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The Fed's Preference for Policy Rate Smoothing: Overestimation due to Misspecification?

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Abstract

The federal funds rate is featured by frequent, small changes in the same direction and infrequent reversals. How to replicate the observed smooth behavior of the federal funds rate with a small scale macroeconomic model? This paper compares the descriptive performance of an empirical fully backward looking model with that of an empirical new-Keynesian hybrid framework. It turns out that the Fed's monetary policy conduct can be very well described with a framework allowing for the presence of a small but positive fraction of forward looking agents in the IS curve. This element remarkably reduces the large interest rate smoothing weight otherwise needed to track the observed macroeconomic series.

KEYWORDS: monetary policy authorities, interest rate smoothing, forward looking agents, hybrid IS curve

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1 Introduction

In the applied monetary policy literature, a simple framework representing the Central Bank (CB hereafter)'s problem has been extensively employed for some years now. 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] Macroeconomists working with this framework aim, among other things, at capturing the correlations and persistences present in the data. In particular, in the real world we observe smooth paths of the policy rates, a regularity labeled as *interest rate smoothing.* To capture the observed policy rate gradualism, the empirical literature has typically enriched the policy-makers' loss function with an *interest rate smoothing argument*, i.e. a penalty for the interest rate *change.*

Such an argument enters a loss function already featured by the presence of the main - possibly unique - CB's goals, i.e. inflation and output stability. Therefore, it would be plausible to think of the interest rate smoothing argument as being of minor importance for descriptive purposes, as commented by Sack and Wieland (2000). Interestingly, a *trade-off* between economic plausibility (of the relative importance of the interest rate smoothing volatility in the loss function, identified by the parameter μ) and goodness-of-fit (of the small-macro scale model in use) arises, i.e. the higher the μ, the better the fit, but the more implausible the representation of the monetary policy authorities' preferences.[2] Indeed, a high value of μ is hardly in line with what economists think as being the preferences of a CB. In commenting a loss function attributing *equal* weights to the volatilities of inflation, the output gap, and the interest rate in first-differences, Rudebusch (2005, p.13) states: "This penalty on interest rate volatility appears to be implausibly high, given the overwhelming emphasis among central banks on the first two objectives relative to the third (e.g. the "dual mandate" in the United States)."[3]

Sack and Wieland (2000) conjecture that monetary authorities may im-

[1] For a prominent analysis of this set-up, see Woodford (2003).

[2] To show this trade-off, Castelnuovo and Surico (2004) consider different studies - Dennis (2006), Ozlale (2003), and 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), but different econometric techniques are employed. One of Castelnuovo and Surico (2004)'s findings is the following: When economically plausible (i.e. relatively low) values of the μ parameter are estimated, the optimal simulated interest rate is featured by frequent reversals, i.e. the volatility of the simulated policy rate in first differences is much higher than the historical one.

[3] Goodhart (1999), Sack (2000), Sack and Wieland (2000), and Cecchetti (2000) offer similar considerations on this issue.

plement a cautious path of the policy rate because of the presence of *forward looking agents* in the economy. From this standpoint, the interest rate smoothing element embedded into the loss function is just a *catch all* capturing the omission of this (and possibly other) 'ingredients' usually considered by the policy-makers when determining the monetary policy.

Sack and Wieland (2000)'s considerations motivate this research. In particular, in this paper we focus on the empirical relationship between interest rate smoothing and the explicit formalization of *forward looking agents* (FLA hereafter) in a new-Keynesian model for output and inflation. As pointed out by Woodford (2003) and Giannoni and Woodford (2002a,b), private sector's expectations play a central role in monetary policy making. In fact, the announcement of a small change in the short term policy rate may trigger important nominal and real effects if private agents *expect* this change to be followed by a sequence of others, which is what happens under discretion if the objective function of the monetary policy-maker is featured by the presence of the interest rate smoothing argument.[4]

This paper aims at understanding *how much* descriptive power a standard small macro model may gain when taking FLA into account. To do so, we employ an encompassing AS-AD model *a la* Rudebusch (2002) that, under some identifying restrictions, may collapse to a backward looking, hybrid, or fully forward looking representation of the economy. For each different vector of the key parameters identifying such a framework, we compute the weight we need to attribute to the interest rate smoothing component in the CB's loss function for fitting the macroeconomic series of interest - inflation, the output gap, and the federal funds rate - best: The lower this weight, the better the model's performance. Our results suggest that the presence of a small but positive fraction of FLA in the IS curve allows for significant gains in terms of data-fitting. By contrast, the Phillips curve turns out to be completely backward looking. To our knowledge, this is the first effort that sheds some light on the *empirical* relationship existing between FLA and the interest rate smoothing penalty in the loss function.[5]

[4]There are several possible explanations for this regularity, including i) imperfect knowledge of the dynamics concerning the economic environment (Brainard, 1967; Sack, 2000; Söderström, 1999, Favero and Milani, 2005; Milani, 2003, Castelnuovo and Surico, 2004), ii) real time data (Orphanides, 2003), iii) learning (Sack, 1998; Ellison, 2003), iv) fears of financial markets disruption (Goodfriend, 1991; Blinder, 1997; Mishkin, 1999). In this study we deal with a different, possibly complementary potential source of misspecification affecting the standard backward looking models of monetary policy. Rudebusch (1995), Goodhart (1999), Lowe and Ellis (1998), and Srour (2001) are other examples of studies focused on the interest rate smoothing evidence.

