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The Fed's monetary policy rule and U.S. inflation: The case of asymmetric preferences

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Abstract

This paper investigates the empirical relevance of a new framework for monetary policy analysis in which the decision makers are allowed, but not required, to weight differently positive and negative deviations of inflation and output from the target values. The estimates of the central bank's Euler equation indicate that the preferences of the Fed had been asymmetric only before 1979, with the interest rate response to output contractions being larger than the response to output expansions of the same magnitude. We show that this asymmetry on output implied an *average inflation bias* around 1.5%. While the implicit inflation target also declined, the asymmetric preferences induced inflation bias appears to account for a sizable fraction of the historical decline in the inflation mean.

JEL classification: E52; E58

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1. Introduction

A popular method of monetary model building is to regard policy interventions as the solution of an optimal control problem in which the central bank minimizes

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some quadratic criterion subject to a linear structure of the economy. The quadratic characteristic of the objective and the linear feature of the constraints give rise to a linear first-order condition, usually referred to as a targeting rule (see Svensson, 1999), which describes the optimal response of the central bank to the developments in the economy. While the quadratic specification implies that the monetary authorities weight evenly positive and negative deviations of inflation and output from the target values, such modeling choice had been questioned by several practitioners at the policy committees of various central banks on the ground that it has little justification beyond analytical tractability.[1]

Blinder (1997, p. 6) argues that '*academic macroeconomists tend to use quadratic loss functions for reason of mathematical convenience, without thinking much about their substantive implications. The assumption is not innocuous*, [...] *practical central bankers and academics would benefit from more serious thinking about the functional form of the loss function*'. Describing his experience as Fed Vice-Chairman, Blinder (1998, pp. 19–20) pushes the argument even further and claims '*in most situations the central bank will take far more political heat when it tightens pre-emptively to avoid higher inflation than when it eases pre-emptively to avoid higher unemployment*', suggesting that political pressures can induce asymmetric central bank interventions. Similar concerns emerge also at other central banks like the ECB and on the occasion of an interest rate cut of 50 basis point Duisenberg (2001) states '*the maintenance of price stability remains our first priority*. [...] *today's action could be taken* "*without prejudice to price stability*", *and it thereby supported the other goals of EMU, such as economic growth*'.

On the theoretical side, a number of recent studies explore some novel mechanisms through which the costs of the business cycle can be asymmetric. Persson and Tabellini (1999) combine retrospective voting with imperfect information about the incumbent's talent to show that career concerned politicians can make reappointment more likely by endowing the central bank with an asymmetric objective that requires a larger monetary policy response in periods of poor economic performance. Galí et al. (2003a) construct a theoretical measure of welfare gap based on price and wage markups, and find that the costs of output fluctuations for the U.S. had historically been large and asymmetric. Erosa and Ventura (2002) introduce transaction costs and heterogeneity in portfolio holdings in an otherwise neoclassical model and show that these frictions can make the costs of inflation variation asymmetric. Lastly, the psychology of choice reveals that people tend to place a greater weight on the prospect of losses than on the prospect of gains in decision making under uncertainty (see Kahneman and Tversky, 1979), also suggesting that policy makers, who aggregate over individual welfare, may be loss-averse.

On the empirical side, only a few studies, developed independently, estimate asymmetric reaction functions. Cukierman and Muscatelli (2003) and Martin and Milas (2004) show some international evidence supporting the notion of nonlinear

[1] Notable exceptions include Rotemberg and Woodford (1999) and Woodford (2003, Chapter 6), who show that the quadratic form can be obtained as a second-order approximation of the representative agent's utility.

interest rate rules. Ruge-Murcia (2003) and Cukierman and Gerlach (2003) adopt an inflation rate reaction function that is nonlinear in either inflation or the output gap, and they favor the hypothesis of an asymmetric objective for some OECD economies. Dolado et al. (2004) estimate an interest rate rule that is asymmetric in inflation only, and find evidence of nonlinearity after 1983 for the U.S.

Despite the increasing number of empirical works, the inflation bias associated with asymmetric preferences had not been quantified yet. In particular, no study had assessed, to our knowledge, the *average* contribution of asymmetric preferences to inflation during the 1960s and 1970s. This paper attempts to fill the gap. The specification of a potentially asymmetric loss function generates the testable prediction that the monetary authorities respond nonlinearly to the inflation and the output gaps. This prediction is used to identify the degree of asymmetry with respect to both objectives.

A main result of the paper is that the Fed's monetary policy can be characterized by a nonlinear interest rate rule only before 1979 and with respect to the output gap. According to the model, these estimates imply an average inflation bias around 1.5% before 1979 but a value not statistically different from zero over the last two decades. The fall in the bias is found to account for a larger fraction of the historical decline in average inflation relative to a reduction in the Fed's implicit inflation target. Asymmetric preferences seem thus to provide a new, additional explanation for the great inflation of the 1960s and 1970s, which may also be relevant for other countries.

The paper proceeds as follows. Section 2 presents the model and derives the interest rate rule as the first-order condition of the central bank optimization problem. Section 3 reports the results of the hypothesis testing for symmetric preferences and the estimates of the asymmetric preference parameters. The following part maps the estimates of the nonlinear Euler equation into a measure of inflation bias. Section 5 concludes.

