach, while Castelnuovo and Surico (2003) calibrate a value equal to 1. With a slightly different underlying representation of the economy, Cecchetti, Flores-Lagunes, and Krause (2001) find negligible values for sub samples regarding the '80s and '90s, while Cecchetti and Ehrmann (2001)'s results support a value of about 1/4. For the same period, but with a VAR representation of the economy, Salemi (1995) finds very low relative weights for the output gap with respect to inflation. Finally, Dennis (2003) designs a hybrid representation of the economy, and estimates a value equal to zero, while Mayer (2003) calibrates a value equal to 0.15. We somehow arbitrarily fix a benchmark value of $\lambda = 0.5$; however, we

check for the robustness of our results by considering also values such as 0.0, 0.2, and 1.0.[11]

3) Given steps 1) and 2), we can perform the calibration of the remaining parameters μ, γ_π, γ_y, and γ_r.[12] We do so by implementing a grid-search based on a minimum-distance criterium. In particular, we compute, *per each battery* $j : [\mu^j, \gamma_\pi^j, \gamma_y^j, \gamma_r^j]$, an optimal simulated interest rate $i^{sim,j}$ to be compared with the actual one i^{actual}.[13] For our calibration we exploit the following measure of Distance:

$$Distance(i^{simulated}, i^{actual}) = \sqrt{\frac{\sum_{t=1}^{T} (i_t^{simulated} - i_t^{actual})^2}{T}} \tag{8}$$

With this measure of distance we can pick up the simulated interest rate $i^{sim,j*}$ (i.e. the one delivering the minimum distance) implied by the calibrated vector $[\mu^*, \gamma_\pi^*, \gamma_y^*, \gamma_r^*]$. We recall here that, when the backward looking model is employed, the calibration exercise just regards the weight μ, given the identifying restriction $\gamma_\pi = \gamma_y = \gamma_r = 0$.[14]

Notice that our calibration strategy relies on the assumption of optimal behavior undertaken by the Fed in the period analyzed. As pointed out by Cecchetti, McConnell, and Perez-Quiros (2002), this is equivalent to assume that Greenspan has operated along the efficiency-frontier that defines the trade-off between inflation and output gap, otherwise labelled as 'Taylor Curve' (Taylor, 1979). Moreover, our search for the optimal weight μ assumes that the parameters of our economy remains unvaried after a modification of the monetary policy conduct. Given the presence of FLA, the calibration of our hybrid

[11] For reasons of comparability, we normalized some of the estimates for λ cited in the text, i.e. all the estimates listed above indicate the relative importance of the output gap with respect to the unitary weight attributed to the inflation rate volatility.

[12] To have a more easily manageable problem, we demean all the variables involved in our study. As argued by Dennis (2000), this operation does not affect the derivation of the CB's weights in the loss function, but it constraints the average inflation target π^* to be equal to zero, which is to say its sample mean (2.49 in our case) in an undemeaned world. Actually, our analysis is meant to identify the weights of the CB's loss rather than the targets *per se*. A number of papers cover the latter issue, including Judd and Rudebusch (1998), Sack (2000), Dennis (2002,2003), and Favero and Rovelli (2003).

[13] For our calibration exercise, we consider values belonging to the interval [0.1 - 1.0] for the forwardness coefficients γ_π and γ_y, while [0.0 - 1.0] for γ_r. We also take into account a value of 10^{-4} for γ_π and γ_y. Finally, for the weight μ we take into account values belonging to the interval [0.0 - 10.0]. The step-lenght of our grid search is 0.1.

[14] Notice that in performing these calibrations we do not deal with the Zero Lower Bound issue (see Amirault and O'Reilly, 2001, for a survey on this problem).

model is not affected by the Lucas (1976) critique. Instead, our exercise with the backward looking specification of the economy is potentially concerned by this critique. Of course, if a variation in the policy rule implied a change of the structural parameters of the economy, our empirical analysis would risk to be flawed. However, the empirical relevance of the Lucas critique in this context seems to be discussable. In fact, Rudebusch (2002c) and Estrella and Fuhrer (2003) show that with an AD-AS backward looking model like the one used in this study the empirical relevance of the critique turns is likely to be empirically negligible. We now turn to the analysis of our results.

4 Findings

In this section we present our findings. In Table 2/Panel a) we collect the results of our calibration exercise, the calibration regarding the parameter μ and, in case of the Hybrid model, also the parameters γ_π, γ_y, and γ_r. Indeed, in absence of FLA, the value of this parameter is quite large, and we judge it as being economically implausible. If we believed that the CB could indeed have an interest rate smoothing goal, this goal would surely not be 2.1 times more important than the volatility of inflation. Since we think of the smoothing argument as being a sort of 'catch all' approximating omitted (potentially important) components, then such a large value might signal the existence of an omitted variable problem. In fact, when adding FLA to the model, our results change quite dramatically. The weight attached to the smoothing argument collapses to 0.5, so supporting FLA as being a quite important element for correctly representing the economic dynamics. Some descriptive statistics support this intuition. In fact, both for the mean and for the standard deviation of the interest rate *level* the simulated interest rate related to the Hybrid framework is much closer than the one deriving from the Benchmark model. As far as the standard deviation of the interest rate *change* is concerned, it is actually difficult to distinguish between the two models; however, we recall that the Benchmark formulation needs an incredible value of 2.1 to replicate the historical data.

What if we control for the weight μ? Table 2/Panel b) collects the results coming from simulations in which the value 0.5 (i.e. the calibrated weight μ in the Hybrid model case) is imposed also to the backward looking set up. This is done in order to *quantitatively* gauge the role of FLA. Notably, all the descriptive

Panel a): Calibration of the parameter μ						
Interest rate	μ	$E(i_t)$	$\sigma(i_t)$	$\sigma(\Delta i_t)$		
Actual	-	0	1.7273	0.4961		
Backward	2.1	0.8074	2.9924	0.6364		
Hybrid	0.5	0.5692	1.7942	0.5074		
Panel b): Conditional comparison ($\mu = 0.5$)						
Interest rate	$E(i_t)$	$\sigma(i_t)$	$\sigma(\Delta i_t)$	$\rho(i_{act}, i_{sim})$	$D(i_{act}, i_{sim})$	Dist. reduct.
Actual	0	1.7273	0.4961	-	-	-
Backward	0.8431	3.4839	0.9272	0.9087	2.1445	-
Hybrid	0.5692	1.7942	0.5074	0.9411	0.8519	60.24%
Backward model: $\gamma_\pi = \gamma_y = 10^{-4}$; $\gamma_r = 0$.						
Hybrid model: $\gamma_\pi = 0.1$; $\gamma_y = 0.2$; $\gamma_r = 1$.						
Moments of the Actual interest rate refer to the demeaned rate.						

Table 2: Calibration outcomes and descriptive statistics with $\lambda = 0.5$

statistics are clearly in favor of the Hybrid Model. In particular, with such a low μ, the backward looking model's simulated policy exhibits an excessive volatility both in levels and in first differences. Moreover, the distance reduction gained when passing from the B model to the Hybrid one is about 60%. This can loosely be seen as a measure of the bit of the observed smoothness that the Benchmark model is not capable to justify - so implying such a high value of μ - and that FLA help explaining. Figure 1 graphs the difference between the Backward Model (i.e. Benchmark) and the FLA-augmented one.[15]

5 The importance of FLA

What is the economic *rationale* for this result? Why are forward looking agents so important in describing the observed smooth path of the policy rate, which is to say in *squeezing the interest rate smoothing weight*? A sentence by Woodford (2001) represents a good starting point for our discussion. Woodford (2001, page 15) writes:

" *When the effects of policy depends crucially upon private sector expectations about future policy as well, it is generally optimal for*

[15] The path of simulated interest rates deriving form the two models is the one that the federal funds rate would have followed if the Fed had hystorically implemented the optimal policy rule. Notice that all the policy rates have been demeaned. Key parameters featuring the benchmark model: $\lambda = 0.5$, $\mu = 0.5$, $\gamma_\pi = \gamma_y = 10^{-4}$, $\gamma_r = 0$. Instead, those featuring the hybrid model are $\lambda = 0.5$, $\mu = 0.5$, $\gamma_\pi = 0.1$, $\gamma_y = 0.2$, $\gamma_r = 1$.

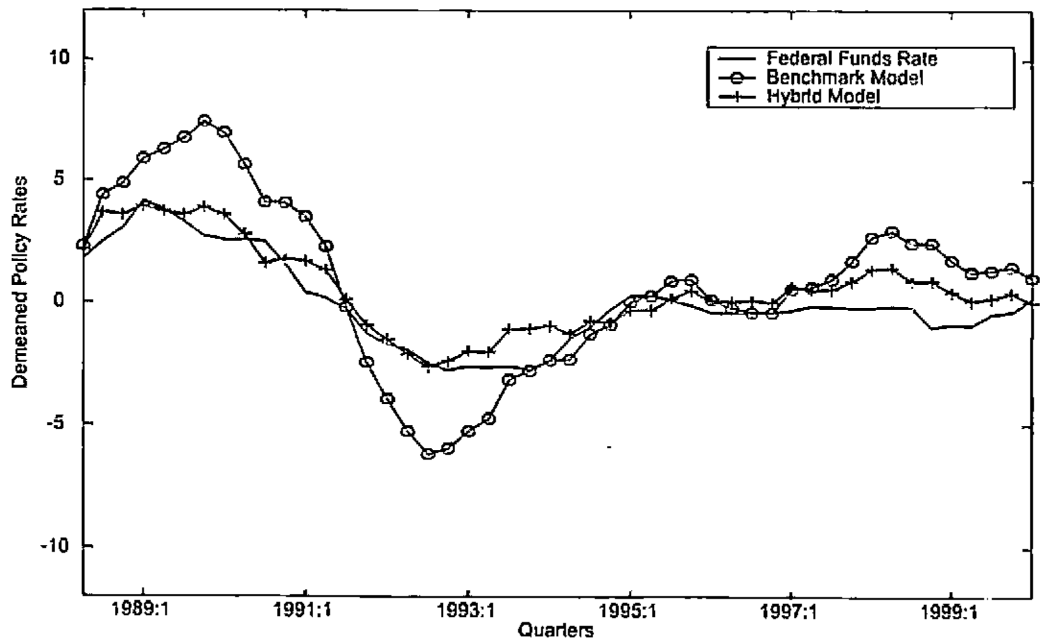

Figure 1: Policy rates behavior: benchmark versus hybrid model

policy to be history-dependent, so that the anticipation of later policy responses can help to achieve the desired effect upon private sector behavior."

The presence of FLA implies that current inflation and output gaps are influenced by both current and future expected policy rates. Given the interest rate smoothing penalty in the loss function, private sector agents expect an inertial policy rate, and move their expectations toward the targets, so moving also the current realizations of inflation and output gap toward their steady-state values. This implies that the optimal policy rate, set by following the rule (7), will be less volatile. Therefore, an optimally determined policy rate will show, *ceteris paribus*, a higher degree of inertia in presence of FLA than when just a fully adaptive private sector is taken into account. Of course, the introduction of the expectations channel will have an impact on the calibrated weight μ. Given that our aim is to replicate the observed smooth actual rate, it should be clear that with an economy featured by FLA, just a moderate weight attached to the interest rate argument in the loss function will be sufficient to trigger beneficial, stabilizing expectations. By contrast, in an economy characterized by fully adaptive agents, Woodford's discussion on the optimality of an inertial policy rate would not find any room; in this case, the optimal policy rate would be less inertial, so forcing a researcher to impose a high weight on the interest rate smoothing argument in order to fit the facts.[16]

6 Robustness check: Some considerations

We perform a robustness check of our results focusing on the value of the relative preference parameter λ. The figures concerning this check are contained in Tables 3-5, and refer to values such as 0.0, 0.2, and 1.0. We list here some intuitions that may be gained when looking at our sensitivity analysis:

[16] Another way to understand this result is the following. Suppose that the calibrated fully backward looking model, i.e. the fully backward model that fits at best the federal funds rate, is featured by the weight $\mu^*_{FullyBackward}$. Now, suppose that we add the expectations channel to the model, but still keep the same weight $\mu^*_{FullyBackward}$. Private sector agents will expect a quite smooth future path for the policy rate; this will lead them to move expectations toward the targets. Given this additional channel, the resulting optimal policy rate will turn out to be *smoother* than the one computed in absence of FLA, then also smoother than the actual one! This implies that, to fit the data with a hybrid model, we will have to *reduce* μ^*, i.e. $\mu^*_{Hybrid} < \mu^*_{FullyBackward}$.

Panel a): Calibration of the parameter μ						
Interest rate	μ	$E(i_t)$	$\sigma(i_t)$	$\sigma(\Delta i_t)$		
Actual	-	0	1.7273	0.4961		
Backward	10	0.5369	2.5432	0.3876		
Hybrid	0.4	0.1890	1.5930	0.4026		
Panel b): Conditional comparison ($\mu = 0.4$)						
Interest rate	$E(i_t)$	$\sigma(i_t)$	$\sigma(\Delta i_t)$	$\rho(i_{act}, i_{sim})$	$D(i_{act}, i_{sim})$	Dist. reduct.
Actual	0	1.7273	0.4961	-	-	-
Backward	0.6079	4.7276	1.0106	0.8672	3.3049	-
Hybrid	0.1890	1.5930	0.4026	0.9478	0.6241	81.12%
Backward model: $\gamma_\pi = \gamma_y = 10^{-4}$; $\gamma_r = 0$.						
Hybrid model: $\gamma_\pi = 0.1$; $\gamma_y = 0.3$; $\gamma_r = 1$.						
Moments of the Actual interest rate refer to the demeaned rate.						

Table 3: Calibration outcomes and descriptive statistics with $\lambda = 0.0$

1) From a descriptive viewpoint, FLA dramatically reduce the importance of the interest rate smoothing argument in the loss function. In fact, the distance reductions got when embedding FLA into the model span from a minimum of 46.67% (case with $\lambda = 1.0$) up to a maximum of 81.12% ($\lambda = 0.0$).