[5]By contrast, several researchers (e.g. Amato and Laubach, 1999; Levin, Wieland, and Williams, 1999,2003; Woodford, 2003; Giannoni and Woodford, 2002a,b) have already in-

The structure of the paper goes as follows. 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 presents the results of our robustness check. Section 6 concludes. References follow.

2 Modeling the Fed's problem

We assume that the Fed determines the optimal path of its control variable, i.e. the short-term nominal interest rate, in order to minimize a quadratic penalty function.[6] The period loss function reads as follows:

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

where $\bar{\pi}_t = \frac{1}{4}{}_{j=1}^{4}\pi_{t+1-j}$ represents a measure of core-inflation, y_t is the output gap, and i_t is the short-term nominal interest rate (e.g. the federal funds rate).[7] The target level for inflation is normalized to zero, while that for the GDP is the potential output level (the choice plausibly implemented by the Fed as commented by Blinder, 1997). The weight λ represents the preference of the Fed over the output gap *relative to inflation* (whose weight is normalized to one), while the weight μ captures the importance attributed to the interest rate smoothing argument (relative to inflation). Given that we

vestigated this issue from a *normative* standpoint, i.e. they asked themselves a question like 'Can a credible, inertial policy be beneficial when the private sector is forward looking?'. Their answer has unanimously been positive, the intuition being that agents expecting future gradual moves by a central bank will adjust their inflation and output gap expectations towards the policy targets, so helping policy-makers to stabilize the economy.

[6]This assumption, quite common in the literature, allows us to solve the policy-maker's problem by employing known techniques (given the linearity of the model of the economy at hand). In doing so, the underlying assumption is that there is a single agent setting the monetary policy. In fact, the Fed's decision on how to move the policy rate over time is a function of the set of opinions and votes expressed by the members of the Federal Open Market Committee. With our 'mathematical approach' we are just approximating the complexity of the decisions taken by the FOMC: The reader should bear this in mind when analyzing our results.

[7]The variables used in our study were 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 $q_t \equiv 100 ln Q_t$, while $q_t^* \equiv 100 ln Q_t^*$. Q_t is the real GDP level, while Q_t^* is the potential output as computed by the Congressional Budget Office. Finally, the upper-barred variable $\bar{\pi}$ indicates a MA(4) process computed by taking simple averages over the contemporaneous observation and the previous three lags of inflation. The data used in our analysis were downloaded on January 2006 from the Federal Reserve Bank of St. Louis' web-site, i.e. http://research.stlouisfed.org/fred2/.

think of the arguments of the function (1) as being 'bads', we will consider just positive values for the weights λ and μ throughout the paper.

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

$$(1-\delta)E_t\sum_{j=0}^{\infty}\delta^j L_{t+j} \tag{2}$$

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

$$E(L_t) = \sigma^2_{\bar{\pi}} + \lambda\sigma^2_y + \mu\sigma^2_{(i_t - i_{t-1})} \tag{3}$$

with the conditional mean (2) collapsing to its unconditional counterpart, i.e. the loss function is specified in terms of unconditional variances.

To describe the economic environment, we adopt a model *a la* Rudebusch (2002), which reads as follows:

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

$$y_{t+1} = \gamma_y E_t y_{t+2} + (1-\gamma_y)\sum_{j=1}^{2}\beta_{yj}y_{t-j+1} - \beta_r(i_t - E_t\bar{\pi}_{t+4}) + \eta_{t+1} \tag{5}$$

where γ_π represents the share of FLA playing a role in the dynamic Phillips curve (4), while γ_y and β_r are the weights on the FLA elements of the expected demand and the expected real interest rate in the IS equation (5). A few comments are due here. The Phillips curve is featured both by forward looking elements (typical feature of a model coming from micro-foundations) and intrinsic persistence (finding its rationale in e.g. price indexation, as in Christiano *et al*, 2005, and Smets and Wouters, 2003), and a cost-push shock is appended. Also the stochastic IS curve allows both for forward looking agents and for lags, the latter being justified by e.g. habit formation (as in Fuhrer, 2000, and Fuhrer and Rudebusch, 2004). Finally, when $\gamma_\pi = \gamma_y = 1$ this model collapses to the well-known 'New Neoclassical Synthesis' framework by Goodfriend and King (1997), while when $\gamma_\pi = \gamma_y = 0$ we are left with a model a la Rudebusch and Svensson (1999).[8]

[8]Notice that even if the restriction $\gamma_\pi = \gamma_y = 0$ is imposed, the model (4)-(5) is still featured by the presence of the *ex-ante* real interest rate. In this sense, this empirical formalization of the aggregate demand curve lines up with others in the literature, e.g.

The CB optimally sets the interest rate i_t in order to minimize the expected loss (3) subject to the constraints (4)-(5). The timing of the game played by the central bank and the private sector is the following: In each period i) the private sector forms its expectations, ii) the interest rate is set by the Central Bank, finally iii) demand and supply shocks strike the economy. In our positive exercises we compute optimal monetary policy under *discretion*. Our choice is supported both by several researchers (Söderlind, Söderström, and Vredin, 2005; Dennis, 2004a,b; Ozlale, 2003, among the others) and by some Governors' official declarations (e.g. Bernanke, 2003).[9]

With this tool at hand we can calibrate the value of the weight μ in order to find the optimal simulated interest rate that most closely track the Fed's policy rate. The next section describes our econometric strategy.