2. Theoretical model

The monetary policy rule is modeled as the discretionary outcome of an intertemporal optimization problem in which the decision makers minimize a given criterion subject to the constraints provided by the structure of the economy. The optimizing device allows us to back out the objectives of the monetary authorities, which are unobserved, from the observed path of policy rates implying that evidence on the latter can be interpreted as informative about the former. Since our identification strategy relies on the estimation of a model-based specification of the reaction function, we challenge the assumption of symmetric policy preferences in the context of a popular framework for monetary policy analysis. This is a version of the New-Keynesian model of the business cycle derived in Yun (1996) and Woodford (2003, Chapters 3 and 4), among many others.[2]

[2] Surico (2003) shows that both the theoretical and the empirical results obtained here using a New-Keynesian model are robust to the specification of a Lucas aggregate supply curve as structure of the economy.

2.1. The structure of the economy

This subsection describes an aggregate, log-linearized version of the New-Keynesian forward-looking model with sticky prices surveyed by Clarida et al. (1999). The evolution of the economy is compactly represented by the following two-equation system:

$$\pi_t = \theta E_t \pi_{t+1} + k y_t + \varepsilon_t^s, \tag{1}$$

$$y_t = E_t y_{t+1} - \varphi(i_t - E_t \pi_{t+1}) + \varepsilon_t^d. \tag{2}$$

Eq. (1) captures the staggered feature of a Calvo-type world in which each firm adjusts its price with a constant probability in any given period, and independently from the time elapsed from the last adjustment. The discrete nature of price setting creates an incentive to adjust prices more the higher is the future inflation expected at time t. The inflation level is π_t whereas the output gap is denoted by y_t and captures the movements in marginal costs associated with variations in excess demand. For analytical convenience, the aggregate supply curve is assumed purely forward-looking. Galí and Gertler (1999), Ireland (2001, 2005), Galí et al. (2003b), and Smets and Wouters (2003a) provide empirical support for this choice as a good first approximation to the dynamics of U.S. inflation.

Eq. (2) is a standard Euler equation for consumption combined with the relevant market clearing condition. It basically brings the notion of consumption smoothing into an aggregate demand formulation by making the output gap a positive function of its future value and a negative function of the real interest rate, $i_t - E_t\pi_{t+1}$. Lastly, ε_t^s and ε_t^d are cost and demand disturbances that obey an autoregressive, mean reverting process.

2.2. An asymmetric specification of the loss function

An important aspect of monetary policy making is that the policy actions are taken before the realization of the economic shocks and therefore before the variables in the system are determined. Accordingly, the problem of the central bank is to choose the interest rate at the beginning of period t conditional upon the information available at the end of the previous period. This timing is captured by the following intertemporal criterion:

$$\underset{\{i_t\}}{\text{Min}}\ E_{t-1} \sum_{\tau=0}^{\infty} \delta^{\tau} L_{t+\tau}, \tag{3}$$

where δ is the discount factor and L stands for the period loss function.

Our framework differs from the conventional quadratic set-up in that we employ a more general specification of the monetary authorities' objectives. Indeed, the quadratic form may approximate reasonably well a number of different functions and in the absence of a rigorous theoretical foundation any specific non-quadratic proposal is destined to be unsatisfactory against the wide range of plausible alternatives. Hence, rather than attempting to uncover the correct functional form of policy makers' preferences, we evaluate the symmetric quadratic set-up upon the empirical merits of the monetary policy rule that this specification implies. With this descriptive scope in mind, we write L_t as follows:

$$L_t = \frac{e^{[\alpha(\pi_t - \pi^*)]} - \alpha(\pi_t - \pi^*) - 1}{\alpha^2} + \lambda\left[\frac{e^{(\gamma y_t)} - \gamma y_t - 1}{\gamma^2}\right] + \frac{\mu}{2}(i_t - i^*)^2. \tag{4}$$

The coefficients λ and μ represent the central bank's aversion towards output fluctuations around potential and towards interest rate *level* fluctuations around the target i^*. The policy preference towards inflation stabilization is normalized to one and therefore λ and μ are expressed in relative terms. The inflation target is π^*, whereas the parameters α and γ capture any asymmetry in the objective function of the monetary authorities.

The linex specification (4) departures from the quadratic objective in that policy makers are allowed, but not required, to treat differently positive and negative deviations of inflation and output from the target. Varian (1974) and Zellner (1986) proposed this functional form in the context of Bayesian econometric analysis while Nobay and Peel (2003) introduced it in the optimal monetary policy literature.[3]

A negative value of γ implies that, everything equals, an output contraction relative to the potential level is weighted more severely than an output expansion of the same magnitude. To see this, note that whenever $y_t < 0$ the exponential component of the loss function dominates the linear component while the converse is true for $y_t > 0$. A similar reasoning holds for the coefficient α. However, if the monetary authorities are more concerned about overshooting π^* rather than undershooting it, the value of α would be positive meaning that high inflation relative to the target is more costly than low inflation. It should be noted that while these sign predictions seem plausible for the sample at hand, the linex specification does not prevent α to be negative corresponding to a case in which the risk of deflation outweighs the risk of inflation. Fig. 1 compares the standard quadratic with the linex function for both the inflation (panel a) and the output (panel b) objective.