2) As far as the *real* interest rate in the AD equation is concerned, the FLA component seems to be particularly important. Indeed, all along our sensitivity exercises, γ_r turns out to be equal to 1. By contrast, the percentage of firms and households fully forward looking seems to be low: γ_π assumes values such as 0.1 or 0.2, while γ_y figures like 0.2 or 0.3. Notably, these figures are quite in line with those contained in many other empirical investigations.[17]

3) The smallest value of our distance measure is the one related to the framework in which the output gap weight is zero. This means that if we calibrated the preference λ over the grid [0.0; 0.2; 0.5; 1.0] we would find that the first figure is the one that most closely represents Greenspan's preferences. A possible interpretation of this result is provided by Dennis (2002) and Favero and Rovelli (2003), who underline the role of the output gap as *leading indicator for future inflation*. In fact, the optimal feedback rule related to the our best model (i.e. that with $\lambda = 0$; see Table 6 for details) reads as follows:

[17] For similar estimates concerning the Phillips curve, see e.g. Roberts (1998,2001), Lindé (2002), Rudd and Whelan (2001), Rudebusch (2001), Söderlind, Söderström, and Vredin (2002). Relatively to the IS equation, see Fuhrer and Rudebusch, 2002.

Panel a): Calibration of the parameter μ						
Interest rate	μ	$E(i_t)$	$\sigma(i_t)$	$\sigma(\Delta i_t)$		
Actual	-	0	1.7273	0.4961		
Backward	7.4	0.6303	2.5787	0.4309		
Hybrid	0.5	0.4443	1.9436	0.4968		
Panel b): Conditional comparison ($\mu = 0.5$)						
Interest rate	$E(i_t)$	$\sigma(i_t)$	$\sigma(\Delta i_t)$	$\rho(i_{act}, i_{sim})$	$D(i_{act}, i_{sim})$	Dist. reduct.
Actual	0	1.7273	0.4961	-	-	-
Backward	0.7198	3.8366	0.9031	0.9060	2.4134	-
Hybrid	0.4443	1.9436	0.4968	0.9474	0.7721	68.01%
Backward model: $\gamma_\pi = \gamma_y = 10^{-4}$; $\gamma_r = 0$.						
Hybrid model: $\gamma_\pi = 0.2$; $\gamma_y = 0.2$; $\gamma_r = 1$.						
Moments of the Actual interest rate refer to the demeaned rate.						

Table 4: Calibration outcomes and descriptive statistics with $\lambda = 0.2$

Panel a): Calibration of the parameter μ						
Interest rate	μ	$E(i_t)$	$\sigma(i_t)$	$\sigma(\Delta i_t)$		
Actual	-	0	1.7273	0.4961		
Backward	2.6	0.9166	2.7908	0.6353		
Hybrid	1.3	0.6977	1.6167	0.4314		
Panel b): Conditional comparison ($\mu = 1.3$)						
Interest rate	$E(i_t)$	$\sigma(i_t)$	$\sigma(\Delta i_t)$	$\rho(i_{act}, i_{sim})$	$D(i_{act}, i_{sim})$	Dist. reduct.
Actual	0	1.7273	0.4961	-	-	-
Backward	0.9395	3.0101	0.7677	0.8916	1.8648	-
Hybrid	0.6977	1.6167	0.4314	0.9248	0.945	46.67%
Backward model: $\gamma_\pi = \gamma_y = 10^{-4}$; $\gamma_r = 0$.						
Hybrid model: $\gamma_\pi = 0.1$; $\gamma_y = 0.2$; $\gamma_r = 1$.						
Moments of the Actual interest rate refer to the demeaned rate.						

Table 5: Calibration outcomes and descriptive statistics with $\lambda = 1.0$

Model components	Parameters	Values (Assignment Strategy)
Loss function	λ	0.000 (imposed)
	μ	0.400 (calibrated)
Phillips curve	γ_π	0.100 (calibrated)
	$\alpha_{\pi 1}$	0.282 (OLS estimated)
	$\alpha_{\pi 2}$	-0.025 (OLS estimated)
	$\alpha_{\pi 3}$	0.292 (OLS estimated)
	$\alpha_{\pi 4}$	0.385 (OLS estimated)
	α_y	0.141 (OLS estimated)
	σ_ε	0.660 (OLS estimated)
AD curve	γ_y	0.300 (calibrated)
	β_{y1}	1.229 (OLS estimated)
	$\beta_{\pi 2}$	-0.244 (OLS estimated)
	γ_r	1.000 (calibrated)
	β_r	-0.073 (OLS estimated)
	σ_η	0.510 (OLS estimated)

Table 6: Best model: List of parameters values

$$\begin{aligned} i_t &= .3867\pi_t + .2692\pi_{t-1} + .2633\pi_{t-2} + .1447\pi_{t-3} \\ &\quad +.5340y_t - .1282y_{t-1} + .6368i_{t-1} \end{aligned} \tag{9}$$

As already commented, the optimal coefficients associated to the contemporaneous and lagged output gap in the feedback rule take non-zero values even in absence of output gap targeting. An alternative possible explanation for our finding (i.e. $\lambda = 0$), in the spirit of the evidence on output gap uncertainty in Smets (2002) and Estrella and Mishkin (1999), is that monetary authorities may have placed a low weight on the most poorly measured goal, or yet, that the market productivity growth of the 90s may have drastically reduced any concern for output stabilization. A similar result is also present in Cecchetti, Flores-Lagunes, and Krause (2001). Finally, this result also arises in studies that take into account analogous hybrid models (e.g. Söderlind, Söderström, and Vredin, 2002, and Dennis, 2003) and in contributions that deal with the model uncertainty issue (e.g. Castelnuovo and Surico, 2003). Table 6 summarizes the parameters values featuring our best (in terms of minimum distance) model.

Our calibration strategy concentrates on the federal funds rate. Table 7 reports some descriptive statistics relative to the actual and simulated series of

Inflation rate	$E(\pi_t)$	$\sigma(\pi_t)$	$\sigma(\Delta\pi_t)$	$\rho(\pi_{act}, \pi_{sim})$
Actual	0	1.0031	0.8438	-
Simulated	0.1579	0.8517	0.8468	0.5503
Output gap	$E(y_t)$	$\sigma(y_t)$	$\sigma(\Delta y_t)$	$\rho(y_{act}, y_{sim})$
Actual	-0.2612	1.8182	0.5230	-
Simulated	-0.3547	1.0269	0.3975	0.6518
Moments of the Actual variables refer to the demeaned processes.				

Table 7: Best model: Descriptive statistics of inflation and output gap

the inflation rate and the output gap. Importantly, these statistics are quite close to each other, and the correlation rates reported are fairly satisfactory. We take these figures as evidence in favor of our calibration strategy, i.e. our strategy turns out to produce sensible results also for the other variables of our economic system.

7 Still a positive μ: possible reasons

The explicit formalization of forward looking expectations in the economic framework squeezes the value of the parameter μ needed to track Greenspan's federal funds rate. Nevertheless, μ is still strictly positive. Then, what is this model missing in order to fully explain the observed policy gradualism? Sack and Wieland (2000) suggest that also parameter uncertainty and measurement error affecting real-time data may imply optimal gradualism. As far as the former explanation is concerned, Söderström (1999) and Sack (2000), working on an idea originally proposed by Brainard (1967), show that parameter uncertainty may contribute to rationalize the observed cautiousness. However, Estrella and Mishkin (1999), Peersman and Smets (1999), and Rudebusch (2001) claim that parameter uncertainty is not so important from a quantitative viewpoint. Moreover, robust-control oriented work (e.g. Onatski and Stock, 2002) tend to suggest an optimally *aggressive* conduct of monetary policy. Then, the importance of parameters uncertainty is still to be fully understood. As far as data uncertainty is concerned, an important contribution is offered by Orphanides (1998). His point is intuitive: Monetary authorities should respond to shocks gradually, because it is difficult to understand if the one under consideration is a pure economic shock, or just a measurement error (or a mix between the two). Indeed, when simple Taylor rules are taken into account, the increase in volatility caused by measurement errors matters.

Another possible explanation for the observed monetary policy gradualism is offered by the learning argument. Does learning enhance gradualism? Sack (1998) shows how a CB that periodically refines his estimates of the key-parameters linking the variables of interest in a given framework may choose to act gradually. This result is due to the stochastic features of the economic dynamics, that render particularly informative the most recent observations. As a result, the Fed faces more uncertainty about the reaction of the economy as it moves the funds rate away from its recent levels. However, Sack (1998) himself and Wieland (2000) point out that there exist a dynamic trade-off between gradualism and learning, i.e. it may become optimal in a dynamic set-up to implement an aggressive policy in order to learn how the economy react to new, different monetary policy shocks. Indeed, an aggressive policy might speed up the learning process. However, this approach, termed *experimentation* (see Bertocchi and Spagat, 1993, and Caplin and Leahy, 1996), do not seem to be supported by Policy Makers' official declarations.[18]

McCallum (1999) claims that a good policy rule is the one that is capable to perform well across many different models. In fact, not only a CB is uncertain about the key-parameters of the equations formalizing the economy; indeed, the CB is uncertain regarding the structure of the economy itself. From the descriptive side, recent empirical contributions by Favero and Milani (2001) and Castelnuovo and Surico (2003), conducted in a class of linear backward looking models, show that model uncertainty helps explaining the observed policy rate behavior.

Finally, a positive value of the μ parameter might also be the expression of the concern that the CB has for the financial markets, markets that are thought as being very reactive to large swings of the nominal interest rate (Goodfriend, 1991; Blinder, 1997; Mishkin, 1999).[19]

[18] Regarding this point, it is worth to signal a comment by a former Vice-Chairman of the Fed, Alan Blinder (1998, p.11): "You don't conduct experiments on a real economy solely to sharpen your econometric estimates".

[19] An interesting point tackling this view is provided by Cecchetti (2000). In fact, he claims that large jumps in the policy instruments could be disruptive only if financial markets are relatively certain that it will never happen. Instead, if market participants expect that new information can precipitate large and sudden interest rate changes, then they will defend themselves by building up institutions that can withstand the potential disruptions this would otherwise cause. In synthesis, the only reason that people believe smooth interest rates enhance financial stability is because interest rate has been smooth up to now.

8 Conclusions

The interest rate smoothing argument has been debated quite intensely in the past few years. From a positive perspective this argument is needed in order to generate the observed policy rate persistence. In fact, in small scale fully backward looking models the interest rate smoothing weight has usually got a puzzling high relative value in the CB's loss function.

In this paper we show that the 'forward looking agents' ingredient may play a big role in partially solving this puzzle. Indeed, by comparing the outcomes stemming from a fully backward looking model with those deriving from a calibrated hybrid one, we found that this ingredient dramatically reduces the - otherwise arising - interest rate smoothing puzzle. Implicitly, this suggests that the Fed has seriously taken private sector's expectations into account when taking its policy decisions.

Interestingly enough, Wieland (2002) obtains the same result (i.e. much more gradualism when forward looking agents are explicitly modelled) in a model in which both the Central Banker and the private sector are uncertain about the relationship between inflation and unemployment, and learn on that. We see this evidence as a further confirmation on the robustness of our findings.

Overall, our calibration exercises suggest that a hybrid new-Keynesian model may very well fit the data. In particular, a low relative concern for output gap volatility with respect to inflation volatility, a low degree of 'forward lookingness' in both the Phillips curve and the IS curve, and a high weight for future inflation in the expected real interest rate are the features of our best positive model. In this sense, our findings are fairly in line with those contained in recent works by Söderlind, Söderström, and Vredin (2002), Dennis (2003), and Mayer (2003), and suggest that much more should be done to better understand the role of adjustment costs and habit formation in shaping the dynamics of variables such as inflation and the output gap. It is worth signalling that efforts in this direction have already been undertaken by e.g. Fuhrer and Moore (1995), Fuhrer (2000), and Estrella and Fuhrer (2002).

Although very much important, the presence of forward looking agents in small scale macroeconomic models is not sufficient to get rid of the interest rate smoothing argument when performing positive exercises. Apart from model uncertainty and real-time data (ingredients already suggested by Sack and Wieland, 2000), an interesting attempt could be that of investigating if a framework admitting 'quasi-commitment' solutions of the monetary authorities' optimal control problem might reduce (if not completely eliminate) the interest rate smoothing penalty even further. Interestingly, Schaumburg and Tambalotti (2003) and Hakan Kara (2003) notice how the observed monetary policy gradualism is lower than the one suggested by the optimal solution under commitment, but higher than that featuring the optimal solution under full discretion. Following their approach, the introduction of a credibility parameter in the set up analyzed in this paper could lead to an optimal solution featured by a large degree of inertia even in absence of the interest rate smoothing penalty. This effort is the next one in our research agenda.

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Technical appendix [Squeezing the Interest Rate Smoothing Weight with a Hybrid New-Keynesian Model]

The algorithm to solve the optimal control problem faced by the CB is more easily understandable if the model representing the economy is written in its state-space form. Consider equations (4) and (5), which we rewrite here below:

$$\begin{aligned}\pi_{t+1} &= \gamma_\pi E_t(\frac{\pi_{t+1}+\pi_{t+2}+\pi_{t+3}+\pi_{t+4}}{4}) \\ &\quad +(1-\gamma_\pi)(\alpha_{\pi 1}\pi_t+\alpha_{\pi 2}\pi_{t-1}+\alpha_{\pi 3}\pi_{t-2}+\alpha_{\pi 4}\pi_{t-3})+\alpha_y y_t+\varepsilon_{t+1}\end{aligned} \tag{10}$$

$$\begin{aligned}y_{t+1} &= \gamma_y E_t y_{t+2}+(1-\gamma_y)(\beta_{y1}y_t+\beta_{y2}y_{t-1}) \\ &\quad -\beta_r\gamma_r[i_t-E_t(\frac{\pi_{t+1}+\pi_{t+2}+\pi_{t+3}+\pi_{t+4}}{4})] \\ &\quad -\frac{\beta_r(1-\gamma_r)}{4}(i_t+i_{t-1}+i_{t-2}+i_{t-3}-\pi_t-\pi_{t-1}-\pi_{t-2}-\pi_{t-3})+\eta_{t+1}\end{aligned} \tag{11}$$

To solve the optimal control problem, we basically have to compute the expectations terms $E_t\pi_{t+4}$ and $E_t y_{t+2}$. Noticing that $\pi_{t+1} = E_t\pi_{t+1}+ \varepsilon_{t+1}$ and $y_{t+1} = E_t y_{t+1}+ \eta_{t+1}$ (where ε_{t+1} and η_{t+1} are white noise), it is then possible to write (10) and (11) as follows:

$$\begin{aligned}\frac{\gamma_\pi E_t\pi_{t+4}}{4} &= (1-\frac{\gamma_\pi}{4})E_t\pi_{t+1}-\frac{\gamma_\pi}{4}E_t\pi_{t+2}-\frac{\gamma_\pi}{4}E_t\pi_{t+3} \\ &\quad -(1-\gamma_\pi)(\alpha_{\pi 1}\pi_t+\alpha_{\pi 2}\pi_{t-1}+\alpha_{\pi 3}\pi_{t-2}+\alpha_{\pi 4}\pi_{t-3})-\alpha_y y_t\end{aligned} \tag{12}$$

$$\begin{aligned}\gamma_y E_t y_{t+2}+\beta_r\gamma_r E_{t+4} &= E_t y_{t+1}-(1-\gamma_y)(\beta_{y1}y_t+\beta_{y2}y_{t-1}) \\ &\quad +\beta_r\gamma_r[i_t-E_t(\frac{\pi_{t+1}+\pi_{t+2}+\pi_{t+3}}{4})] \\ &\quad +\frac{\beta_r(1-\gamma_r)}{4}\sum_{j=0}^{3}(i_{t-j}-\pi_{t-j})\end{aligned} \tag{13}$$