3 Econometric strategy

We aim at replicating the federal funds rate in the sample 1987Q3-2005Q4.[10] In doing so, we consider two different versions of the model (4)-(5). The first one - our benchmark model, i.e. a fully backward looking specification - is identified by $\gamma_\pi = \gamma_y = 0$.[11] This benchmark model will deliver the value that we have to assign to the parameter μ to track the historical path of the federal funds rate *while neglecting the FLA component*. The second set of restrictions identifies our hybrid version of the model, featured by the presence of an explicit formalization of the FLA component. Referring once more to equations (4)-(5), we are in this case allowing for strictly positive values for

Rudebusch (2002).

[9]Söderlind (1999) proves the optimality of the linear feedback rule $i_t = -Fx_{1t}$, where F is a $(1 \times n1)$ row vector whose elements are convolutions of the structural parameters in (4)-(5) and the CB's preferences over the arguments in the objective function (3), and x_{1t} is the (7×1) column vector of state variables, i.e. $x_{1t} = [\pi_t, \pi_{t-1}, \pi_{t-2}, \pi_{t-3}, y_t, y_{t-1}, i_{t-1}]'$. Notice that we compute the *unique* and *stable* solution of the optimal control problem under rational expectations. Therefore, we get rid of any (possible) indeterminacy issue whose relevance in the post-Volcker sub-sample seems to be unlikely (Lubik and Schorfheide, 2004). A technical appendix explaining how to conveniently set up and solve the optimal control problem is available upon request.

[10]The choice of Alan Greenspan (or, more appropriately, the FOMC chaired by Greenspan)'s monetary regime is suggested both by sample-length considerations (Greenspan 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.

[11]A fully backward looking framework like this has been employed for monetary policy analyses by e.g. Ball (1999), Rudebusch and Svensson (1999), Peersman and Smets (1999), Favero and Milani (2005), Milani (2003), Aksoy *et al* (2002), Ozlale (2003), Favero and Rovelli (2003), and Castelnuovo and Surico (2004), among others.

the parameters γ_π and γ_y, that are calibrated jointly with μ. Notice that we *allow* for the formalization of FLA, but we do *not impose* it.

To assign values to the parameters of the model (3) and (4)-(5), i.e. λ, μ, γ_π, and γ_y, α_s, and β_s, we do the following. *First*, we estimate the parameters α_s and β_s of our backward looking specification, i.e. we estimate equations (4)-(5) subject to the constraint $\gamma_\pi = \gamma_y = 0$. Our estimates are reported in Table 1.[12] *Second*, we exogenously fix a value for the output gap (relative to inflation) preference parameter 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. The choice of a sensible value for this parameter is essential in our analysis. Indeed, it is possible to find many different estimates for λ in the literature. Focusing on backward representations of the economy *a la* Rudebusch and Svensson (1999), Favero and Rovelli (2003) estimate with GMM the Euler conditions of the CB's problem, finding a (statistically insignificant) value of 0.00125. Ozlale (2003) employs a Maximum-Likelihood approach and estimates a value of 0.525, Dennis (2006) gets 4.517 with QMLE, while Castelnuovo and Surico (2004) calibrate a value equal to 1. With a slightly different underlying representation of the economy, Cecchetti, Flores-Lagunes, and Krause (2004) find negligible values for subsamples regarding the '80s and '90s, while Cecchetti and Ehrmann (2002)'s results support a value of about 0.25. For the same period, but with a VAR representation of the economy, Salemi (1995) finds very low relative weights. Finally, Dennis (2004a,b) employs a hybrid representation of the economy and estimates a value equal to zero, quite in line with that obtained by Söderlind, Söderström, and Vredin (2005), while Mayer (2003) calibrates a value equal to 0.15.[13] We fix a benchmark value of $\lambda = 0.5$.[14] As a *third* and final step, we perform the calibration of the parameters μ, γ_π, and γ_y.[15] We do so by implementing a grid-search based on a minimum-distance criterium. In particular, we compute, *per each battery* $j : [\mu^j, \gamma_\pi^j, \gamma_y^j]$, the model-consistent behavior of inflation, the output gap, and the nominal interest rate, and compare it to the

[12] The Phillips curve was estimated by OLS, while the IS schedule was estimated with 2SLS. The list of instruments is reported at the bottom of Table 1. The analog-F statistic is well over the critical values tabulated by Stock and Yogo (2004) for the goodness of a set of instruments at a 99% statistical confidence. The standard errors were computed by employing the Newey-West HAC variance-covariance matrix.

[13] 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.

[14] A check for the robustness of our results to the variation of this choice is provided in the next Section.

[15] To have a more easily manageable problem, we demean all the variables involved in our study. Our choice does not affect the derivation of the CB's weights in the loss function (Dennis, 2000).

actual one.[16]

Phillips curve	$\widehat{\alpha_{\pi 1}}$	$\widehat{\alpha_{\pi 2}}$	$\widehat{\alpha_{\pi 3}}$	$\widehat{\alpha_{\pi 4}}$	$\widehat{\alpha_{y}}$
Point Estim. (Standard dev.)	0.485^{***} (0.120)	0.119 (0.101)	0.119 (0.088)	0.252^{***} (0.089)	0.185^{***} (0.047)
$\pi_{t+1} =_{j=1}^{4} \widehat{\alpha_{\pi j}} \pi_{t+1-j} + \widehat{\alpha_y} y_t + \widehat{\varepsilon_{t+1}}. \bar{R}^2 = 0.81, \widehat{\sigma_\varepsilon} = 1.11$					
IS curve	$\widehat{\beta_{y1}}$	$\widehat{\beta_{y2}}$	$\widehat{\beta_r}$		
Point Estimate (Standard deviation)	1.186^{***} (0.103)	-0.281^{**} (0.105)	-0.056^{*} (0.030)		
$y_{t+1} = \widehat{\beta_{y1}} y_t + \widehat{\beta_{y2}} y_{t-1} + \widehat{\beta_r}(i_t - E_t \overline{\pi}_{t+4}) + \widehat{\eta_{t+1}}.\ \bar{R}^2 = 0.88, \widehat{\sigma_\eta} = 0.78$					