The linex function nests the quadratic form as a special case such that when both α and γ tend to zero L_t reduces to the symmetric parametrization $\frac{1}{2}[(\pi_t - \pi^*)^2 + \lambda y_t^2 + \mu(i_t - i^*)^2]$. The latter can be obtained as a second-order approximation of the utility-based welfare function in a New-Keynesian model of the business cycle that involves a zero lower bound for nominal interest rate (see Woodford, 2003, Chapter 6). It follows that under the null of a quadratic loss, the policy preferences are functions of some primitive parameters of the model and therefore potential evidence of asymmetries in the central bank objective may be interpreted as evidence of asymmetries in the representative agent's utility. The implication is that business cycle fluctuations may have important welfare effects beyond the second order.

[3]Additional references include Chadha and Schellekens (1999), Ruge-Murcia (2003) and Surico (2003).

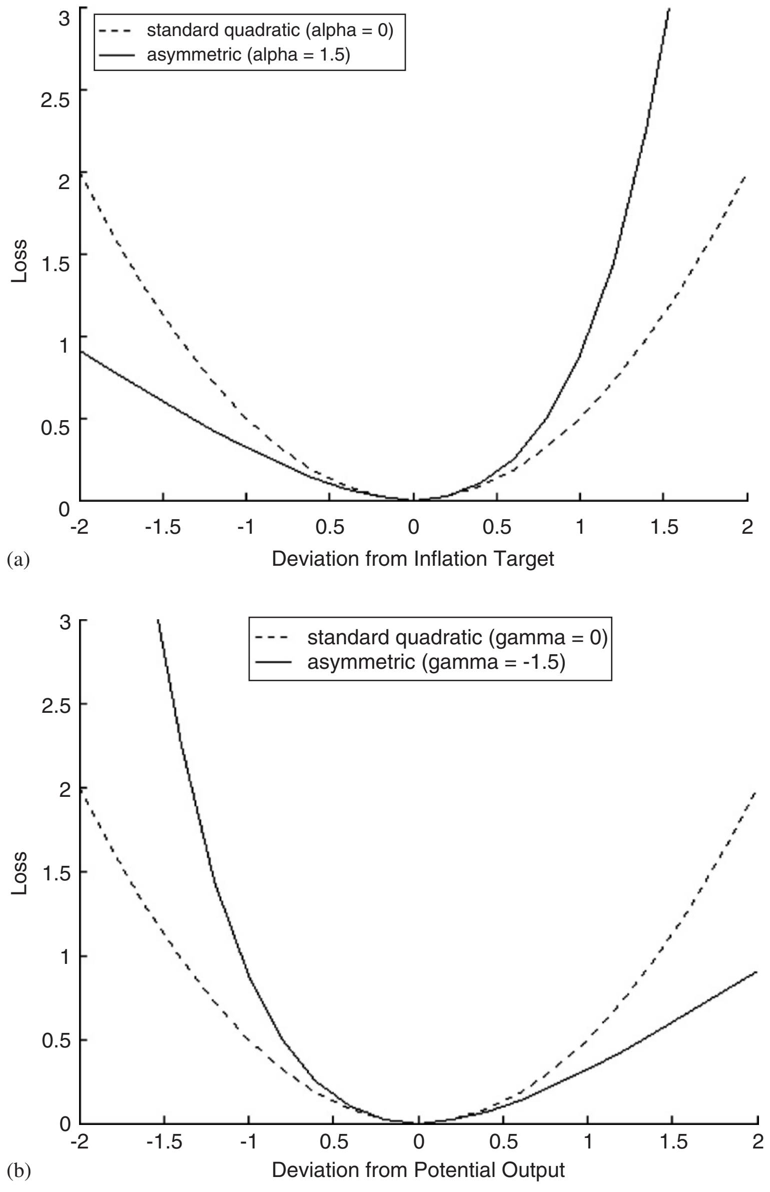

Fig. 1. (a) Preference over inflation stabilization and (b) preference over output stabilization.

2.3. A nonlinear policy rule

We solve for the optimal monetary policy under discretion. Because no endogenous state variable enters the model, the intertemporal problem reduces to a sequence of static optimization problems. This amounts to choosing in each period the instrument i_t such as to minimize

$$E_{t-1}\left(\frac{e^{[\alpha(\pi_t-\pi^*)]}-\alpha(\pi_t-\pi^*)-1}{\alpha^2}\right)+\lambda E_{t-1}\left[\frac{e^{(\gamma y_t)}-\gamma y_t-1}{\gamma^2}\right]+\frac{\mu}{2}(i_t-i^*)^2+F_t$$