As already specified in the text, we aim at computing the discretionary solution of the problem, given that it is time-consistent. To find it, we use Söderlind (1999)'s strategy.[20] This strategy requires a precise distinction of the elements involved in the problem between state (predetermined) and jump (forward-looking) variables. So, we define the $(n1x1)$ vector of predetermined state variables as follows $(n1 = 9)$:

$$x_{1t} = \begin{bmatrix} \pi_t & \pi_{t-1} & \pi_{t-2} & \pi_{t-3} & y_t & y_{t-1} & i_{t-1} & i_{t-2} & i_{t-3} \end{bmatrix}' \qquad (14)$$

and the $(n2x1)$ vector of forward-looking jump ones as here below $(n2 = 4)$:

$$x_{2t} = \begin{bmatrix} E_t\pi_{t+3} & E_t\pi_{t+2} & E_t\pi_{t+1} & E_t y_{t+1} \end{bmatrix}' \qquad (15)$$

Since we are solving a stochastic problem, we also define the $(n1x1)$ vector of shocks to the predetermined variables as:

$$v_{1t} = \begin{bmatrix} \varepsilon_t & 0_{1x3} & \eta_t & 0_{1x4} \end{bmatrix}' \qquad (16)$$

Then, the state-space representation of the problem is the following:

$$A_0 \begin{bmatrix} x_{1t+1} \\ E_t x_{2t+1} \end{bmatrix} = A_1 \begin{bmatrix} x_{1t} \\ x_{2t} \end{bmatrix} + B_1 i_t + v_{t+1} \qquad (17)$$

where

$$v_{t+1} = \begin{bmatrix} v_{1t+1} \\ 0_{n2x1} \end{bmatrix} \qquad (18)$$

and where the matrices A_0, A_1, and B_1 read as follows:

[20] The Gauss and Matlab routines for solving the optimal stochastic regulator problem presented in this Technical Appendix can be found in Söderlind's webpage, i.e. http://www.hhs.se/personal/PSoderlind/.

$$A_0 = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \frac{\gamma_\pi}{4} & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \frac{\beta_r\gamma_r}{4} & 0 & 0 & \gamma_y \end{bmatrix}$$

$$A_1 = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \\ 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ \widetilde{\alpha}_{\pi 1} & \widetilde{\alpha}_{\pi 2} & \widetilde{\alpha}_{\pi 3} & \widetilde{\alpha}_{\pi 4} & -\alpha_y & 0 & 0 & 0 & 0 & -\frac{\gamma_\pi}{4} & -\frac{\gamma_\pi}{4} & (1-\frac{\gamma_\pi}{4}) \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \\ \widehat{\beta}_r & \widehat{\beta}_r & \widehat{\beta}_r & \widehat{\beta}_r & \widetilde{\beta}_{y1} & \widetilde{\beta}_{y2} & -\widehat{\beta}_r & -\widehat{\beta}_r & -\widehat{\beta}_r & -\frac{\beta_r\gamma_r}{4} & -\frac{\beta_r\gamma_r}{4} & -\frac{\beta_r\gamma_r}{4} \end{bmatrix}$$

$$B_1 = \begin{bmatrix} 0_{1x6} & 1 & 0_{1x5} & \beta_r\gamma_r - \widehat{\beta}_r \end{bmatrix}'$$

where $\widetilde{\alpha}_{\pi j} = -(1-\gamma_\pi)\alpha_{\pi j}, \widehat{\beta}_r = -\frac{\beta_r(1-\gamma_r)}{4}, \widetilde{\beta}_{yj} = -(1-\gamma_y)\beta_{yj}$.

To obtain the standard state-space representation, we just have to premultiply (17) by A_0^{-1}, so obtaining

$$\begin{bmatrix} x_{1t+1} \\ E_t x_{2t+1} \end{bmatrix} = A \begin{bmatrix} x_{1t} \\ x_{2t} \end{bmatrix} + Bi_t + v_{t+1} \tag{19}$$

with $A = A_0^{-1}A_1$ and $B = A_0^{-1}B_1$.[21]

[21] Notice that $A_0^{-1}v_{t+1} = v_{t+1}$, since A_0 is block diagonal with an identity matrix as its

It is useful to express also the CB's objective function in a compact form. To do so, it is necessary to write down the vector of the arguments targeted by the CB. This vector is defined as:

$$z_t = \begin{bmatrix} \bar{\pi}_t & y_t & \Delta i_t \end{bmatrix}' \tag{20}$$

Notice that, given our choice of working with demeaned variables which renders easier the management of the optimal stochastic regulator problem, π^* is normalized to be equal to zero.

The goal variables included in vector (20) can be expressed via the following formula:

$$z_t = C_x x_t + C_i i_t \tag{21}$$

where

$$C_x = \begin{bmatrix} \frac{1}{4} & \frac{1}{4} & \frac{1}{4} & \frac{1}{4} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & -1 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

and

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

The CB attributes to the quadratic transformation of the arguments in (20) different weights. We normalize the weight on the average inflation rate to one, and we attribute relative weights to the other targets, as follows:

$$L_t = \bar{\pi}_t^2 + \lambda y_t^2 + \mu \Delta i_t^2 \tag{22}$$

which can be re-expressed as:

$$L_t = z_t' K z_t \tag{23}$$

upper left block and the lower block of v_{t+1} is equal to zero. Notice also that the requirement for having $det(A_0) \neq 0$ is that $\gamma_{\bar{\pi}}, \gamma_y \neq 0$. That is why, when identifying the Benchmark model (i.e. fully backward looking model) in our exercise, we do not set those weights to a zero value. Instead, we set them equal to 10^{-4}. This is a drawback deriving from our choice of using the procedure elaborated by Paul Söderlind (1999) for solving RE models. Richard Dennis made us notice that, if we were to solve for the optimal discretionary rule using the *structural* form of the model rather than the *state-space* form, this problem would vanish. For further information abour this point, see Dennis (2000).

where K is a $3x3$ diagonal matrix containing the relative concerns of the CB. K is shaped in this way:

$$K = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \lambda & 0 \\ 0 & 0 & \mu \end{bmatrix} \tag{24}$$

Using (21), the period loss function (23) can be re-expressed as follows:

$$\begin{aligned} L_t &= \begin{bmatrix} x_t' & i_t' \end{bmatrix} \begin{bmatrix} C_x' \\ C_i' \end{bmatrix} K \begin{bmatrix} C_x & C_i \end{bmatrix} \begin{bmatrix} x_t \\ i_t \end{bmatrix} \\ &= x_t' C_x' K C_x x_t + x_t' C_x' K C_i i_t + i_t' C_i' K C_x x_t + i_t' C_i' K C_i i_t \\ &= x_t' Q x_t + x_t' U i_t + i_t' U' x_t + i_t' R i_t \end{aligned}$$

where $x_t = \begin{bmatrix} x_{1t} \\ x_{2t} \end{bmatrix}$,
and where $Q = C_x' K C_x$, $U = C_x' K C_i$, $R = C_i' K C_i$.

Hence the CB's optimal control problem is given by the intertemporal penalty function

$$J_t = E_t \sum_{\tau=t}^{\infty} \delta^{\tau-t} (x_\tau' Q x_\tau + x_\tau' U i_\tau + i_\tau' U' x_\tau + i_\tau' R i_\tau) \tag{25}$$

subject to the law of motion of the economy (19). As already written in the text, it turns out that the optimal discretionary policy is a rule for the interest rate as a linear function of the predetermined variables in the vector x_{1t}, i.e.

$$i_t = -F x_{1t} \tag{26}$$

The law of motion of the predetermined variables is given by

$$x_{1t+1} = M x_{1t} + v_{1t+1} \tag{27}$$

while the jump variables are defined as

$$x_{2t} = N x_{1t} \tag{28}$$

Details on how to compute the matrices M and N are provided by Söderlind (1999).

Notice an important result. Rudebusch and Svensson (1999) underline how, when the discount factor $\delta \to 1$, the intertemporal loss function (25) approaches the unconditional mean of the period loss function. Hence, we can write it as

$$E(L_t) = Var(\bar{\pi}_t) + \lambda Var(y_t) + \mu Var(\Delta i_t) \tag{29}$$

After having

1) initialized the vector x_{10} with historical observations,

2) attributed to the vector x_{20} nil values,

3) set the values of the key-coefficients $\alpha_s, \beta_s, \gamma_\pi, \gamma_y$, and γ_r in the matrices A_0, A_1, and B,

4) stored the structural residuals into the vector v_t,

5) determined the relative weights λ and μ in the loss function (29), and

6) computed the optimal feedback coefficients in F,

we can exploit expressions (19) and (26) in order to simulate how the economy would have evolved if the CB had implemented the policy rule solution of the optimal control problem. Finally, given the simulated time-series for π, y, and i, it is easy to compute the value of the expected loss (29).

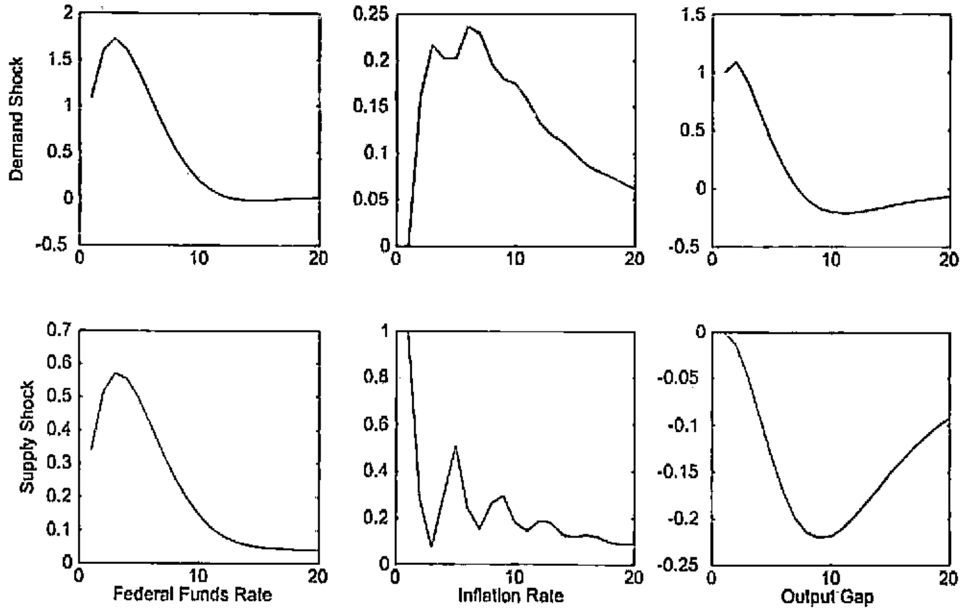

Figure 2: Impulse response functions of the hybrid new-Keynesian model (unitary shocks)

Impulse response functions [Squeezing the Interest Rate Smoothing Weight with a Hybrid New-Keynesian Model]

Figure 2 shows some impulse response functions.[22] It is immediate to notice that shocks to output and inflation are followed by *gradual* movements of the policy rate; this gradualism finds its rationale in the presence of a strictly positive interest rate smoothing weight. After a positive demand shock, the central bank must drive downwards the output gap rendering it negative, in order to tackle the inflationary pressure. Instead, in response to a cost-push shock, the CB raises the short-term nominal interest rate, so depressing the real economy. This induces the return of the average inflation rate to its target, at the cost of periods of under-production. The volatile pattern shown by the inflation rate in both these cases may be due to the will of the CB to target annual inflation.

[22]These impulse response functions are computed by considering the following key parameters' values: $\lambda = 0.5$, $\mu = 0.5$, $\gamma_\pi = 0.1$, $\gamma_y = 0.2$, $\gamma_r = 1$.

Describing the Fed's Conduct with Taylor Rules: Is Interest Rate Smoothing Important?

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May 2003

Abstract

In this paper we estimate simple Taylor rules paying particular attention to interest rate smoothing. Following English, Nelson, and Sack (2002), we employ a model in first differences to gain some insights into the presence and significance of the degree of partial adjustment as opposed to a serially correlated policy shock. Moreover, we estimate a nested model to take into account both interest rate smoothing and serially correlated deviations from various Taylor rates prescriptions. Our findings suggest that the lagged interest rate enters the Taylor rule in its own right, and may very well coexist with (usually omitted) variables that relate to asymmetric preferences on the output gap, or financial market indicators. Therefore, while we cannot exclude that serially correlated policy shocks may play a role in describing the federal funds rate path, our results significantly support the importance of the lagged interest rate in Taylor-type models.

JEL classification system: E4, E5.

Keywords: Taylor rules, omitted variables, serial correlation, interest rate smoothing.

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1 Introduction

Researchers involved in monetary policy analyses have been discussing the Taylor (1993) rule for a decade now. This simple rule, which links the inflation rate and a measure of output gap to the monetary policy rate, has turned out to be a satisfactory approximation of the various Central Banks' policy conduct all over the world. In fact, numerous researchers have focussed their attention on a *modified* Taylor rule, i.e. $i_t = (1-\rho)\hat{i}_t + \rho i_{t-1}$, with i_t identifying the short term nominal interest rate controlled by the Central Bank (CB henceforth), while $\hat{i}_t$ is the original Taylor rule, whose implied policy rate level has been termed 'Taylor rate'. The modified Taylor rule suggests a *partial*, gradual adjustment to the Taylor rate after a shock has hit the economy. Notably, the estimated degree of partial adjustment ρ has typically been very high, so suggesting the existence of *interest rate smoothing*, or *monetary policy inertia*.[1]

Indeed, the literature has offered various sensible reasons to interpret the estimated policy gradualism.[2] Nevertheless, Rudebusch (2002a) criticizes this conventional wisdom. In his stimulating contribution, he claims that *the interest rate smoothing behavior at quarterly frequencies is just an illusion.* By employing US data, Rudebusch tests for the Partial Adjustment (PA hereafter) hypothesis, i.e. the interest rate smoothing one, versus the Serial Correlation (SC) alternative, which relates to persistent deviations of the policy variable from the Taylor rate due to extraordinary episodes, such as shocks having a persistent effect on the economic system, or financial turmoils. In Rudebusch's work, a *direct* proof of the existence of this illusion, based on the estimation of a nested model in levels, turns out not to be definitive.[3] Then, the author goes for an *indirect* proof. In a nutshell, his reasoning is the following: If the partial

[1] Clarida, Galí, and Gertler (1999,2000) estimate such a partial adjustment degree with various specifications of the Taylor rule with US data, finding a magnitude $\simeq 0.8$. The same magnitude is found by Kozicki (1999), Amato and Laubach (1999), Domenéch, Ledo, and Taguas (2002). Estimates for some other industrialized countries are offered by Clarida, Galí, and Gertler (1998), Gerlach and Schnabel (2000), and Domenéch, Ledo, and Taguas (2002).