Variables demeaned before estimation, so no constants appear.
Sample: 1987Q3-2005Q3. $^{***}/^{**}/^{*}$: 99/95/90% level of significance.
Newey-West HAC Standard Errors & Covariance (lag truncation = 4).
Phillips curve estimated with OLS, IS curve with 2SLS. Instruments employed:
$Z = [c, \overline{\pi}_t, .., \overline{\pi}_{t-4}, y_t, .., y_{t-4}, i_t, .., i_{t-4}]'$. First-stage regression,
$F - stat = 57.96$,much larger than the critical values computed by
Stock and Yogo (2004) for the power of the instruments in a 2SLS regression
at a 99% confidence level.

Table 1: Estimates of the AS-AD model, sample: 1970Q1-2005Q4.

For our calibration we employ the following measure of distance:

$$D^j(\xi^{sim,j}, \xi^{act}, V) =_{t=1}^{T} \left[\left(\xi_t^{sim,j} - \xi_t^{act} \right)' V^{-1} \left(\xi_t^{sim,j} - \xi_t^{act} \right) \right] \qquad (6)$$

where $\xi_t^{sim,j} = \left[\begin{array}{ccc} i_t^{sim,j} & y_t^{sim,j} & \pi_t^{sim,j} \end{array} \right]'$ and $\xi_t^{act} = \left[\begin{array}{ccc} i_t^{act} & y_t^{act} & \pi_t^{act} \end{array} \right]'$ are $(3x1)$ vectors containing realizations of the time-series of interest, 'sim' and 'act' stand respectively for 'simulated' and 'actual', and V is a $(3x3)$ diagonal matrix whose non-zero elements are represented by the standard deviations of the actual time-series in the sample under analysis.

We then select the battery $j^* : [\mu^{j^*}, \gamma_\pi^{j^*}, \gamma_y^{j^*}]$ that minimizes our measure of distance (6). Notice that, when the backward looking model is employed, the calibration exercise just regards the weight μ, given the identifying restriction $\gamma_\pi = \gamma_y = 0$.

Our choice of performing a *calibration* exercise deserves an explanation. In fact, the model at hand could be estimated via Maximum Likelihood or with Bayesian techniques. Our goal is that of understanding the impact of FLA

[16]We perform our grid search by considering values belonging to the interval $[0, 1]$ for the 'forwardness' coefficients γ_π and γ_y. To avoid singularity problems, we replace $\gamma_\pi = 0$ or/and $\gamma_y = 0$ with $\gamma_\pi = 0.0001$ or/and $\gamma_y = 0.0001$. Finally, for the weight μ we take into account values belonging to the interval $[0, 3]$. The step-lenght of our grid search is 0.05.

on the interest rate smoothing parameter μ in the loss function. Hence, to perform a *ceteris paribus* exercise we need to keep all the other parameters of the model *fixed* when moving from the fully backward looking representation of the economy to the hybrid one. Clearly, this would heavily harm the potential benefits stemming from the use of likelihood-based techniques, and motivates our choice of performing a calibration exercise.

Notice that our econometric 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 the Fed operated along the efficiency-frontier that defines the trade-off between inflation and output gap. 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, i.e. that the model (4)-(5) is structural. More importantly, this exercise neglects the impact of other possible sources of misspecification, e.g. those listed in Footnote 4. With these *caveats* in mind, we now turn to the analysis of our results.

4 Findings

In this section we present our findings. Table 2 collects the results of our calibration exercise. It is immediate to notice that, when the fully backward looking model is taken into account, the calibrated value of the parameter μ is quite large - i.e. 1.6 - and frankly implausible from an economic standpoint. About this issue, Rudebusch (2005, p.13) states that "In the academic literature, μ is often set equal to 0.5 or 0.1." Since we think of the smoothing argument as being a sort of catch all capturing the impact of omitted (potentially important) components, then such a large value might signal a misspecification problem. In fact, when adding FLA to the model, the picture changes quite remarkably. The weight attached to the smoothing argument collapses to 0.55, so indicating that FLA is a key-element for correctly representing the historical economic dynamics. Notice that, according to our econometric exercise, the key-element for this result is the share of forward looking consumers $\gamma_y = 0.2$. In fact, the IS curve in the best fitting calibration turns out to be hybrid. This value is slighly lower than the median maximum-likelihood estimate (0.36) proposed by Fuhrer and Rudebusch (2004), and lower than the point estimate by Söderlind Söderström, and Vredin (2005), who obtain 0.556.[17] The difference