subject to $\pi_t = ky_t + f_t$ and $y_t = -\varphi i_t + g_t$, where $F_t \equiv E_{t-1}\sum_{\tau=1}^{\infty}\delta^{\tau}L_{t+\tau}$, $f_t \equiv \theta E_t\pi_{t+1} + \varepsilon_t^s$ and $g_t \equiv E_t y_{t+1} + \varphi E_t\pi_{t+1} + \varepsilon_t^d$ are taken as given reflecting the fact that the monetary authorities cannot directly manipulate expectations. The first-order condition reads

$$-E_{t-1}\left(\frac{e^{[\alpha(\pi_t-\pi^*)]}-1}{\alpha}\right)k\varphi - E_{t-1}\left(\frac{e^{(\gamma y_t)}-1}{\gamma}\right)\lambda\varphi+\mu(i_t-i^*)=0 \tag{5}$$

and it describes implicitly the optimal, potentially nonlinear response of the central bank to the developments in the economy. Eq. (5) nests the linear form as a special case and when both α and γ tend to zero the reaction function collapses to an implicit interest rate rule of the type analyzed by Taylor (1993), Rudebusch (2002) and Clarida et al. (2000)

$$-k\varphi E_{t-1}(\pi_t-\pi^*)-\lambda\varphi E_{t-1}(y_t)+\mu(i_t-i^*)=0. \tag{6}$$

This feature is attractive as it produces a joint restriction on policy makers' preferences that can be formally tested for. The parameters α and γ are indeed crucial for the analysis of optimal monetary policy not only because they introduce an asymmetric motive in the central bank objective function but also because, more importantly, they make nonlinear an otherwise conventional policy rule. This suggests that the hypothesis of symmetric central bank preferences can simply be tested by evaluating the functional form of the interest rate reaction function as the latter would correspond to testing whether the structural parameters α and γ are significantly different from zero.

3. Hypothesis testing and Euler equation estimates

This section reports the estimates and the relevant tests of the optimal policy rule. The analysis is conducted on U.S. quarterly data spanning the period 1960:1–2003:2. The data set has been obtained from the web site of the Federal Reserve Bank of St. Louis and embodies two alternative measures of inflation. In the baseline case, inflation is measured as the changes in the log of the personal consumption expenditure (PCE) deflator while the output gap is constructed using the series of potential output provided by the Congressional Budget Office (CBO).[4] As a way to

[4]The use of a low frequency filter to obtain estimates of the target level of real activities is consistent with the model-based definition of the flexible-price level of output. As argued by Woodford (2003, Chapter 7), the central bank can make society better off by accommodating technology and preference shocks while offsetting disturbances to inflation and wage mark-ups. In this vein, Smets and Wouters (2003b) show that if the monetary authorities wish to hedge against shocks of unknown nature, they would regard persistent

provide a robustness check, we also report results using the changes in the GDP deflator.

We divide the full sample around the third quarter of 1979, which corresponds to the appointment of Paul Volcker as Fed Chairman. This lines up with a number of empirical studies that demonstrate a significant difference in the way monetary policy was conducted pre- and post-1979 (see Clarida et al., 2000; Favero and Rovelli, 2003 among many others). Moreover, we remove from the second sub-sample the period 1979:4–1982:3 when, as documented by Bernanke and Mihov (1998), the operating procedure of the Fed temporarily switched from federal funds rate to non-borrowed reserves targeting.

We estimate a version of the central bank Euler equation using the generalized method of moments (GMM) with an optimal weighting matrix that accounts for possible heteroskedasticity and serial correlation in the error terms (see Hansen, 1982). In practice, we employ a two lag Newey – West estimate of the covariance matrix.

Starting from date $t-1$, two lags of the level and the square of the explanatory variables, the federal funds rates and the measure of inflation left out from the regression are included as instruments corresponding to a set of seven over-identifying restrictions that can be tested for.[5] The null hypothesis of valid overidentifying restrictions is never rejected. Moreover, the multiple endogenous regressor analog of the *F*-statistics from the first stage regression is close and exceeds in most cases the critical value that ensures that the bias is no more than 10% of the inconsistency of OLS (see Stock and Yogo, 2003). Given the conservative nature of the test, we deem the instruments strong and consider GMM inference reliable here.

3.1. Testing for symmetric central bank's preferences

An important step before the estimation of asymmetric central bank's preferences consists in assessing the empirical relevance of the nonlinear model. To this end, we test for linearity in the policy rule against the exponential alternative (5). The testing procedure as well as the estimation is complicated by the fact that some important parameters are not restricted by the null hypothesis and thus nothing can be learnt from the data about them when the null hypothesis holds true.

If α and γ are equal to zero, then the inflation and the output gap terms in the Euler equation (5) are indeterminate, implying that the null hypothesis of symmetric

(*footnote continued*)
disturbances as the only shocks affecting the target level of output. When applied to an estimated New-Keynesian model for the Euro area, they find that the counterfactual flexible-price level of output, which is the one responding to all non-monetary shocks in the economy, is indeed extremely volatile, whereas the target level of output, which is the one only affected by supply and demand disturbances, actually follows a relatively smooth path.