[2] Discussions concerning the interest rate smoothing issue may be found in Lowe and Ellis (1997), Goodhart (1999), Sack and Wieland (2000), Cecchetti (2000), and Srour (2001). In Section 2 we review some of the reasons why a CB may optimally implement a *gradual* path of its policy rate.

[3] High correlation in the Taylor rule's regressors, their dynamic endogeneity, small sample bias, and uncertainty about the appropriate arguments of the historical policy rate are among the motivations put forward by Rudebusch (2002a, pp. 1178-1179) to justify the lack of power regarding the PA vs. SC test constructed on his nested model.

adjustment strategy had such a high importance in the policy rate setting, then rational agents should be capable of predicting future values of the quarterly rate with a high degree of precision. On the contrary, standard term structure regressions show how unpredictable the policy rate is over one quarter. Rudebusch takes this evidence to claim that the *quarterly* interest rate smoothing is just negligible, and that the observed persistency of the federal funds rate is mainly due to serially correlated *deviations* from the Taylor rate. As far as the Fed is concerned, such deviations could be due to particular circumstances, e.g. commodity price scares (1988-89 and 1994-95), credit crunches (1992-93), and financial crises (1998-99).[4]

Söderlind, Söderström, and Vredin (2002a, SSV henceforth) go a step further. By working with an AD-AS model à la Rudebusch (2002b), they show that with model consistent rational expectations on the interest rate *change*, the predictability of the latter increases as the PA parameter ρ becomes larger. Importantly, SSV underline how a high ρ is a *necessary but not sufficient* condition to effectively predict the policy rate variations. In fact, this predictability also comes from the high predictability of variables such as the inflation rate and the output gap level.[5] SSV (2002a) also verify, with survey data and a small VAR model, that the predictability of the short term interest rate change is very low (as also shown in Rudebusch 2002a). Then, they conclude that a high degree of PA cannot coexist with a standard Taylor rate, given that the latter is composed of highly predictable variables, and this would indeed imply largely forecastable policy rate changes. In SSV (2002a)'s opinion, there might be an omitted variable problem in the Taylor (1993) rate $\hat{i}_t$ definition. Notice that, to be consistent with a high degree of PA, this potentially missing variable should not be easily predictable, because otherwise it would not be compatible with the yield curve *indirect* test.[6]

A reply to Rudebusch (2002a)'s conjecture is offered by English, Nelson, and

[4] In fact, in drawing the conclusions of his paper, Rudebusch (2002a) acknowledges for the possibility of "[...] some intermediate case of partial adjustment, [...] along with some serially correlated shocks, that is not strictly rejected by the term structure evidence".

[5] When SSV (2002a) make the hypothesis that both inflation and output gap are white noise, they find that the larger the PA coefficient ρ, the *less* predictable future changes in the policy rate are. In this sense, the extreme case (i.e. $\rho \rightarrow 1 \Rightarrow \Delta i_t \rightarrow$ random walk) is illuminating.

[6] This last statement finds its basis on the Rational Expectation Hypothesis. In fact, most of the empirical literature reject the expectations model of the term structure. As an exception on this point, see Favero (2002).

Sack (2002, ENS hereafter). These authors, working on the *first differences* of the policy rate, show that it is possible to test *directly* the null of SC versus the alternative of PA. Their findings indicate a significant role for the latter; nevertheless, a *nested* model seems to be better suited for capturing the policy rate behavior. Gerlach-Kristen (2002) also comments on Rudebusch (2002a)'s contribution. In her paper she investigates the role of omitted variables in the estimation of the Taylor rule. By using Kalman filtering, she finds that both PA and a financial indicator such as the risk-premium are important components in replicating the observed federal funds rate path.

In this paper we extend ENS's analysis. In exploiting their modeling strategy, we consider a richer set of alternative Taylor rate definitions. To do so, we take into account diverse, possibly important omitted variables, so capturing the stimuli coming from Surico (2002) and Gerlach-Kristen (2002). In particular, we assess the statistical relevance of regressors such as the quadratic gap (indicator of asymmetric preferences on the output gap level by a CB, as shown in Surico), and the credit spread (an indicator of financial stress, as discussed in Gerlach-Kristen).

Our results indicate that US data largely support the partial adjustment mechanism hypothesis. Indeed, if it is hard to rebut the importance of a serially correlated policy shock in a Taylor type scheme, it seems even harder to reject that of the lagged interest rate. Notably, this conclusion turns out to be quite robust across the different Taylor rates specifications we employed.

The structure of the paper reads as follows. In Section 2 we discuss some reasons why a CB should optimally implement a gradual policy. Section 3 explains Rudebusch (2002a)'s opinion regarding the conventional wisdom on monetary policy inertia. In the same Section, the identification problem affecting a test performed with a model in levels is underlined, and English, Nelson, and Sack (2002)'s alternative strategy is described. In Section 4 we present the alternative specifications of the Taylor rate we employ in our analysis, while in the following Section we discuss our findings, that confirm that the lagged interest rate plays a role *per se* in the description of the American monetary policy conduct in the last two decades. Then, in Section 6 we make a qualitative point regarding the 'real time versus revised data' discussion which has been very lively in this literature in the past few years. Section 7 concludes. A Technical appendix on how to solve a Rational Expectations model with a simple Taylor rule is provided, together with a Data appendix illustrating the sources of the time-series and the construction of the variables employed in our analysis. References follow.

2 Rationalizing monetary policy gradualism

The issue of dynamics is important from a policy perspective. In fact, in the last two decades we have observed an improvement of the inflation-output gap trade-off in many industrialized countries. Part of this improvement is surely attributable to better monetary-policy management, as remarked by Cecchetti, Flores Lagunes, and Krause (2001) and Favero and Rovelli (2003).[7] In general, it is important to understand the determinants of this successful management, in order to possibly replicate this success in presence of future, similar macroeconomic conditions. Among these determinants, has monetary policy gradualism played an important role? Recent research in monetary policy has indicated various possible reasons for a CB to move in a moderate manner its policy rate. In this section, we quickly discuss some of them.

Private Sector Expectations

It is well known that, in absence of a commitment technology, the CB is incapable of manipulating private sector's expectations, due to the time-inconsistency feature of its promises of fighting inflation which renders these promises non-credible (Kydland and Prescott, 1977). Indeed, this leads the Society to an inferior level of efficiency with respect to that coming from a solution under commitment, as explained by Rogoff (1985). In studying this problem, Woodford (1999) suggests the possibility to reduce the gap existing between these two solutions. He proposes to induce the CB to target an interest rate smoothing argument, i.e. to limit the volatility of the interest rate *change*. In doing so, an optimally behaving CB would implement an inertial interest rate close to the one that it would set under the commitment scenario. The inertia implied by the interest rate smoothing targeting would have an effect on

[7] The same authors underline that the improved inflation-output gap trade-off has probably not been uniquely caused by a better monetary policy management. In fact, there is a certain evidence of a change in monetary policy preferences, and of more favourable sequences of supply shocks. Still, better monetary policy management seems to have been quite significant.

the economic system through private sector expectations as if the CB owned a commitment technology.

Parameter Uncertainty

In the real world, monetary policy-making is an exercise undertaken in an uncertain environment (Goodhart, 1999). Indeed, the CB does face a lack of information concerning the monetary transmission mechanism. One of these uncertainties regard the parameters linking the aggregates which compose the relevant economic environment the CB is interested in. The first impacting contribution in this context was Brainard (1967)'s. His story is simple: A policy-maker who is partially ignorant relative to the key-parameters of the economy may implement prudent monetary actions when responding to shocks, since in this way it will reduce the 'uncertainty cost', i.e. the possibility of inducing a large volatility in the economy due to a misinterpretation of the monetary transmission mechanism.[8] Söderström (1999) and Sack (2000) empirically demonstrate that in an optimal control context with VAR representations of the economic dynamics it is possible to replicate fairly well the federal funds rate path by taking into account parameter uncertainty.[9]

Model Uncertainty

McCallum (1999) sustains that a good policy rule is the one that is capable of performing well across many different models. In fact, the CB's uncertainty is likely to concern the formalization of the whole economic framework. Empirical contributions by Favero and Milani (2001) and Castelnuovo and Surico (2003), conducted with a class of linear backward looking models, show that considering many diverse models may lead the CB to implement a gradual, optimal

[8] It should be noticed that in his contribution Brainard (1967) points out how this result is driven by the low covariance existing between the policy instrument and the state variables; indeed, a high covariance could overturn the result.

[9] However, there is not yet a complete agreement on the link between this type of uncertainty and the optimal CB's behavior. In fact, Söderström (2002) suggests that uncertainty related to the persistence of the inflation mechanism may induce CBs to implement an aggressive strategy to reduce the uncertainty about the future development of inflation. Robust-control oriented works, such as those by Sargent (1999) and Onatski and Stock (2002) show that the best possible reaction of the CB to the worst-scenario drawn by the Nature is an aggressive monetary action. Finally, with the use of small scale models and focusing just on a few key-parameters, Estrella and Mishkin (1999), Peersman and Smets (1999), and Rudebusch (2001) claim that parameter uncertainty seems not to have an important impact on the optimally determined feedback rule coefficients.

monetary policy. Indeed, model uncertainty may be an important component in tracking the CB's historical policy rate path.

Learning

Does learning enhance gradualism? Sack (1998) shows how a CB that periodically refines his estimates of the key-parameters linking the variables of interest in a given framework may choose to act gradually. This result is due to the stochastic features of the economic dynamics, that render particularly informative the most recent observations. As a result, the Fed faces more uncertainty about the reaction of the economy as it moves the funds rate away from its recent levels.[10]

Data Uncertainty - Measurement Error

Orphanides (1998) offers an important contribution regarding the noise affecting the data. His point is intuitive: Monetary authorities should respond to shocks gradually, because it is difficult to understand if the one under consideration is a pure economic shock, or just a measurement error (or a mix between the two). Indeed, when simple rules à la Taylor (1993) are taken into account, the increase in volatility caused by measurement errors matters.[11]

Financial Markets Reaction

A cautious monetary policy may also reflect the attention that the CB poses to the reactions that financial markets exert after a monetary policy decision has been implemented. In fact, Goodfriend (1991)'s claim is that markets could over-react to a series of swings of the reference nominal rate, so negatively affecting the real side of the economy.[12]

[10] However, Sack (1998) himself and Wieland (2000) point out that there exist a dynamic trade-off between gradualism and learning, i.e. it may become optimal in a dynamic set-up to implement an aggressive policy in order to learn how the economy react to new, different monetary policy shocks. Indeed, an aggressive policy might speed up the learning process. Nevertheless, this approach, termed *experimentation* (see Bertocchi and Spagat, 1993, and Caplin and Leahy, 1996), do not seem to be supported by Policy Makers' official declarations. In fact, it is worth to mention a comment by a former Vice-Chairman of the Fed, Alan Blinder (1998, p.11): "You don't conduct experiments on a real economy solely to sharpen your econometric estimates".

[11] Notice that this does not hold if we consider the policy rule coming from first principles in a linear-quadratic context. For a formal demonstration of this application of the certainty equivalence principle, see Ljungqvist and Sargent (2000, chapter 4).

[12] An interesting point tackling this view is provided by Cecchetti (2000), who underlines

3 A direct test for partial adjustment versus serial correlation

Rudebusch (2002a) performs an *indirect* test on the importance of PA versus SC. He exploits standard term structure regressions in order to show that the predictive power of the market regarding future changes of the short-term interest rate over a quarter is very low.[13] Then, Rudebusch's claim is that interest rate levels cannot be explained by a large degree of PA, because this would lead to a easily forecastable variation of the policy rate. In fact, Rudebusch (2002a) also tries to test *directly* the non-significance of the PA hypothesis. Formally, he builds up an empirical model nesting the PA specification

$$i_t = (1-\rho)\widetilde{i}_t + \rho i_{t-1} + \eta_t \tag{1}$$

(η_t = white noise process) with the SC specification

$$i_t = \widetilde{i}_t + \varepsilon_t,\ \varepsilon_t = \rho_\varepsilon \varepsilon_{t-1} + \eta_t \tag{2}$$

(ε_t = AR(1) process).[14] The nested model reads as follows:

$$i_t = (1-\rho)\widehat{i}_t + \rho i_{t-1} + \varepsilon_t,\ \varepsilon_t = \rho_\varepsilon \varepsilon_{t-1} + \eta_t \tag{3}$$

As far as the Taylor rate $\widetilde{i}_t$ is concerned, Rudebusch concentrates on two different formalizations. The first one is the original Taylor (1993) rate, which reads as follows:

how large jumps in the policy instrument could be disruptive only if financial markets are relatively certain that it will never happen. If market participants expect that new information can precipitate large and sudden interest rate changes, then they will defend themselves by building up institutions in order to avoid any negative consequence. In his opinion, the only reason that people believe smooth interest rates enhance financial stability is because interest rate has been smooth up to now.

[13] The standard term structure regressions run by Rudebusch (2002a) refer to the following model: $\Delta i_{t+j} = \delta + \gamma E_t \Delta i_{t+j} + \psi^j_{t-j}$, for $j \geqslant 1$.