[17]Fuhrer and Rudebusch (2004) propose a comparison between the point estimates of a hybrid IS curve for the U.S. obtained with maximum-likelihood vs. GMM. With a Montecarlo exercise they show that the former provides consistent estimates, while the latter tends to provide biased point-estimates. Their median maximum-likelihood point estimate of the forward looking component in the IS curve is 0.36, but the distribution of the estimates is

with respect to the point estimate proposed by Fuhrer and Rudebusch (2004) and Söderlind et al (2005) might be due to the different sample-selection (ours: 1987Q3-2005Q4; Fuhrer and Rudebusch's: 1966Q1-2000Q4; Söderlind et al's: 1987Q4-1999Q4), the different econometric techniques (Fuhrer and Rudebusch employ maximum-likelihood), and to the difference in the construction of the objective function employed in the GMM-type estimation (Söderlind et al concentrate on some *moments* of the U.S. time-series, while we concentrate on the *time-series per se*). By contrast, the Phillips curve is predominantly backward looking, i.e. $\gamma_\pi = 0.0$. Interestingly, this result lines up with Fuhrer (1997)'s and Söderlind et al (2005)'s finding on the empirical unimportance of the forward looking component in the U.S. Phillips curve. By contrast, this value is lower than the one in Rudebusch (2002), who obtains a point estimate of 0.3. The difference might be due to the different sample adopted (Rudebusch's: 1968Q3-1996Q4), to the different econometric technique employed (OLS single equation estimation for Rudebusch, GMM-type full model approach in our study), and to the different series at hand (Rudebusch approximates the private sector's expectations with survey data taken from the Michigan survey of inflation expectations). Overall, our model calibration seems to support some recent findings by Estrella and Fuhrer (2002) that attribute quite a lot of importance to intrinsic inertia for describing the U.S. macroeconomic time-series with new-Keynesian models.

Table 2 presents the statistics regarding the volatilities (standard deviations) of the actual and simulated time-series of interest, together with the volatility of their first-differences, and a measure of persistence of the time-series under investigation.[18] Interestingly, when concentrating on the interest rate statistics, it is possible to see that the benchmark fully backward looking model displays a larger volatility (both in levels and in first-differences) of the implied interest rate with respect to the moments of the actual rate. Moreover, the backward looking formulation needs an incredible value of 1.6 to replicate the historical data vs. the more reasonable 0.55 of the hybrid formulation. Regarding the other time-series at hand, it must be noticed that the hybrid model underestimates the volatility of the output gap (both in levels and in first differences). By contrast, the benchmark model overestimates the standard deviation of the output gap in levels, as well as the persistence of the inflation process.[19]

bimodal, with one cluster of estimates at 0.0 and a second around 0.40.

[18]We measure the persistence of a generic time-series z_t by OLS estimating the autoregressive process $z_t = \phi_1 z_{t-1} + \phi_2 z_{t-2} + ... + \phi_n z_{t-n} + \xi_t^z$ and computing the statistic $z_\phi \equiv \sum_{j=0}^{n} \phi_j$. We admit up to four lags for the AR(n) process at hand. The number of lags is selected according to the Schwarz's Bayesian Criterion.

[19]These statistics seem to underline some deficiencies of the IS/Phillips/Monetary policy

Calibration Results			
Benchmark: $\mu^* = 1.6, \gamma_\pi = \gamma_y = 0$			
Hybrid: $\mu^* = 0.55, \gamma_\pi^* = 0, \gamma_y^* = 0.2$			
Descriptive Statistics			
Variable	$\sigma(x)$	$\sigma(\Delta x)$	$pers(x)$
i_actual	2.28	0.48	0.94
i_bench	3.74	0.73	0.96
i_hybrid	2.22	0.54	0.94
y_actual	1.74	0.56	0.91
y_bench	1.92	0.56	0.92
y_hybrid	0.98	0.40	0.89
π*_actual*	1.01	0.97	0.72
π*_bench*	0.94	0.91	0.82
π*_hybrid*	0.84	0.90	0.72

Table 2: Calibration outcomes and descriptive statistics with $\lambda = 0.5$. Starred parameter were calibrated as described in the text.

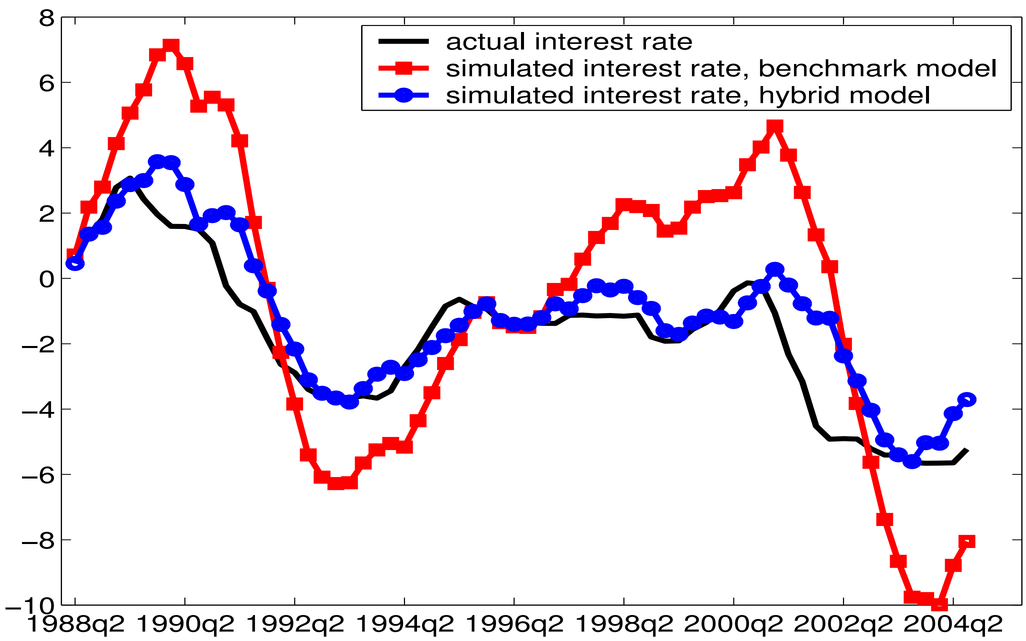

Figure 1: Policy Rates Behavior: Benchmark vs. Hybrid model, conditional comparison. The key parameters featuring the Benchmark model are $\lambda = 0.5$, $\mu = 0.55$, $\gamma_\pi = \gamma_y = 0$, while those identifying the Hybrid model are $\lambda = 0.5$, $\mu = 0.55$, $\gamma_\pi = 0$, $\gamma_y = 0.2$. Calibration strategy: See the main text.