[5]The choice of a relatively small number of instruments is meant to minimize the potential small sample bias that may arise when too many overidentifying restrictions are imposed.

preferences does not restrict the convolutions of parameters $k\varphi/\mu$ and $\lambda\varphi/\mu$. To be sure, using either the linear specification (6) when $\alpha = \gamma = 0$ or the *nonlinear* Euler equation (5) when α and γ are *different* from zero, it is only possible to estimate the ratios $k\varphi/\mu$ and $\lambda\varphi/\mu$ but not the coefficients k, φ, λ and μ individually. If the *nonlinear* specification (5) is adopted when α and γ are actually *equal* to zero, however, it is no longer possible to estimate those ratios as the inflation and the output gap terms in Eq. (5) are not defined at $\alpha = \gamma = 0$.[6] Furthermore, when the null hypothesis is valid, the estimation criterion is unaffected by the values of the inflation target, which is therefore an unidentified nuisance parameters.[7]

The problem of testing linearity against nonlinear alternatives, including exponential forms, was first addressed by Luukkonen et al. (1988) and recently surveyed by van Dijk et al. (2002). The proposed solution consists in replacing the nonlinear function by a Taylor series approximation. In the reparameterized equation, the identification problem is no longer present and standard asymptotic theory is available for obtaining critical values for the test statistics under the null hypothesis.

We follow this strategy and hence linearize the exponential terms in (5) by means of a first-order Taylor series expansion. The resulting expression is then solved for i_t. Prior to GMM estimation, we replace expectations with realized values and, in line with most empirical studies on monetary policy rules, we introduce a lagged dependent variable capturing interest rate smoothing (see Woodford, 1999; Sack and Wieland, 2000; Castelnuovo, 2003 for a theoretical underpinning of this choice). The central bank's first-order condition is reparameterized as follows:

$$i_t = c_0 + c_1\pi_t + c_2 y_t + c_3\pi_t^2 + c_4 y_t^2 + \rho i_{t-1} + v_t. \tag{7}$$

The coefficients c_i with $i = 0, \ldots, 4$ are convolutions of the structural parameters of the model while the error term is a linear combination of the forecast errors associated with the predictions at time $t-1$ plus the remainder of the Taylor series approximation.

An important feature of Eq. (7) is that the restrictions $\alpha = \gamma = 0$ correspond to $c_3 = c_4 = 0$. Hence, testing the hypothesis $\mathrm{H}_0' : c_3 = c_4 = 0$ in (7) is equivalent to testing the hypothesis $\mathrm{H}_0 : \alpha = \gamma = 0$ in (5). Under the null of a linear reaction function, which fully corresponds to the null of symmetric preferences, the statistics has an asymptotic χ^2 distribution with as many degrees of freedom as the number of restrictions, and it can be successfully evaluated through a standard Wald test.

Table 1 reports two sets of GMM estimates of Eq. (7). The top (bottom) panel displays results based on the changes in PCE index (GDP deflator). The parameter c_4 is highly significant over the pre-Volcker era in the second column. The squared

[6] When α and γ tend to zero in fact, the linear specification is derived from the nonlinear Euler equation (5) applying L'Hôpital's rule.

[7] By 'estimation criterion' we mean the object that is minimized by the method of estimation. GMM is based on the distance between the moments in the model and the moments in the data.

Table 1
Testing for asymmetric preferences

	1960:1–1979:3	1982:4–2003:2
Personal consumption expenditure inflation		
c_1	0.33**	0.89**
	(0.12)	(0.36)
c_2	0.25**	0.17**
	(0.04)	(0.04)
c_3	−0.01	−0.11
	(0.01)	(0.06)
c_4	−0.04**	−0.01
	(0.01)	(0.01)
ρ	0.65**	0.86**
	(0.08)	(0.04)
$W(2)$ p-value	0.003	0.164
$J(7)$ p-value	0.349	0.178
GDP deflator inflation		
c_1	0.17	2.23
	(0.12)	(1.17)
c_2	0.18**	0.09
	(0.03)	(0.09)
c_3	0.01	−0.41
	(0.01)	(0.25)
c_4	−0.03**	−0.02
	(0.01)	(0.02)
ρ	0.71**	0.92**
	(0.08)	(0.07)
$W(2)$ p-value	0.001	0.085
$J(7)$ p-value	0.789	0.578

Specification: $i_t = c_0 + c_1\pi_t + c_2 y_t + c_3\pi_t^2 + c_4 y_t^2 + \rho i_{t-1} + v_t$.
Notes: Standard errors are reported in brackets. The output gap is obtained using the CBO potential output. The instrument set includes two lags of inflation, squared inflation, output gap, squared output gap, the Fed funds rate and the alternative measure of inflation. $W(n)$ refers to the Wald statistics of the test for n parameter restrictions, which is distributed as a $\chi^2(n)$ under the joint null hypothesis $c_3 = c_4 = 0$. The latter is equivalent to the original null of symmetric central bank preferences, $\alpha = \gamma = 0$. $J(m)$ refers to the statistics of Hansen's test for m overidentifying restrictions which is distributed as a $\chi^2(m)$ under the null hypothesis of valid overidentifying restrictions. The superscripts ** and * denote the rejection of the null hypothesis that the true coefficient is zero at the 1% and 5% significance levels. Constants are omitted for brevity.

output gap however loses its explanatory power during the later period in the third column. A negative coefficient on y_t^2 implies that the interest rate easings associated with output contractions of a given size are larger than the tightenings required by output expansions of the same magnitude, consistently with an asymmetric objective on the output gap.