[14] We performed some econometric exercises in order to measure the order of serial correlation featuring the residuals of simple backward and forward looking Taylor rules without smoothing. Our findings suggest that an AR(1) process is a good approximation of the policy shocks behavior. We did not include these figures in the paper for sake of brevity; however, these figures are available upon request.

$$\tilde{i}_t = c + b_\pi \overline{\pi}_t + b_y y_t \tag{4}$$

where c is a constant, $\overline{\pi}_t$= four quarter average inflation rate, and y_t = output gap.[15] This is a natural benchmark definition of the Taylor rate.[16] A different specification of the Tayor rate has been popularized by CGG (1998,1999,2000). These authors have underlined the importance for the CB to adjust the policy rate with respect to *future*, forecast movements of both inflation and output gap. Their idea finds its rationale in the lags affecting the monetary policy transmission.[17] Their definition of the Taylor rate can be captured by the following formalization:

$$\tilde{i}_t = c + b_\pi E_{t-1}\overline{\pi}_{t+4} + b_y E_{t-1} y_t \tag{5}$$

Then, by working with equation (3) and - alternatively - (4) or (5), Rudebusch (2002a) tests first for the significance of the PA, then for that on SC. The test suggests rejection neither for PA nor for SC. Why so? Rudebusch explains that there is an identification problem at this point. In fact, it is very difficult to distinguish between the dynamics deriving from a PA mechanism and those induced by a SC specification when observing at the realizations of the policy rate, since both these processes (which are very different from an economic standpoint) may induce the same (or similar) path of the policy rate.[18]

To better understand this identification problem, we construct two counterfactual policy rates, the first one just driven by a PA mechanism, and the second one by SC. To do so, we employ an AD-AS model à la Rudebusch (2002b). The Phillips curve reads as follows:

[15] The variables definition may be found in the Data appendix. About the Taylor rate definitions, notice that they do not have any error term, since the policy deviations with respect to the suggested rate are represented in our set up by the vector η_t.

[16] In Taylor (1993), the policy rule reads as follows: $i_t = \overline{\pi}_t + 0.5y_t + 0.5(\overline{\pi}_t - \pi^*) + r^*$, with $\pi^* = r^* = 2\%$. Then, the constant c in the various Taylor rates is a linear convolution of the inflation target π^* and the real interest rate of equilibrium r^*, i.e. $r^* - (b_\pi - 1)\pi^*$. Neither in Rudebusch (2002a)'s nor in our study the focus is the one of assessing these elements. For investigations concentrating on these components, see Judd and Rudebusch (1998), and Domenéch, Ledo, and Taguas (2002).

[17] An already 'classical' reference for the dynamics of the monetary policy transmission is Christiano, Eichembaum, and Evans (1998).

[18] See Rudebusch (2002a)'s discussion at page 1178.

$$\pi_{t+1} = \mu_\pi E_t \overline{\pi}_{t+4} + (1-\mu_\pi) \sum_{j=1}^{4} \alpha_{\pi j} \pi_{t-j+1} + \alpha_y y_t + \varepsilon^\pi_{t+1} \tag{6}$$

while the dynamic IS equation is

$$\begin{aligned} y_{t+1} &= \mu_y E_t y_{t+2} + (1-\mu_y) \sum_{j=1}^{2} \beta_{yj} y_{t-j+1} \\ &\quad - \mu_r \beta_r (i_t - E_t \overline{\pi}_{t+4}) - (1-\mu_r) \beta_r (\overline{i}_t - \overline{\pi}_t) + \varepsilon^y_{t+1} \end{aligned} \tag{7}$$

where π_t is the four-quarter inflation rate, y_t is the output gap, i_t is the short term nominal interest rate, and $\overline{x}_t = \sum_{s=0}^{3} x_{t-s}$, x_t being either inflation or the policy rate. As shown by Söderlind, Söderström, and Vredin (2002b), this stylized representation of the economy is capable of replicating fairly well the observed dynamics of the variables here considered. By using the system of equations (3), (4), (6), and (7), we can build two counterfactual policy rates whose explanatory variables are fully endogenously determined by the system itself.[19] In constructing these rates, we keep fixed parameters such as α_s, β_s, μ_s, and the coefficients of the original Taylor rate b_s. The estimated coefficients are presented in Table 1. Moreover, we impose $\mu_\pi = 0.1$, $\mu_y = 0.3$, and $\mu_r = 1$, as in Castelnuovo (2003).

Then, we just use two different pairs of calibrated values (ρ, ρ_ε), in order to plot the two counterfactual rates.[20] We use the pair (0.7,0.0) to identify the PA specification, while (0.0,0.9) for the SC one. Figure 1, which also includes the actual federal funds rate, is the outcome of our effort.

As it is possible to see, the three rates are roughly tracking the same pattern. In fact, the similarities regarding a few descriptive statistics, presented in Table 2, reinforce the idea that in assessing the existence and importance of the PA mechanism versus SC process we cannot rely on the sole estimation of

[19] In the Technical appendix we describe how to implement this exercise.

[20] Given all the other parameters of the model, as well as the estimated shocks affecting inflation, output gap, and the monetary policy rule, we calibrated the coefficients ρ and ρ_ε in order to minimize the squared deviations of each simulated rate with respect to the actual one.

Phillips curve: $\pi_{t+1} = \alpha_{\pi1}\pi_t + \alpha_{\pi2}\pi_{t-1} + \alpha_{\pi3}\pi_{t-3} + \alpha_{\pi4}\pi_{t-4} + \alpha_y y_t + \eta^{\pi}_{t+1}$					
Parameters	$\alpha_{\pi1}$	$\alpha_{\pi2}$	$\alpha_{\pi3}$	$\alpha_{\pi4}$	α_y
Point Estimates	0.28	0.08	0.26	0.31	0.11
(*St. Dev.*)	(0.15)	(0.14)	(0.12)	(0.17)	(0.06)
Adjusted $R^2 = 0.60$; $\sigma^{\pi}_{\eta} = 0.63$.					
AD curve: $y_{t+1} = \beta_{y1} y_t + \beta_{y2} y_{t-1} + \beta_r(\bar{i}_t - \bar{\pi}_t) + \eta^y_{t+1}$					
Parameters	β_{y1}	β_{y2}	β_r		
Point Estimates	1.220	−0.178	−0.122		
(*St. Dev.*)	(0.176)	(0.183)	(0.061)		
Adjusted $R^2 = 0.92$; $\sigma^y_{\eta} = 0.51$.					
Taylor rule: $i_t = (1-\rho)(b_\pi \bar{\pi}_t + b_y y_t) + \rho i_{t-1} + \varepsilon_t$, $\varepsilon_t = \rho_\varepsilon \varepsilon_{t-1} + \eta_t$					
Parameters	b_π	b_y	ρ	ρ_ε	
Point Estimates	1.397	0.749	0.609	0.578	
(*St. Dev.*)	(0.371)	(0.209)	(0.146)	(0.202)	
Adjusted $R^2 = 0.96$; $\sigma^i_{\eta} = 0.33$.					
Sample:1987Q4-1999Q4, US data. Estimators: OLS (AS-AD curves), NLS (Taylor rule). Newey-West corrected standard errors (3 lags). All the variables have been demeaned, so no constants appear in the equations.					

Table 1: Estimates of the AD-AS-Taylor rule model

the encompassing model (1)-(2). Moreover, small-sample limitations may very much imply large parameter uncertainty. Indeed, a definitive choice between PA and SC seems to be difficult in this context. Therefore, a sharp 'either-or' test must rely on an alternative, different econometric model.

The importance of the contribution by ENS (2002) relates exactly to this identification issue. They notice that while the two different specifications (1)

Policy rates	*Mean*	*St. Dev.* (i_t)	*St. Dev.* (Δi_t)
Actual	5.52	1.82	0.46
PA specification	5.55	1.81	0.45
SC specification	5.75	1.49	0.48
Simulated rates constructed by using an AD-AS-Taylor rule representation of the economy. Partial Adjustment mechanism coefficients: ρ=0.7; ρ_ε=0.0. SC specification: ρ=0.0; ρ_ε=0.9. Estimates of the coefficients α_s, β_s, and b_s are reported in Table 1. The values of the parameters μ_s are μ_π=0.1, μ_y=0.3, μ_r=1, as calibrated in Castelnuovo (2003).			

Table 2: Policy rates descriptive statistics

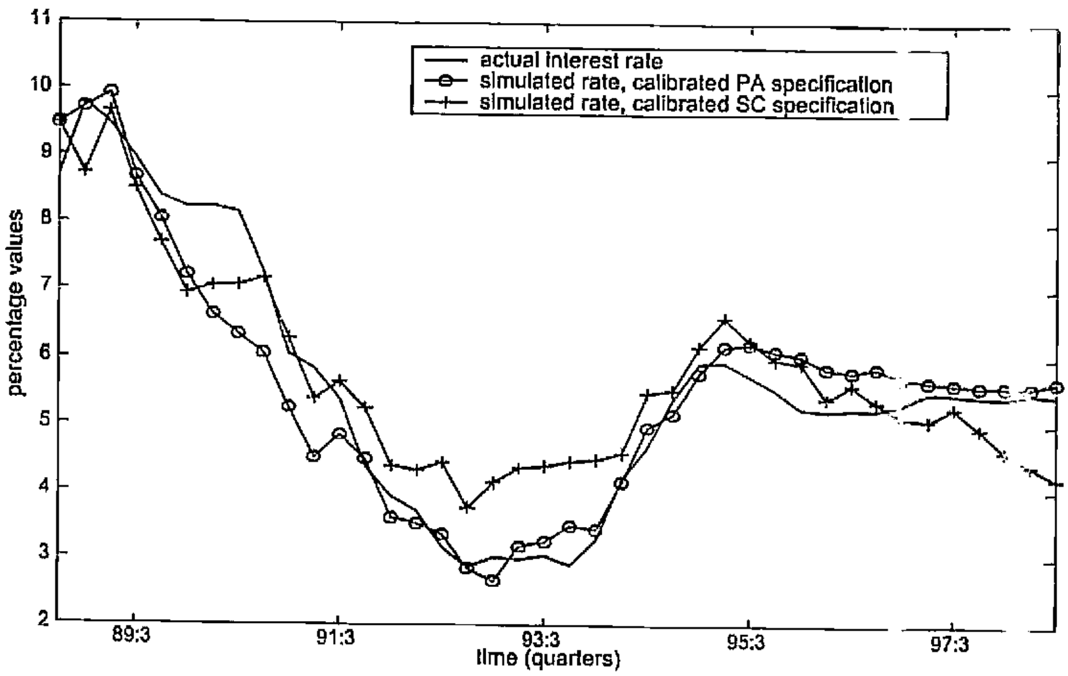

Figure 1: Actual, simulated PA, and simulated SC policy rates

and (2) have similar implications for the behavior of the interest rate *level*, this similarity does not hold anymore when *first differences* are taken into account. To see why, consider equation (1). Making some algebra, it is possible to arrive at the following formulation:

$$\Delta i_t = (1-\rho)\Delta \breve{i}_t + (1-\rho)(\breve{i}_{t-1} - i_{t-1}) + \eta_t \tag{8}$$

Differently, the SC specification (2) leads to this alternative equation:

$$\Delta i_t = \Delta \breve{i}_t + (1-\rho_\varepsilon)(\breve{i}_{t-1} - i_{t-1}) + \eta_t \tag{9}$$

The latter equation sheds some light on the implications of the SC engine. Here, variations of the Taylor-rate cause an immediate and full reaction of the policy rate change; by contrast, an inertial adjustment is present in equation (8) via the coefficient $(1-\rho)$. Then, it is possible to build up a direct test on the PA versus SC hypotheses. ENS estimate the empirical model

$$\Delta i_t = \gamma_2 \Delta \breve{i}_t + \gamma_3(\breve{i}_{t-1} - i_{t-1}) + \eta_t \tag{10}$$

and test the null hypothesis

$$H0_{SC} : \gamma_2 = 1 \tag{11}$$

Under the null (11), the SC specification holds true. ENS verify that the null is undoubtedly rejected, and conclude that the SC model is not sufficient to replicate the observed federal funds rate persistence. Then, they check if the PA model alone is sufficient to replicate the policy rate pattern, and test the null

$$H0_{PA} : \gamma_2 = \gamma_3 \tag{12}$$

In fact, there is no reason to believe that only one of the two hypotheses holds. Indeed, both PA and SC could be important in fitting the actual monetary policy rate. ENS build up and test a nested structure equivalent to (3), finding that both PA and SC are supported by the data. So, even in the presence of a SC component, the data seem not to discard the PA specification.

To summarize, ENS (2002) tackle the identification problem raised by Rudebusch (2002a) and succeed in constructing a test to directly support the importance of the PA hypothesis in describing the Fed's decisions during Greenspan's regime.

In this paper we extend ENS's contribution. When testing for the PA versus SC hypotheses, we allow for different specifications of the Taylor rate. In particular, we consider (usually omitted, but potentially important) variables such as the quadratic gap (indicator of asymmetric preferences on the output gap level, see Surico, 2002) or the credit spread (computed as the difference between a risky investment, i.e. the Moody's BAA yield on corporate bonds, and the 10-year government bond yield). We do so to check if these variables are capable of (at least partly) offsetting the high degree of PA recorded so far in the literature. In the next Section we fully describe our approach, and we comment on our findings.

4 PA versus SC: Alternative Taylor rate specifications

Before exploiting the estimation strategy set up by ENS (2002), we have to specify the Taylor rate $\widetilde{i}_t$. Naturally, we consider the already commented feedback rules (4) and (5). However, as mentioned above, Rudebusch (2002a) suspects that the omission of serially correlated variables could potentially be the cause of the estimated high degree of PA. To also check for this, we enrich the original specifications (4) and (5) by adding a third regressor, as follows:

$$\widetilde{i}_t = c + b_\pi \overline{\pi}_t + b_y y_t + b_z z_t \tag{13}$$

and

$$\widetilde{i}_t = c + b_\pi E_{t-1} \overline{\pi}_{t+4} + b_y E_{t-1} y_t + b_z E_{t-1} z_t \tag{14}$$

In our exercise, the regressor z_t plays different roles. A variable that we want to control for is a quadratic transformation of the output gap level, i.e. z_t

$= y_t^2$, that captures asymmetric concern by the CB as far as deviations of the realized output with respect to the potential one are concerned. In doing so we feel inspired by recent works on CBs' asymmetric preferences, which imply a non-quadratic representation of their loss function.[21] Many normative analyses conducted so far have relied on a quadratic formalization of the CB's penalty function. Indeed, apart from analytical tractability, there does not seem to be an obvious reason why a CB should symmetrically target the output gap measure (Blinder, 1997; Goodhart, 1999; Mayer, 2002). A Taylor rule with a quadratic gap as additional explanatory variable does encompass an asymmetric preference by the CB on output gap realizations. In particular, Surico (2002) shows that, if b_z is statistically relevant and assumes a negative sign, then we may think of that as an indicator of more moderate policy responses in booms than in recessions.