What if we control for the weight μ? Table 3 (bottom panel) collects the results coming from simulations in which the value $\mu = 0.55$ is imposed to the backward looking framework as well. This is done in order to *quantitatively* gauge the role of FLA. With such a low μ, the backward looking model's simulated policy exhibits an excessive policy rate volatility both in levels and in first differences, roughly twice the actual figures. Figure 1 depicts the remarkable difference between the Benchmark (fully backward looking) model ad the Hybrid (FLA-augmented) one.[20]

To show that the hybrid model offers an overall better fit to the data than the backward-looking model, we compute three information criteria, i.e. AIC (Akaike), BIC (Bayesian Information Criterion), and HQ (Hannan-Quinn).[21] Table 4 displays the ratios between information criteria of the hybrid model and those of the benchmark models. The statistical criteria are all in favor of the hybrid model.

The importance of FLA: Discussion

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?

According to our calibration, *current* output gaps are influenced both by current/past policy rates (given the intrinsic persistence of the business cycle) and by *future expected realizations* of the federal funds rate. Once the FLA ingredient is explicitly admitted to play a role in the framework, the private sector will expect a future *inertial* policy rate both because of the endogenous persistence associated to inflation and the output gap and because of the interest rate smoothing penalty in the policy-makers' loss function. About this point, Woodford (2003) - among the others - underlines the link existing between the *expected future monetary policy conduct* and the *adjustment of the private sector's expectations* towards the CB's target values also under

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3 equation models. Dennis (2004b) performs a careful analysis of a microfounded version of 3-equation hybrid monetary framework, and finds that it is on average inferior in terms of data-fitting with respect to a benchmark, vector autoregressive framework. His suggestion is to include capital as a productive input in the model. We plan of re-doing the exercise proposed in this study with a more sophisticated monetary policy model a la Christiano et al (2005) in the near future.

[20] 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 time-series were demeaned.

[21] Under the assumption of a multivariate normal distribution of the errors, the log-likelihood value is defined as $l = -\frac{TM}{2}(1+\log 2\pi) - \frac{TM}{2}\det(\widehat{\Omega})$, where T is the sample-size, M is the number of equations of the system, $\widehat{\Omega} = \frac{1}{T}{}_{t=1}^{T}\widehat{\varepsilon}_t\widehat{\varepsilon}'_t$, and $\det(\widehat{\Omega})$ is its determinant. The three information criteria were computed as follows: $AIC = -2(\frac{l}{T})+2(\frac{q}{T})$, $BIC = -2(\frac{l}{T}) + q(\frac{\log T}{T})$, $HQ = -2(\frac{l}{T}) + 2q(\frac{\log(\log T)}{T})$, with q being the number of free parameters of the model.

Conditional Analysis			
Benchmark: $\mu = 0.55, \gamma_\pi = \gamma_y = 0$			
Hybrid: $\mu^* = 0.55, \gamma_\pi^* = 0, \gamma_y^* = 0.2$			
Descriptive Statistics			
Variable	$\sigma(x)$	$\sigma(\Delta x)$	$pers(x)$
i_actual	2.28	0.48	0.94
i_bench	4.60	0.99	0.95
i_hybrid	2.22	0.54	0.94
y_actual	1.74	0.56	0.91
y_bench	1.66	0.55	0.90
y_hybrid	0.98	0.40	0.89
π_actual	1.01	0.97	0.72
π_bench	0.90	0.90	0.78
π_hybrid	0.84	0.90	0.72

Table 3: Calibration outcomes and descriptive statistics with $\lambda = 0.5$. Starred parameters were calibrated as described in the text.

Type of analysis	**AIC**	**BIC**	**HQ**
Unconditional	0.8626	0.8721	0.8664
Conditional	0.8487	0.8584	0.8526

Table 4: Information criteria with $\lambda = 0.5$: Ratios. The ratios are computed as 'information criterion of the hybrid model' over 'information criterion of the benchmark model'. Unconditional analysis: Parameters as in Table 2. Conditional analysis: Parameters as in Table 3.

discretion if the central bank seeks to minimize a loss function that includes a smoothing objective. In this sense, a federal funds rate shock exerts a huge impact on expectations if the monetary policy is *history-dependent*. Then, a small policy move oriented towards the stabilization of inflation and the output gap generates expectations of subsequent gradual moves in the same direction. As a consequence, agents set their expectations on *future* inflation and the output gap towards the CB's targets, so helping the policy-maker to keep the *current* realizations of inflation and the output gap close to the target (as suggested by equations [4] and [5]). Overall, this implies that the optimal policy rate set by the CB will be featured by *small adjustments* and *infrequent reversals*. As far as our calibration exercise is concerned, this policy gradualism translates in the requirement of a lower weight μ to be attributed to interest rate smoothing argument $\sigma^2_{(i_t - i_{t-1})}$ to replicate the smooth actual federal funds rate behavior (vs. the benchmark scenario in which expectations are not an 'ingredient' of the framework).