The parameter c_3 attached to squared inflation, in contrast, is never statistically different from zero. The latter result implies that the hypothesis of a linear interest rate response to inflation is not rejected over both the pre- and post-1979 policy regimes. It is worth emphasizing that a consequence of the *symmetric* reaction to inflation is that, according to Eq. (5), the target π^* is an *unidentified* nuisance parameter. We return on this issue in the following section.

The last two rows of each panel report the p-value for the joint hypothesis of symmetric preferences and for the hypothesis of valid over-identifying restrictions. The two sets of estimates, based on different measures of inflation, paint a similar picture for both tests. In particular, the hypothesis of a linear Euler equation is strongly rejected during the pre-Volcker period only. In contrast, after 1982 the coefficients on the squared terms become of limited importance and the Wald statistics indicate that the null hypothesis of symmetric preferences is not rejected at the 5% significance level.

3.2. Estimates of the asymmetric policy preferences

The results of Table 1 support the notion of asymmetric preferences on the output gap during the pre-1979 monetary policy regime. In contrast, no asymmetry is detected with respect to inflation. This section quantifies the nonlinearities in the policy rule by estimating the Euler equation implied by a linex objective function.

Preliminary attempts to estimate the asymmetric preference parameters led to very large and insignificant values for π^*, and insignificant values for α. As discussed in the previous section, these values may simply reflect the fact that under *symmetric* inflation preferences, the inflation target is an unidentified nuisance parameter.[8] We rewrite hence the first-order condition (5) as follows:

$$-E_{t-1}\left\{d_1\left(\frac{\exp(\alpha\pi_t)-1}{\alpha}\right)+d_2\left(\frac{\exp(\gamma y_t)-1}{\gamma}\right)\right\}+i_t-d_0=0, \tag{8}$$

where the coefficients d_0, d_1 and d_2 are convolutions of the parameters of the model, and the weight on the stabilization of the interest rate was normalized to one. The asymmetric preference parameters α and γ can thus be estimated on the basis of a nonlinear Euler equation.[9] For the sake of consistency with a large empirical literature on interest rate rules, Eq. (8) is augmented with a lagged value of the policy rate prior to estimation.

Table 2 reports GMM evidence on the nonlinear Euler equation using PCE inflation in the top panel and GDP deflator inflation in the bottom panel. The list of instruments is the same used for the hypothesis testing.

The values of the asymmetric preference parameter on the output gap, γ, take always a negative sign, being statistically different from zero only during the pre-Volcker era. The point estimates are around -0.5 and are significantly larger than

[8]This is consistent with the results on the null hypothesis of a linear interest rate response to inflation reported in Table 1.

[9]An alternative strategy is to impose additional restrictions on the parameters of the model, including the inflation target, and use the estimates of the policy rule (7) to recover the values of the asymmetric preferences (see Surico, 2004, for empirical results based on this strategy).

Table 2
Estimates of the Euler equation

	1960:1–1979:3	1982:4–2003:2
Personal consumption expenditure inflation		
d_1	0.30*	0.89
	(0.14)	–
d_2	0.16**	0.17
	(0.06)	–
α	−0.03	−0.35
	(0.09)	(0.20)
γ	−0.48**	−0.12
	(0.14)	(0.08)
ρ	0.70**	0.85**
	(0.09)	(0.08)
$J(7)$ p-value	0.468	0.667
GDP deflator inflation		
d_1	0.23*	1.17**
	(0.09)	(0.42)
d_2	0.14**	0.17**
	(0.05)	(0.03)
α	0.08	−0.54
	(0.06)	(0.28)
γ	−0.52**	−0.08
	(0.14)	(0.08)
ρ	0.66**	0.85**
	(0.08)	(0.03)
$J(7)$ p-value	0.400	0.256

Specification: $i_t - d_0 - d_1 \frac{[\exp(\alpha\pi_t)-1]}{\alpha} - d_2 \frac{[\exp(\gamma y_t)-1]}{\gamma} - \rho i_{t-1} = 0$.
Notes: Standard errors are reported in brackets. The output gap is obtained using the CBO potential output. The instrument set includes two lags of inflation, squared inflation, output gap, squared output gap, the Fed funds rate and the alternative measure of inflation. $J(m)$ refers to the statistics of Hansen's test for m overidentifying restrictions which is distributed as a $\chi^2(m)$ under the null hypothesis of valid overidentifying restrictions. The superscripts ** and * denote the rejection of the null hypothesis that the true coefficient is zero at the 1% and 5% significance levels. Constants are omitted for brevity.

the post-Volcker values. In line with the results of the hypothesis testing, linearity is not rejected in the most recent sample.