We also want to control for the impact of financial market conditions. This seems to be an interesting check, given the lively discussion that has been taking place for a couple of years now on the attention that the CB should pose on financial markets.[22] In particular, z will be a measure of *credit spread*, i.e. the spread between corporate and treasury bonds. Guha and Hiris (2002) empirically demonstrate that this is a counter-cyclical, leading indicator of macroeconomic business conditions. An economic *rationale* for the causality link going from the spread to the business cycle is the credit channel of monetary policy transmission, formalized first by Bernanke and Blinder (1988), and updated by Bernanke and Gertler (1995) and Bernanke, Gertler, and Gilchrist (1996).[23]

[21] Along with Surico (2002), Cukierman and Muscatelli (2002) and Cukierman and Gerlagh (2003) have performed empirical endeavours on this issue. See also the references quoted in those papers.

[22] See for example the two stimulating and opposite views by Bernanke and Gertler (2001) and Cecchetti, Genberg, and Wadhwani (2002), and the citations therein. Notice that in their discussion the key variable taken into account as indicator of the financial markets conditions is the asset prices misalignements. Instead, in our empirical exercise we work with the credit spread, as defined in Gerlach-Kristen (2002).

[23] In brief, the credit channel works as follows. Suppose to be in a good moment for the economy. Current income is high, and expectations are positive. Then, investors are willing to buy profitable shares; as a consequence, asset prices raise. This improves the situation of the firms' balance sheets, and imply an easier access to banks' loans, on average. The larger collateral available guarantees also more favourable rates on these loans for the firms. As a consequence, firms need to raise less funds via their corporate bonds, then returns on those bonds will be lower. This tightens the credit spread, and triggers (with some lags) the economic boost. However, at some point this boom in economic activities will become inflationary. The CB will react by raising the real interest rates, so profits and expectations will turn down. This implies a reduction of the asset prices, so of the collateral that firms may

Given its properties as a counter-cyclical, leading indicator of the business cycle, a significant and negative sign associated to b_z would make us conjecture that the credit spread has played an important role in Greenspan's feedback rule.

Our exercise aims at testing the PA versus SC hypotheses. To do so, we first estimate equation (10) with the Taylor rate alternatively specified as (4), (5), (13), and (14). As a second step, we estimate the nested model (3), once more considering all the above indicated Taylor rate specifications, in order to assess if there is trace of a 'joint significance'. Since we want to compare our results with Rudebusch (2002a)'s, we employ his sample choice, i.e. 1987Q4-1999Q4. We adopt a Non-linear Least Square estimator in backward looking models (i.e. when (4) and (13) are considered), while GMM when (5) and (14) are taken into account. A robustness check on our GMM estimates, performed on the basis of Survey data, is also presented. Our results and a discussion follow.

5 Findings

We now present our results. Table 3 collects our findings regarding the PA versus SC test run with a backward looking framework.[24] A few remarks are worthwhile. First of all, the values and the significance of the parameters b_π and b_y seem to be robust across specifications. In particular, the elasticity of the policy rate with respect to inflation is statistically in line with the value posed by Taylor (1993).[25] Our point-estimates for b_y are slightly larger than the value proposed by Taylor, but are roughly in line with those obtained by Judd and Rudebusch (1998), Kozicki (1999), Amato and Laubach (1999), and Rudebusch (2002a). Moreover, the parameter b_z is statistically significant and has got the expected sign both in the case of asymmetric preferences and in the case of financial stress. Indeed, it seems possible to conjecture that Greenspan

provide to banks. This will induce banks to augment their returns on loans, so firms will have to switch toward other financial channels, e.g. corporate bonds. The increase in the latter's yields will enlarge the credit spread, while the cycle starts declining.

[24] A note of cautious in evaluating our findings is needed. Our econometric estimates rely on the assumption of stationarity of the series at hand. In fact, as far as some of the series employed here are concerned, the null of unit root turns out to be very hard to reject when a standard augmented Dickey-Fuller test is employed. However, it is well known that the Dickey-Fuller test is not very reliable in short sample analyses.

[25] In fact, a standard Wald test cannot reject the restriction $b_\pi = 1.5$ for none of the estimated backward looking Taylor rules. Nevertheless, a bit of cautiousness is necessary here, given the large estimated standard deviations, probably due to the small sample at hand.

Taylor rate specification	Standard Taylor	Asymmetric preferences	Credit spread
b_π	1.508** (0.405)	1.438** (0.330)	1.363** (0.241)
b_y	0.864** (0.195)	0.696** (0.135)	0.826** (0.075)
b_z	-	−0.224** (0.075)	−2.611** (0.531)
γ_2	0.440** (0.167)	0.332** (0.151)	0.392** (0.071)
γ_3	0.197** (0.070)	0.301** (0.057)	0.290** (0.073)
$\bar{R}^2$	0.954	0.965	0.979
$H_0 : \gamma_2 = 1$ (*F−test, p−value*)	0.002**	0.000**	0.000**
$H_0 : \gamma_2 = \gamma_3$ (*F−test, p−value*)	0.186	0.841	0.417

*=95%/**=99% rejection of the null hyp. Estimated model:
$\Delta i_t=\gamma_2(b_\pi\Delta\bar{\pi}_t+b_y\Delta y_t+b_z\Delta z_t)+\gamma_3(c+b_\pi\bar{\pi}_{t-1}+b_y y_{t-1}+b_z z_{t-1}-i_{t-1})+\eta_t$
$z_t = y_t^2$ (Asymmetric preferences); z_t =spread (Credit spread). Estimates performed via NLS estimator. Newey-West correction (3 lags) applied to the standard errors (reported in brackets).
c omitted for brevity. $\bar{R}^2$ refers to the *level* of the federal funds rate.

Table 3: Test for PA versus SC: Backward Looking Taylor Rules

has behaved asymmetrically when facing positive and negative deviations of the real gross domestic product with respect to its stochastic trend; in this sense, we share Surico (2002)'s opinion.[26] Moreover, indications coming from the financial market are statistically important for replicating the observed federal funds rate in the analyzed sample, so confirming results reached by Gerlach-Kristen (2002).[27]

According to the $\bar{R}^2$ statistic, the descriptive power of all the models employed seems to be high. For our purposes, the most important row of Table 3

[26] By constrast, Kim, Osborn, and Sensier (2002) apply a non-parametric technique to the CB's policy function, and cannot reject the null of linearity for the feedback rules they estimate for the post-Volcker era. Apart from the difference in the technique exploited, these authors concentrate on the sample 1979Q3-2000Q4, while we focus our attention on Greenspan's regime.

[27] Notice that there might be an endogeneity problem here. In fact, variations of the dependent variable (short term interest rate) are likely to influence all the term structure of interest rates, so also the long term rates featuring the regressor (credit spread). We think that the timing of this feedback still preserves our estimates from the unconsistency threat. Moreover, the sign of the credit spread estimated coefficient is in line with our expectations.

Taylor rule specification	Standard Specification	Asymmetric preferences	Credit spread
b_π	1.146** (0.114)	0.967** (0.343)	1.167** (0.042)
b_y	1.066** (0.081)	0.669** (0.109)	0.405** (0.028)
b_z	-	−0.652** (0.166)	−4.836** (0.160)
γ_2	0.219** (0.034)	0.248** (0.032)	0.194** (0.015)
γ_3	0.245** (0.027)	0.123** (0.028)	0.258** (0.012)
$\bar{R}^2$	0.919	0.927	0.972
$H_0 : \gamma_2 = 1$ (F−test, p−value)	0.000**	0.000**	0.000**
$H_0 : \gamma_2 = \gamma_3$ (F−test, p−value)	0.489	0.000**	0.000**
Over. Restr. (J−statistic, p−value)	0.932 ($\chi^2(12)$)	0.957 ($\chi^2(15)$)	0.940 ($\chi^2(15)$)

*=95%/**=99% rejection of the null hyp. Estimated model:
$\Delta i_t = \gamma_2(b_\pi \Delta E_{t-1}\bar{\pi}_{t+4} + b_y \Delta E_{t-1} y_t + b_z \Delta E_{t-1} z_t) +$
$\gamma_3(c + b_\pi E_{t-1}\bar{\pi}_{t+3} + b_y E_{t-1} y_{t-1} + b_z E_{t-1} z_{t-1} - i_{t-1}) + \eta_t$. $z_t = y_t^2$ (As. pref.);
z_t =spread (Credit spread). Estimator: GMM. Instruments:
$[c\ \bar{\pi}_{t-2}..\bar{\pi}_{t-5} y_{t-2}..y_{t-5} \Delta i_{t-2}..\Delta i_{t-5} \Delta\bar{\pi}^{PPI}_{t-2}..\Delta\bar{\pi}^{PPI}_{t-5} \Delta z_{t-2}..\Delta z_{t-5}]$,
$\bar{\pi}^{PPI}_t$ four quarter inflation from the Producer Price Index (Finished Goods).
z instrument introduced when z present in the estimated equation.
Newey-West correction (Bartlett kernel, 3 lags) applied to the st. err. (in brackets).
$\bar{R}^2$ refers to the *level* of the federal funds rate. c omitted for brevity.

Table 4: Test for PA versus SC: Forward Looking Taylor Rules

is the one where we collect all the p-values concerning the Wald test on the null (11). Robustly enough, the null is rejected at the 99% confidence level for all the three cases under investigation, so discarding SC as the unique ex-post descriptive mechanism of the federal funds rate path. By contrast, the null (12) is not rejected, even if the p-values corresponding to the models 'Standard Taylor' and 'Credit Spread' are not overwhelming on average. However, our findings tend to support ENS (2002)'s, and cast some doubts on Rudebusch (2002a)'s position.

In Table 4 we place our estimates obtained by working on forward looking Taylor rules. From a qualitative viewpoint, these figures tend to confirm those got with the backward looking models. In fact, all the estimated coefficients are statistically significant, and have the expected sign. The Taylor principle is not rejected, and this is a robust finding across rules. The output gap coefficient turns out to be lower when omitted variables are considered, signalling an upward bias in the estimated coefficient for the 'Standard Specification' model. Interestingly, the point estimates for the additional regressor are larger when forward looking rules are considered, while the estimated coefficients attached to the expected inflation rate are smaller. This might suggest that if a CB is targeting a forecast inflation rate then the importance of potentially important leading indicators such as the squared gap or the credit spread rises.[28]

When looking at our testable restrictions, the null (11) of pure SC process is strongly rejected, very much as in the backward looking case. Nevertheless, with the forward looking formulation also the null (12) is rejected in two cases out of three, so implying that the PA process *per se* has got hard time in fully describing the policy rate path in the last 15 years. This leads us to also estimate the encompassing model (3) in order to assess if the PA and SC hypotheses are jointly important from a positive standpoint.

Our results are presented in Table 5. First of all, the significance of all the regressors in the Taylor rules is confirmed. Moreover, point-estimates of the parameter b_π are now much closer to each other. Also with this encompassing specification, the additional regressor z_t seems to be quite relevant in fitting

[28]Notice that the J-statistics (p-values) largely confirm the goodness of our instrument choice. However, the number of overidentifying restrictions in the estimations we undertook is high, and might induce biases (Staiger and Stock, 1997). To check for the robustness of our estimates, we run regressions with survey data using NLS, as explained later in the text.

the path of the federal funds rate; the point estimates present in this Table are statistically in line with those seen in Table 3. As far as our key-parameters ρ and ρ_ε are concerned, both are statistically significant. The point-estimate of the coefficient ρ is about 0.6 in all the three backward looking nested models considered here. Notably, this is lower of a magnitude of 0.2 with respect to what it is conventionally found. This seems to be due to the impact exerted by the explicitly modeled serial correlation process. In fact, the corresponding point estimate turns out to be quite robust to the introduction of omitted variables. Interestingly, the same does not hold for that of the AR(1) process, which falls from a value of about 0.58 to values lower than 0.4. Of course, this does not imply that the relative importance of the SC process lowers with respect to the one of the PA mechanisms. However, it seems to bring evidence in favor of a role of the lagged dependent variable *per se* in estimated Taylor rules, as underlined by ENS (2002).

When moving to the forward looking nested model (Table 6), we find confirmation of some already commented results. In particular, the estimated coefficients of the 1-year ahead inflation rate are lower than those in the backward looking counterpart; by contrast, those of the additional regressors are higher, so confirming their role as leading indicator of future inflation. The significance of both ρ and ρ_ε is confirmed, while the point estimates are higher for ρ (and more in line with the literature, e.g. Clarida, Galí, and Gertler, 2000) and lower for ρ_ε if compared to those of the backward looking case. Once more, it seems to be difficult to think about a Taylor rule whose persistence is exclusively determined by a SC process.

Robustness check: Approximating inflation expectations with survey-based data

GMM estimates are often seen as being fragile, and may heavily be instrument-dependent In fact, all the p-values presented in Tables 4 and 6 seem to suggest that the over-identifying restrictions imposed on our estimated models are statistically valid. However, as a check on the validity of our results, we estimate forward looking Taylor-type rules using a different strategy. Instead of instrumenting our one-year ahead inflation expectations, we exploit a series provided

Taylor rate specification	Standard Taylor	Asymmetric preferences	Credit spread
b_π	1.397** (0.371)	1.433** (0.205)	1.359** (0.195)
b_y	0.749** (0.209)	0.677** (0.132)	0.781** (0.091)
b_z	-	−0.185* (0.072)	−2.346** (0.512)
ρ	0.609** (0.146)	0.637** (0.096)	0.618** (0.065)
ρ_ε	0.578** (0.202)	0.379* (0.175)	0.318 (0.161)
$\bar{R}^2$	0.965	0.970	0.980

*=95%/**=99% rejection of the null hyp. Estimated model:
$i_t = (1-\rho)(c+b_\pi\bar{\pi}_t+b_y y_t+b_z z_t)+\rho i_{t-1}+\varepsilon_t$, $\varepsilon_t = \rho_\varepsilon \varepsilon_{t-1} + \eta_t$
$z_t = y_t^2$ (Asymmetric preferences); z_t =spread (Credit spread).
Estimator: NLS. Newey-West correction (3 lags) applied to the standard errors (in brackets). c omitted for brevity.