5 Robustness check

Given the key-role played by the relative preference parameter λ in our analysis, we perform a robustness check of our results by perturbing it. Figure 2 diplays our findings. The top panel clearly shows that, as far as the shares of forward looking agents are concerned, the findings presented in the previous Section are quite robust, i.e. the IS curve is mildly hybrid, while the Phillips curve is purely backward looking. The bottom panel shows the interest rate smoothing weights computed either under the benchmark scenario or when allowing for the FLA component. Once more, the main finding of this paper is clearly confirmed, i.e. a share of forward looking agents playing a role just in the IS curve implies a quite remarkable reduction of the interest rate smoothing weight μ. Such a difference turns out to be much larger when the relative weight attached to the output gap stabilization is low. By raising λ, we can observe a gradual reduction of the differential $(\mu^*_{bench} - \mu^*_{hybrid})$, that stabilizes for intermediate values of λ, and just slightly opens up when values closer to $\lambda = 1.0$ are allowed for. Overall, our robustness check confirms the huge gain in terms of model-plausibility one may enjoy when allowing for a mildly hybrid IS curve.

In fact, an arbitrary choice of the output stabilization weight might bias our results both in terms of interest rate smoothing weight and in terms of forward-looking characteristics of the model.[22] To tackle this issue, we re-run our exercise by allowing for the joint calibration of the output stabilization weight and the other parameters of interest, i.e. the minimization of the loss (6) is now obtained by working on the new battery $\widetilde{j}^* : [\lambda^{j^*}, \mu^{j^*}, \gamma_\pi^{j^*}, \gamma_y^{j^*}]$. Our new point estimates read as follows: $\lambda_{hybrid} = 3.6$, $\mu_{hybrid} = 1.25$, $\gamma_\pi = 0, \gamma_y = 0.2$. While both the output gap weight and the interest rate smoothing weight are higher than those presented in the previous Section, the previously commented results regarding the forward-looking degrees of the hybrid model turn out to be robust.[23] Interestingly, the conditional calibration of the benchmark (backward looking) model under the parameterization $\lambda = 3.6, \gamma_y = \gamma_\pi = 0$ reveals that the minimization of the distance (6) requires an interest rate smoothing weight $\mu_{backward} = 3.4$, almost three times as large as the one of the hybrid model. Then, while acknowledging that the interest rate smoothing weight

[22] We thank an anonymous referee for pointing this out to us.

[23] In particular, the point estimate of the parameter on the output gap stabilization seems to be higher than what suggested by the literature (see the literature review in Section 3). The difference between our result and those proposed in previous contributions may be due to sample-selection and to the different econometric techniques employed.

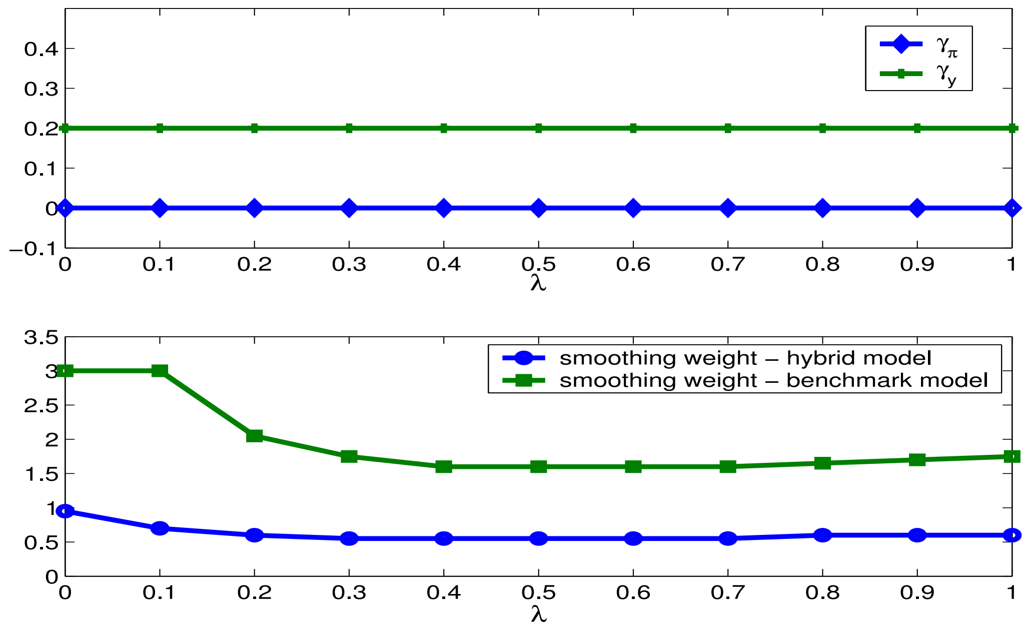

Figure 2: Robustness check as a function of different λ. Calibration strategy: See the main text.

might still be large even when forward looking expectations are introduced in the framework, our claim concerning the impact of the forward looking agents in the IS curve on the interest rate smoothing weight seems warranted.