The coefficient on inflation asymmetric preferences, α, is never statistically different from zero, which has the unfortunate consequence that the inflation target is not identified in this framework. The value of the inflation slope, d_1, is significantly larger in the later period using GDP deflator inflation, though the small values of α suggest that some caution should be used in interpreting this parameter.

It should be noted that when inflation is measured as changes in the PCE index, free estimation of the parameters d_1 and d_2 led to convergence problems over the post-1982 era, which according to the results of the hypothesis testing is a period characterized by a linear interest rate rule. The estimates in the last column of the top panel of Table 2 are hence derived imposing, prior to estimation, the slope of inflation and the slope of the output gap reported in Table 1.

3.3. Interpreting the results

To the extent that the preferences of the Fed changed over time, it is important to offer a possible interpretation of such shift. An interesting hypothesis mentioned in the introduction and put forward by Persson and Tabellini (1999) refers to political pressures. In a nutshell, the argument is that career-concerned politicians have an incentive to appoint asymmetric preferences central bankers in an effort to stimulate the economy during periods of output contractions and therefore gain consensus among the voters.

Informal support for the notion of 'politics induced' asymmetric preferences during the 1970s can be found in a number of public speeches and interviews by members of U.S. government, Fed officials and press commentators. De Long (1997) and Nelson (2005), for instance, forcefully argue that U.S. monetary policy during the 1970s was highly sensitive to the political pressures for a higher money growth and lower interest rates, and provides extensive narrative evidence about the influence of Nixon's administration on the Chairmanship of Arthur Burns at the Federal Reserve.

In an interview to the newspaper 'Kansas City Star' in 1970, for instance, Nixon argued that '[*the consensus for Mr. Burns at his swearing-in*] *is a standing vote of approval*, *in advance*, *for lower interest rates*. [...] *I have very strong views*, *and I expect to present them to Mr. Burns. I respect his independence*, *but I hope he independently will conclude that my views are the right ones*' (quoted from Nelson, 2005).

Another selected example is provided by Ehrlichman (1982), who reports the following conversation between Richard Nixon (the speaker) and Arthur Burns (the listener) in October 1969, just after that Nixon had announced his intention of nominating Burns as new Fed Chairman. '*I know there's the myth of the autonomous Fed*... [*short laugh*] *and when you go up for confirmation some Senator may ask you about your friendship with the President. Appearances are going to be important*, *so you can call Ehrlichman to get messages to me*, *and he'll call you*.' (quoted from De Long, 1997).

Lastly, Greider (1987, pp. 346–347) analyzes the real interest rate fall at the end of 1976 and comments that '[...] *given that inflation was rising and unemployment was falling*, *this expansion was a stark deviation from modern practice. Burns may have expanded in an effort to win renomination by President Carter*' (quoted from Romer and Romer, 2003).

In addition to the informal evidence collected by De Long (1997), Romer and Romer (2003), Nelson (2005) and the references therein, it is important to bear in mind that central banks had become increasingly independent since the middle of the 1980s. While economic and policy factors are also likely to have contributed to the Great Inflation, it is worth to note that the kind of statements quoted above had been hardly seen during the last two decades and political pressures, at least in the forms used by Nixon's administration, seem far from modern policy making.

3.4. Alternative sources of nonlinearities

The exponential terms in (5) stem from asymmetric central bank preferences. In principle, however, other sources of nonlinearity might be also consistent with an asymmetric policy rule. On the basis of the model developed by Schaling (2004), for instance, Dolado et al. (2005) consider a convex aggregate supply curve in which inflation depends not only from the level of the output gap but also from its squared values.

In this section, we test for possible nonlinearity in the Phillips curve following two strategies. First, we estimate an aggregate supply relation augmented with squared output gap. Second, we perform a REgression Specification Error Test (RESET) adding into the New-Keynesian Phillips curve the squared, and then the squared and the cubes of the predictions $\hat{\pi}_t$ obtained from the linear model.

Eq. (1) is evaluated by Instrumental Variables over the full sample and the two sub-samples using the set of instruments described above. The t-tests on the coefficient associated with the convex term and the F-tests on the transformations of the predicted $\hat{\pi}_t$ indicate that the null hypotheses of *non-convexity* and *non-misspecification* are not rejected. Empirical support for a linear U.S. aggregate supply can also be found in Dolado et al. (2004).

An additional form of nonlinearity may come from the policy makers' (mis)perception of the state of the economy. Suppose that on the basis of the estimates available in real-time the Fed believed for part of the sample that the output gap was larger than indicated by revised data. Then, the policy interventions during that period may appear surprisingly activist from the standpoint of the 2003 vintage. Using real-time data Orphanides (2004) finds, however, that the Fed's response to the output gap was actually more activist in the 1970s when the misperceptions on potential output turned out to be more severe. Moreover, Kuha and Temple (2003) show that measurement error in quadratic regressions tends to hide the presence of nonlinearities. In the view of these arguments, this paper takes an essential step towards asymmetric preferences by extending the available evidence on monetary policy rules using revised data.