Table 5: Nested PA-SC model: Backward Looking Taylor Rules

Taylor rate specification	Standard Specification	Asymmetric preferences	Credit spread
b_π	1.379** (0.521)	1.171** (0.330)	1.024** (0.144)
b_y	0.803** (0.174)	0.546** (0.103)	0.183* (0.073)
b_z	-	−0.293** (0.078)	−4.465** (0.265)
ρ	0.846** (0.037)	0.826** (0.024)	0.794** (0.020)
ρ_ε	0.438** (0.073)	0.319** (0.108)	0.295** (0.043)
$\bar{R}^2$	0.937	0.950	0.971
Over. Restr. (*J−statistic, p−value*)	0.917 ($\chi^2(12)$)	0.962 ($\chi^2(15)$)	0.943 ($\chi^2(15)$)

*=95%/**=99% rejection of the null hyp. Estimated model:
$i_t = (1-\rho)(c+b_\pi E_{t-1}\bar{\pi}_{t+4}+b_y E_{t-1} y_t+b_z E_{t-1} z_t)+\rho i_{t-1}+\varepsilon_t$, $\varepsilon_t = \rho_\varepsilon \varepsilon_{t-1} + \eta_t$
$z_t = y_t^2$ (Asymmetric preferences); z_t =spread (Credit spread).
Estimates performed via GMM. Instruments:
$[c\ \bar{\pi}_{t-2}..\bar{\pi}_{t-5}\ y_{t-2}..y_{t-5}\ \Delta i_{t-2}..\Delta i_{t-5}\ \Delta\bar{\pi}^{PPI}_{t-2}..\Delta\bar{\pi}^{PPI}_{t-5}\ \Delta z_{t-2}..\Delta z_{t-5}]$,
$\bar{\pi}^{PPI}_t$ four quarter inflation from the Producer Price Index (Finished Goods).
Newey-West correction (Bartlett kernel, 3 lags) applied to the stand. errors (reported in brackets). c omitted for brevity.

Table 6: Nested PA-SC model: Forward Looking Taylor Rules

by the Survey of Professional Forecasters (SPF) conducted by the Federal Reserve Bank of Philadelphia.[29] This provides us with an exogenous regressor, that can be employed in our econometric exercise without recurring to any instrument choice.. Of course, we should naturally employ in such a regression also measures of expected output gap (in level and quadratic fashions) and expected credit spread; this approach would be in line with forward looking Taylor rules such as those estimated via GMM in this work. Unfortunately, this is much less feasible. In fact, there are not official real-time estimates of potential GDP, which could allow us to construct an expected output gap series. Moreover, the Federal Reserve Bank of Philadelphia does not provide any measure of expected yield from risky financial investments, such as the Moody's BAA corporate index yield we employed to construct our measure of ex-post credit spread. Then, somewhat arbitrarily, we change the timing-assumption on the CB's expectations formation, and we estimate Taylor rules whose forward-lookingness is related just to the inflation rate. Practically, we consider the following two equations:

$$\begin{aligned} \Delta i_t &= \gamma_2(b_\pi \Delta E_t \pi_{t+4}^{SPF} + b_y \Delta y_t + b_z \Delta z_t) \\ &\quad + \gamma_3(c + b_\pi E_{t-1}\pi_{t+3}^{SPF} + b_y y_{t-1} + b_z z_{t-1} - i_{t-1}) + \eta_t \end{aligned} \tag{15}$$

to test for the PA versus SC dynamic mechanisms, and

$$i_t = (1-\rho)(c + b_\pi E_t \pi_{t+4}^{SPF} + b_y y_t + b_z z_t) + \rho i_{t-1} + \varepsilon_t, \;\; \varepsilon_t = \rho_\varepsilon \varepsilon_{t-1} + \eta_t \tag{16}$$

to gain some insights on the possible coexistence between PA and SC. Notice that, given the timing assumption underling these two models, and given the exogeneity of the SPF inflation forecasts, we can consistently estimate equations (15) and (16) via NLS.[30]

[29] For details regarding the survey data on 1-year ahead inflation expectations used in this paper, see the Data appendix.

[30] A check on the robustness of these results was performed by implementing IV estimations (instrument for the SPF inflation expectations: its lag), and confirmed us that those figures are pretty robust in this sense. IV estimates are available upon request.

Taylor rate specification	Standard Specification	Asymmetric preferences	Credit spread
b_π	2.157^{**} (0.228)	1.983^{**} (0.239)	1.963^{**} (0.228)
b_y	0.867^{**} (0.141)	0.750^{**} (0.128)	0.841^{**} (0.098)
b_z	-	-0.139^{*} (0.059)	-1.860^{**} (0.445)
γ_2	0.375^{**} (0.056)	0.344^{**} (0.055)	0.375^{**} (0.045)
γ_3	0.274^{**} (0.062)	0.281^{**} (0.059)	0.279^{**} (0.056)
$\bar{R}^2$	0.970	0.973	0.981
$H_0: \gamma_2 = 1$ (*F−test, p−value*)	0.000^{**}	0.000^{**}	0.000^{**}
$H_0: \gamma_2 = \gamma_3$ (*F−test, p−value*)	0.098	0.378	0.068

*=95%/**=99% rejection of the null hyp. Estimated model:
$\Delta i_t = \gamma_2(b_\pi \Delta E_t \pi^{SPF}_{t+4} + b_y \Delta y_t + b_z \Delta z_t) + \gamma_3(c + b_\pi E_{t-1}\pi^{SPF}_{t-3} + b_y y_{t-1} + b_z z_{t-1} - i_{t-1}) + \eta_t$.
$z_t = y_t^2$ (Asymm. pref.); z_t =spread (Credit spread). Estimator: NLS.
π^{SPF}_{t+4} = 1-year ahead Expected Inflation from Survey of Professional Forecasters.
Newey-West correction (3 lags) applied to the st. errors (in brackets).
c omitted for brevity. $\bar{R}^2$ refers to the *level* of the federal funds rate.

Table 7: Test for PA versus SC: Taylor Rules, SPF Expected Inflation

Taylor rate specification	Standard Specification	Asymmetric preferences	Credit spread
b_π	2.110^{**} (0.241)	1.976^{**} (0.215)	1.934^{**} (0.173)
b_y	0.827^{**} (0.118)	0.729^{**} (0.107)	0.812^{**} (0.082)
b_z	-	-0.138^{*} (0.060)	-1.654^{**} (0.437)
ρ	0.652^{**} (0.059)	0.673^{**} (0.050)	0.653^{**} (0.042)
ρ_ε	0.296 (0.154)	0.177 (0.152)	0.141 (0.161)
$\bar{R}^2$	0.973	0.976	0.980

*=95%/**=99% rejection of the null hyp. Estimated model:
$i_t = (c + b_\pi E_t \pi^{SPF}_{t+4} + b_y y_t + b_z z_t) + \rho i_{t-1} + \varepsilon_t, \ \varepsilon_t = \rho_\varepsilon \varepsilon_{t-1} + \eta_t$
$z_t = y_t^2$ (Asymmetric preferences); z_t =spread (Credit spread).
Estimator: NLS. Newey-West correction (3 lags) applied to the st. errors (in brackets). c omitted for brevity.

Table 8: Nested PA-SC Model: Taylor Rules, SPF Expected Inflation

A comparison of the figures in Tables 4 with those in Tables 7 triggers some thoughts. First of all, all these coefficients have the expected signs. Also with survey data the Taylor principle turns out to be respected, even if the estimated coefficients are remarkably larger with respect to the GMM ones. This does not seem to hold for the output gap figures we estimated; notably, the output gap turns out to be statistically significant in all the estimated rules. The same holds for the additional variables, which show lower point estimates with respect to those obtained via GMM. The reason of such differences may be attributed to the nature of the SPF inflation expectations, that are not fully rational from a statistical viewpoint (Roberts, 1998).

As already seen in all the previously commented cases, the test on the null (11) suggests a rejection of the hypothesis of SC as the unique engine of the federal funds rate dynamics. By contrast, the PA testable restriction is not rejected, even if the p-values are pretty low.

Moving to Tables 6 and 8, we observe that the above written considerations regarding the estimated coefficients still hold. In fact, the remarkable result obtained with SPF inflation forecasts is that the SC coefficient is never statistically significant at the 95% confidence interval, while the PA one is always significant at the 99% level. Of course, if this does not necessarily imply that SC is not important for shaping an empirically relevant Taylor rules, *a fortiori* it should not cast doubts on the relevance of the smoothing argument in the estimated Taylor rules.

6 A note on real time data analyses

In this paper we use revised data; in fact, these data were not available to the Federal Open Market Committee Members when they took their decisions. What if we used real time data? Lansing (2002) simulates a model in which a CB sets the policy rate without any smoothing, and on the basis of real time estimates of the potential output. In Lansing's study, the measurement error regarding the potential output estimates is serially correlated, because monetary authorities need time to learn about the new potential output process after a shock has occurred. Lansing discusses how an econometrician who used final, revised data would obtain upward biased estimates of the parameter ρ relative to the true value, because the lagged interest rate captures the omitted, serially correlated, measurement error. Indeed, Lansing (2002)'s conclusions support Rudebusch (2002a)'s claim on the massive relative importance of SC versus PA. Mehra (2001) also supports Rudebusch (2002a)'s findings. In particular, he works with real time data, and estimates the potential output as a simple log-linear trend of the GDP. His estimates of the partial adjustment coefficient are indeed low, and sometimes even not significant.

So, are our results misleading? In fact, the impact of real time data on the estimated value of the smoothing parameter is still disputed. Perez (2001) and Orphanides (2001) estimate Taylor rules with real time data, and still obtain high estimated figures regarding the interest rate smoothing coefficients.[31] Moreover, in estimating the nested model (3) we explicitly allow for a serially correlated error term. This choice, not frequently taken in this literature, should enable us to catch the omitted variable effect highlighted by Lansing (2002).

Therefore, from a quantitative point of view, the use of revised data does not necessarily lead to dramatic consequences for our results.[32] Here, we would like to stress the fact that the autoregressive coefficient ρ could indeed have a lower magnitude with respect to the standard assessment of 0.8. However, this does not necessarily imply that the Fed has not smoothed the federal funds rate. Indeed, it could be the case that the sluggishness discussed so far in the literature is not so high, but it is still present.

7 Conclusions

In this paper we have focussed our attention on the interest rate smoothing argument in Taylor-type schemes. In a recent contribution, Rudebusch (2002a) intriguingly challenges the conventional wisdom, and states that the interest rate smoothing behavior at quarterly frequencies is just an illusion. As indirect proof, he claims that if this was not the case, then rational agents should be capable of predicting future movements of the policy rate. Indeed, this is not what happens in reality.

[31] Notice that Lansing (2002) and Mehra (2001) focus on the interest rate smoothing value in the policy rule estimation. Instead, Perez (2001)'s paper regards the (non) accommodativeness of the monetary policy in the '70s, while Orphanides (2001) concentrates on the different policy recommendations arising when using revised vs. real time data.

[32] A similar point about the smoothing parameter is made by Brüggemann and Thornton (2002).

By applying English, Nelson, and Sack (2002)'s modeling strategy to US data, in this paper we assessed the significance of both the interest rate smoothing argument and the serially correlated policy deviations from the Taylor rate prescriptions. In particular, we estimated 9 models in first differences to test for the 'pure' partial adjustment hypothesis versus the one of 'pure' serial correlation. Notably, in all the 9 cases considered in our exercise, the null of pure serial correlation process was rejected. By contrast, the PA mechanism was supported by 7 cases out of 9; however, for some of these cases the p-values suggest cautiousness in the interpretation of these results. Then, we estimated 9 encompassing models, i.e. 9 models admitting both interest rate smoothing and serially correlated policy shocks. While the significance of the interest rate smoothing coefficient turns out to be overwhelming, that of the AR(1) shocks is not supported in 4 cases out of 9.

Indeed, credit crunches or financial crises represent shocks that may very well suggest serially correlated deviations with respect to the policy recommended by the Taylor rate; in this sense, we are sympathetic with Rudebusch (2002a)'s argument. Nevertheless, our estimates indicate that the lagged interest rate does play a key-role in a Taylor-type model. By contrast, the presence of a serially correlated policy shock, although often statistically relevant, does not seem to be sufficient in explaining the observed interest rate gradualism. Therefore, our results do not necessarily contradict Rudebusch (2002a)'s claim on the significance of a serially correlated error term in estimated Taylor rules, but strongly support English, Nelson, and Sack (2002)'s conclusion on the key-role played by the lagged depended variable in this type of policy functions.

Interestingly, the simple average computed on the 9 different estimated interest rate smoothing coefficients is about 0.7, a value lower than the 'standard' 0.8. This may suggest that monetary authorities act gradually, but probably respond faster than claimed in the literature to shocks affecting the Taylor rate. Hence, Rudebusch (2002a)'s conjecture on the 'exaggerated' magnitude usually attributed to the interest rate smoothing component is also supported by our estimates.

Finally, our empirical findings seem to call for further research on non-standard explanatory variables to be included into Taylor type regressions. Asymmetric policy preferences (Surico, 2002) and financial indicators (Gerlach-

Kristen, 2002) are surely worthy of further investigation from both a positive and a normative side, also in the light of some recent contributions on the relationship between asymmetric preferences and ex-ante average inflation bias (Cukierman and Muscatelli, 2002, Cukierman and Gerlach, 2003, and Surico, 2003), and on the importance of financial markets evolution for monetary policy decisions (Cecchetti, Genberg, and Wadhwani, 2002).

Technical appendix

In this Technical appendix we describe how we built up our Figure 1.