Another concern one may have regards our assumption on the *optimality* of the U.S. monetary policy conduct. The optimal feedback rule that minimizes the loss function (1) reads as follows:

$$i_t = f_1\pi_t + f_2\pi_{t-1} + f_3\pi_{t-2} + f_4\pi_{t-3} + f_5 y_t + f_6 y_{t-1} + f_7 i_{t-1} \quad (7)$$

We perform an informal check by estimating the policy rule (7) and comparing it to the optimal policy of the backward-looking model as well as that of the hybrid model, the latter two parameterized with the calibrated values of our benchmark analysis. Table 5 shows the results. Some considerations are in order. First, both optimal policies resemble the estimated one, in the sense that i) they all attribute a larger weight to the contemporaneuos inflation rate with respect to the lagged ones, ii) the output gap plays an important role in all of them, and iii) there is a fairly high interest rate smoothing degree. A closer look to the values assumed by the parameters reveals that the optimal rule of the hybrid model is closer than the one of the backward looking model to the estimated one. In fact, the sums of the inflation coefficients ${}_{i=1}^{4} f_i$ in the three rules read as ${}_{i=1}^{4} f_i^{estimated} = 0.7026$, ${}_{i=1}^{4} f_i^{backward} = 1.1589$, ${}_{i=1}^{4} f_i^{hybrid} = 1.0952$, while the sum of the output gap coefficients is ${}_{i=5}^{6} f_i^{estimated} = 0.4222$, ${}_{i=5}^{6} f_i^{backward} = 0.7661$, ${}_{i=5}^{6} f_i^{hybrid} = 0.5961$. With respect to the policy rule of the benchmark model, the rule of the hybrid model suggests a slightly lower reaction to inflation fluctuations and a much lower reaction to output gap fluctuations. This latter feature squares with the presence of output gap expectations in the IS curve of the hybrid model: Given that current monetary policy influences monetary policy in the future, expectations on the output gap adjust towards the CB's target, so implying a milder monetary policy reaction to the fluctuations of the output gap.

Rule	f_1	f_2	f_3	f_4	f_5	f_6	f_7
B	0.541	0.273	0.206	0.139	1.048	−0.281	0.699
H	0.511	0.258	0.195	0.131	0.832	−0.236	0.667
E	0.467* (0.273)	0.150 (0.177)	−0.030 (0.178)	0.115 (0.194)	0.175* (0.093)	0.247** (0.104)	0.543*** (0.130)

Rule: 'B'=Benchmark, 'H'=Hybrid, 'E'=Estimated.

$i_t = \widehat{f}_1\pi_t + \widehat{f}_2\pi_{t-1} + \widehat{f}_3\pi_{t-1} + \widehat{f}_4\pi_{t-4} + \widehat{f}_5 y_t + \widehat{f}_6 y_{t-1} + \widehat{f}_1 i_{t-1} + \widehat{\varsigma_{t+1}}$.

$\bar{R}^2 = 0.98, \widehat{\sigma}_\varsigma = 0.31$

Table 5: Policy rules: Estimated vs. optimal. Estimated policy rule: Sample 1987Q3-2005Q3, TSLS point estimates (Newey-West standard errors in brackets). ***/**/* = 99/95/90 per cent statistical confidence. Instruments employed: 6 lags of inflation, the output gap, and the federal funds rate. The number of lags was chosen by running a VARX (endogenous variables: inflation and the output gap, exogenous variable: the federal funds rate. Endogenous and exogenous variables inserted in the VAR with the same lag-structure) and checking for the indications coming from the standard lag-length criteria (AIC, BIC, HQ). The error term was modeled as an AR(1) process. Benchmark policy rule: Optimal policy rule under the parameterization of the benchmark model as in Table 3. Hybrid policy rule: Optimal policy rule under the parameterization of the hybrid model as in Table 3.

Table 5 also reveals that the optimal policies we computed are not a perfect replica of the one estimated on actual data. This might be due to some difficulties the simple AD-AS new Keynesian model has in replicating some of the characteristics of the data (see Dennis, 2004b), or to the fact that the Fed did not implement an optimal policy in the period under investigation (or both these reasons). Admittedly, this may cast some doubts on our conclusion on the importance of rational expectations for reducing the interest rate smoothing weight in the policy-makers' loss function. Nevertheless, to the extend that the 3-equation new Keynesian model offers a good "first-approximation" of the dynamics of the series of interest, the finding regarding the reduction of the interest rate smoothing weight under the hybrid version of the IS curve still holds. Moreover, as we have emphasized, our finding is robust to several perturbations to our benchmark analysis.

6 Conclusions

The interest rate smoothing argument has been object of intense investigations for some years now. From a positive perspective this argument is needed in order to generate the observed policy rate persistence when small scale macro models are employed. Interestingly, positive exercises conducted with fully backward looking models tend to return a very high value for the weight over the interest rate smoothing argument in the monetary authorities' loss function. This paper shows that the explicit formalization of forward looking agents in the IS curve dramatically reduces the interest rate smoothing puzzle, i.e. it remarkably lowers the weight needed to track the macroeconomic time-series of interest.

Overall, our findings corroborate the conclusions put forward by Fuhrer (1997), Estrella and Fuhrer (2002), Rudebusch (2002), Fuhrer and Rudebusch (2004), Söderlind et al (2005), and Dennis (2004a,b) on the importance of modeling intrinsic inertia for describing highly autocorrelated macroeconomic variables such as the inflation rate or the output gap.

Interestingly, once we attempt to estimate the weight on output as well as inflation stabilization, the interest rate smoothing term appears to become more important once again. Indeed, there still appears to be some interest rate smoothing behavior that remains to be explained. We leave this issue for future research.

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