Our economy is basically identified by the following 4 equations: (3), (4), (6), and (7). This is a *recursive* economy, whose law of motion can be easily defined. To do it, the first step to undertake is to rewrite equations (6) and (7):

$$\pi_{t+1} = \mu_\pi E_t(\frac{\pi_{t+1}+\pi_{t+2}+\pi_{t+3}+\pi_{t+4}}{4}) + (1-\mu_\pi)(\alpha_{\pi 1}\pi_t + \alpha_{\pi 2}\pi_{t-1} + \alpha_{\pi 3}\pi_{t-2} + \alpha_{\pi 4}\pi_{t-3}) + \alpha_y y_t + \varepsilon^\pi_{t+1} \quad (17)$$

$$y_{t+1} = \mu_y E_t y_{t+2} + (1-\mu_y)(\beta_{y1}y_t + \beta_{y2}y_{t-1}) - \beta_r\mu_r[i_t - E_t(\frac{\pi_{t+1}+\pi_{t+2}+\pi_{t+3}+\pi_{t+4}}{4})] - \frac{\beta_r(1-\mu_r)}{4}(i_t + i_{t-1} + i_{t-2} + i_{t-3} - \pi_t - \pi_{t-1} - \pi_{t-2} - \pi_{t-3}) + \varepsilon^y_{t+1} \quad (18)$$

Our aim is to compute the expectations terms $E_t\pi_{t+4}$ and $E_t y_{t+2}$. Noticing that $\pi_{t+1} = E_t\pi_{t+1} + \varepsilon^\pi_{t+1}$ and $y_{t+1} = E_t y_{t+1} + \varepsilon^y_{t+1}$ (where ε^π_{t+1} and ε^y_{t+1} are white noise processes), it is then possible to manipulate (17) and (18) as follows:

$$\frac{\mu_\pi E_t\pi_{t+4}}{4} = (1-\frac{\mu_\pi}{4})E_t\pi_{t+1} - \frac{\mu_\pi}{4}E_t\pi_{t+2} - \frac{\mu_\pi}{4}E_t\pi_{t+3} - (1-\mu_\pi)(\alpha_{\pi 1}\pi_t + \alpha_{\pi 2}\pi_{t-1} + \alpha_{\pi 3}\pi_{t-2} + \alpha_{\pi 4}\pi_{t-3}) - \alpha_y y_t \quad (19)$$

$$\mu_y E_t y_{t+2} + \beta_r\mu_r E_t\pi_{t+4} = E_t y_{t+1} - (1-\mu_y)(\beta_{y1}y_t + \beta_{y2}y_{t-1}) + \beta_r\mu_r[i_t - E_t(\frac{\pi_{t+1}+\pi_{t+2}+\pi_{t+3}}{4})] + \frac{\beta_r(1-\mu_r)}{4}\sum_{i=0}^{3}(i_{t-i} - \pi_{t-i}) \quad (20)$$

The Central Banker policy rule is described in our experiment by a simple Taylor rule allowing for Partial Adjustment and Serially Correlated deviations:

$$i_t = (1-\rho)(b_\pi\pi_t + b_y y_t) + \rho_{t-1} + \varepsilon_t \quad (21)$$

$$\varepsilon_t = \rho_\varepsilon \varepsilon_{t-1} + \eta_t \tag{22}$$

It should be noticed that this formulation of the economic environment implies the presence of $n1 = 10$ predetermined variables,[33] which can be stacked into the vector

$$x_{1t} = \begin{bmatrix} \pi_t & \pi_{t-1} & \pi_{t-2} & \pi_{t-3} & y_t & y_{t-1} & i_{t-1} & i_{t-2} & i_{t-3} & \varepsilon_t \end{bmatrix}' \tag{23}$$

Moreover, there are $n2 = 4$ jump variables, namely

$$x_{2t} = \begin{bmatrix} E_t\pi_{t+3} & E_t\pi_{t+2} & E_t\pi_{t+1} & E_t y_{t+1} \end{bmatrix}' \tag{24}$$

Since we are solving a stochastic problem, we also define the $n1x1$ vector of shocks to the predetermined variables as:

$$v_{1t+1} = \begin{bmatrix} \varepsilon^{\pi}_{t+1} & 0_{1x3} & \varepsilon^{y}_{t+1} & 0_{1x4} & \eta_{t+1} & 0_{1x4} \end{bmatrix}' \tag{25}$$

Then, the state-space representation of the problem is the following:

$$A_0 \begin{bmatrix} x_{1t+1} \\ E_t x_{2t+1} \end{bmatrix} = A_1 \begin{bmatrix} x_{1t} \\ x_{2t} \end{bmatrix} + B_1 i_t + v_{t+1} \tag{26}$$

where

$$v_{t+1} = \begin{bmatrix} v_{1t+1} \\ 0_{n2x1} \end{bmatrix}$$

and the matrices A_0, A_1, and B_1 read as follows:

[33]The timing of our economic game is the following: 1) at the beginning of each period private agents form their expectations; 2) then, the interest rate level is optimally fixed by the Central Bank, and 3) the demand and supply shocks strike the economy.

$$
A_0 = \begin{bmatrix}
1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \frac{\gamma_\pi}{4} & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \frac{\beta_r\gamma_r}{4} & 0 & 0 & \gamma_y
\end{bmatrix}
$$

$$
A_1 = \begin{bmatrix}
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \\
1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \\
0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \rho & 0 & 0 & 0 & 0 \\
\widetilde{\alpha}_{\pi 1} & \widetilde{\alpha}_{\pi 2} & \widetilde{\alpha}_{\pi 3} & \widetilde{\alpha}_{\pi 4} & -\alpha_y & 0 & 0 & 0 & 0 & 0 & -\frac{\gamma_\pi}{4} & -\frac{\gamma_\pi}{4} & (1-\frac{\gamma_\pi}{4}) & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \\
\widehat{\beta}_r & \widehat{\beta}_r & \widehat{\beta}_r & \widehat{\beta}_r & \widetilde{\beta}_{y1} & \widetilde{\beta}_{y2} & -\widehat{\beta}_r & -\widehat{\beta}_r & -\widehat{\beta}_r & 0 & -\frac{\beta_r\gamma_r}{4} & -\frac{\beta_r\gamma_r}{4} & -\frac{\beta_r\gamma_r}{4} & 1
\end{bmatrix}
$$

$$
B_1 = \begin{bmatrix} 0_{1x6} & 1 & 0_{1x6} & \beta_r(\gamma_r + \frac{(1-\gamma_r)}{4}) \end{bmatrix}'
$$

with $\widetilde{\alpha}_{\pi j} = -(1-\gamma_\pi)\alpha_{\pi j}, \widehat{\beta}_r = -\frac{\beta_r(1-\gamma_r)}{4}, \widetilde{\beta}_{yj} = -(1-\gamma_y)\beta_{yj}$.

To get the standard state-space representation, we just have to pre-multiply (26) by A_0^{-1}, so obtaining

$$
\begin{bmatrix} x_{1t+1} \\ E_t x_{2t+1} \end{bmatrix} = A \begin{bmatrix} x_{1t} \\ x_{2t} \end{bmatrix} + Bi_t + v_{t+1} \qquad (27)
$$

where $A = A_0^{-1} A_1$ and $B = A_0^{-1} B_1$.[34]

[34] Notice that $A_0^{-1} v_{t+1} = v_{t+1}$, since A_0 is block diagonal with an identity matrix as its upper left block and the lower block of v_{t+1} is equal to zero.

In our exercise, the CB sticks to the simple rule (21). That rule can be re-written in compact form as

$$i_t = -Fx_t \tag{28}$$

where F is the following $1x(n1+n2)$ row vector:

$$F = \left[\begin{array}{cccccccccc} \breve{b}_\pi & \breve{b}_\pi & \breve{b}_\pi & \breve{b}_\pi & (1-\rho)b_y & 0 & \rho & 0_{1x2} & 1 & 0_{1x4} \end{array} \right] \tag{29}$$

where $\breve{b}_\pi = \frac{(1-\rho)b_\pi}{4}$.

Then, (27) and (28) imply this law of motion:

$$\left[\begin{array}{c} x_{1t+1} \\ E_t x_{2t+1} \end{array} \right] = (A - BF) \left[\begin{array}{c} x_{1t} \\ x_{2t} \end{array} \right] + v_{t+1} \tag{30}$$

Provided that the F vector leads the system to a unique equilibrium, Söderlind (1999) shows how to compute the matrices $M(n1xn1)$ and $C(n2xn2)$ such that[35]

$$x_{1t+1} = Mx_{1t} + v_{1t+1} \tag{31}$$

$$x_{2t} = Cx_{1t} \tag{32}$$

Therefore, by jointly considering (28)-(32), we can simulate different policy rates, in particular focussing on different pairs (ρ, ρ_ε). The values of the parameters used to build up Figure 1 are indicated below that Figure.[36]

[35] The computation of these matrices exploits the generalized Schur decomposition. Paul Söderlind's codes provide the user with the latter, as well as with the matrices M and C. His codes are available at this URL: http://www.hhs.se/personal/psoderlind/Software/Software.htm.

[36] Notice that the shocks η_{t+1}, as well as the initial value ε_0, are defined with a two-step procedure, by first estimating the Taylor rule (21), and then estimating an AR(1) process for the estimated residuals obtained in Step 1.

Data appendix

The short term rate used in our analysis is the federal funds rate. The quarterly inflation rate has been computed by using the GDP chain-weighted price index P_t. Our measure of output Q_t is the chain weighted real GDP. The potential output Q_t^* series is the one estimated by the Congressional Budget Office. The variables used in our study have been constructed as follows: π_t is the four-quarter inflation rate computed via the price index (P_t), i.e. $\pi_t \equiv 4(p_t - p_{t-1})$, where $p_t = 100 \ln P_t$. y_t is the output gap, which has been defined as $q_t - q_t^*$, where $q_t \equiv 100 lnQ_t$, while $q_t^* \equiv 100 lnQ_t^*$. The credit spread has been built as the difference between the Moody's BAA corporate index yield and the 10-year US treasury note yield. Finally, the upper-barred variables indicate simple averages taken over the contemporaneous observation and the previous three lags of the variable in consideration. All these series, together with the Producer Price Index (Finished Goods) exploited as an instrument in our GMM estimations, were downloaded from the Federal Reserve Bank of St. Louis web site, i.e. http://research.stlouisfed.org/fred2/. The series on one-year ahead inflation expectations used for estimating the models (15) and (16) were taken from the Federal Reserve Bank of Philadelphia web site, i.e. http://www.phil.frb.org/files/spf/cpie1.txt. In our exercise, we used one-year ahead inflation forecast (average). For reasons of time-series continuity, we considered the measure of inflation computed on the basis of the consumer price index. All the variables used either as depended variable or as regressors in our econometric exercises are depicted in Figure 2.

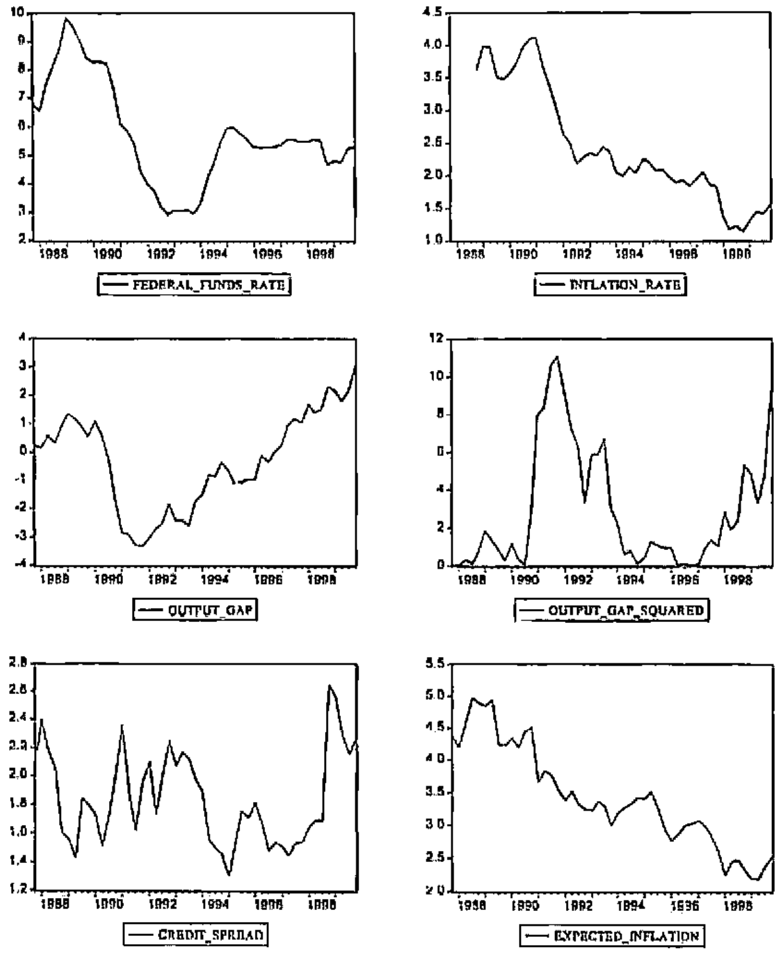

Figure 2: US series

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Conclusions

With the three chapters of my thesis I investigated the rationale and importance of the interest rate smoothing implemented by one of the most appreciated central banks in the world, the Fed. I verified that the uncertainty regarding the true model of the economy may suggest cautiousness to the monetary authority when moving the short-term nominal interest rate. Then, I tried to assess the quantitative importance of agents expectations when describing the observed federal funds rate path. Finally, I econometrically checked the relevance of the Fed's gradualism vis-a-vis that of serially correlated policy shocks.

My perception is that much effort has been done to understand the interest rate smoothing phenomenon. Nevertheless, we are far from having a complete comprehension of that. 'Why do monetary policy makers smooth the interest rate so much?' is one of the questions that many scholars are still posing, and the challenge to satisfactorily answer this question is still there. I hope I will be able to keep participating to this exciting debate in the years to come.

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To conclude, I just would like to thank those people who have helped me during these three years spent as Ph.D. student at Bocconi. First of all, my supervisor, Carlo Favero. If I decided to orient myself toward what I would label as Applied Monetary Policy, well ... it is mainly his fault! He has been supervising my work for some years with remarkable attention, and I am truly grateful for that. As I am grateful to Guido Tabellini, whose advice has been quite precious for improving the quality of my papers. Also the external member of the committee formed for my first oral exam, Frank R. Smets (European Central Bank), provided me with quite insightful comments and suggestions. Along with Frank Smets, I like to thank all the members of the Monetary Policy Strategy Division at the ECB, where I spent five very formative months. In particular, I like to mention Sergio Nicoletti-Altimari, Diego Rodriguez Palenzuela, and Massimo Rostagno for their continuous support during that period, along with Filippo Altissimo, my office mate during my last month in Frankfurt. And I do not want to forget the trainees I had the fortune to meet over there: They really made my experience quite enjoyable.

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Thinking about the Bocconi Group, a special thank is due to Angela Baldassarre, a person whose support I am not going to forget. Also, all the Ph.D. students with whom I happened to talk about my or their research have my personal consideration.

I believe that the art of writing a Ph.D. thesis is very much related to different types of intellectual stimuli. Spillovers are important also in terms of concreteness in executing a project as well as improvements in your writing-style. I sincerely think that all the discussions I have had in these years as a member of the FEEM (Fondazione Eni Enrico Mattei) group just opened up my mind. I am thinking in this moment of researchers such as Marzio Galeotti, Nicola Cantore, and Valentina Bosetti, and all the other scholars in Milan and Venice whom I exchanged some ideas with.

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Last but very far from being least ... I am quite sure that my mom Pasqualina, my dad Giuseppe, and my brother Gianluca do not care about the Fed's interest rate smoothing at all. Still, I decided to dedicate my Ph.D. thesis to them. If you knew how much support they have constantly given me before and during my Ph.D. years, you would surely agree on the goodness of my decision.

Efrem Castelnuovo