A further reason for nonlinearity is associated with the point estimates of the natural rate of real activity. Meyer et al. (2001) show that in periods of heightened uncertainty about the NAIRU, the central bank may have an incentive to move policy rates only when unemployment deviates sufficiently from the target. While potentially relevant, this hypothesis testing requires a real-time series for potential output such as to reflect the policy makers' beliefs about the state of the economy at the time the decisions were taken. For reasons discussed above, however, we use the official estimates of potential output, which are actually revised by the CBO on a regular basis. As these revisions sensibly reduce the uncertainty about the historical measures of the output gap, this form of nonlinearity is likely to play only a marginal role in our analysis.

4. Measuring the average inflation bias

The estimates of the previous section support the notion of a novel inflation bias due to Cukierman (2002). In the presence of an asymmetric objective over the output gap and uncertainty about the state of the economy, the monetary authorities face an incentive to respond more aggressively to output contractions of a given amount than to output expansions of the same magnitude. The expected marginal benefit of policy interventions is convex in the output gap, meaning that in order to satisfy the Euler equation and stimulate aggregate demand the policy makers cut more interest rate when the economic outlook is worse. As the private sector correctly anticipates such an incentive, the precautionary stance of the monetary policy generates a systematic boost in inflation expectations even though, unlike in Barro and Gordon (1983), the central bank targets output at the potential level.[10]

The *asymmetric preferences induced inflation bias* is defined as the difference between the linear first-order condition (6) and a nonlinear Euler equation in the output gap. The focus on the nonlinearity in the output gap is motivated by the empirical results presented in the previous section. The empirically grounded restriction $\alpha = 0$ implies then the following nonlinear first-order condition:

$$-k\varphi E_{t-1}(\pi_t - \pi^*) - E_{t-1}\left(\frac{e^{(\gamma y_t)} - 1}{\gamma}\right)\lambda\varphi + \mu(i_t - i^*) = 0. \tag{9}$$

We normalize the inflation slope to one in the Euler equations and subtract (6) from (9). Computing the unconditional expectations of the resulting difference, we obtain an expression for the average inflation bias:

$$\textit{Average inflation bias} = -\frac{d_2}{\gamma d_1}\left[\exp\left(\frac{\gamma^2}{2}\sigma_y^2\right) - 1\right], \tag{10}$$

where we used the fact that the output gap has an unconditional distribution with zero mean and variance σ_y^2.

An expression similar to (10) was obtained by Chadha and Schellekens (1999) using a backward-looking model of the economy, and derived by Surico (2003) as difference between the optimal policy under discretion and the optimal policy under commitment subject to a Lucas aggregate supply.

The average inflation bias arises here because policy preferences are asymmetric with respect to the output gap rather than because the desired level of output is above the potential level like in Barro and Gordon (1983). The distortion increases with the degree of asymmetry, and to the extent that the penalty associated with an output contraction is larger than the penalty associated with an output expansion of

[10]In the theory of consumption, a precautionary motive emerges from the interaction between non-quadratic preferences and labor income risks such as to generate above-average saving rates in periods of high uncertainty. As shown by Kimball (1990), a sufficient condition for a precautionary saving is that the expected marginal *utility* of the representative agent be *convex* in consumption. Analogously here, the above-average inflation comes from the interaction between an asymmetric central bank objective and uncertainty about the state of the economy. Moreover, as the expected marginal *loss* is *concave* in the output gap, this motive can be thought as a precautionary demand for expansions.

Table 3
The average inflation bias

	1960:1–1979:3	1982:4–2003:2
Average inflation bias	1.48**	0.09
	(0.35)	(0.11)
Inflation target	3.43**	2.85**
	(0.37)	(0.27)
Actual inflation mean	4.5	2.8
Standard deviation of the output gap	2.7	2.1

Specification: Average inflation bias $= -\frac{d_2}{\gamma d_1}\left[\exp\left(\frac{\gamma^2\sigma_y^2}{2}\right) - 1\right]$.

Notes: Standard errors are reported in brackets. Inflation is measured as the change in the PCE index. The values of the inflation target are based on the estimates, not reported, of a nonlinear Euler equation imposing the restriction $\alpha = 0$ prior to estimation. The results from this specification are similar to the estimates displayed in Table 2 and are available upon request. The superscripts ** and * denote the rejection of the null hypothesis that the true coefficient is zero at the 1% and 5% significance levels.

the same size, the model predicts $\gamma < 0$. As d_1 and d_2 are positive, the difference between the linear and the nonlinear Euler equations represents an inflation bias rather than a deflation bias. When γ goes to zero, the expected marginal benefit of a policy intervention becomes linear and the inflation bias disappears together with the precautionary motive.

It should be noted that the identification of the average inflation bias in (10) does not require any further assumption on the parameters of the model. In contrast, it is not possible to recover an estimate of the implicit inflation target from the Euler equation (9) without additional restrictions, as the constant term in that expression is a convolution of the interest rate target, i^*, and the inflation target, π^*. A simple, albeit crude, way of identifying the inflation target from a linear specification in inflation was proposed by Clarida et al. (2000) and consists in assuming that the interest rate target is constant within sub-periods and equal to the sub-sample average of the nominal interest rate.

For the sake of completeness, we also report in Table 3 the estimates of the inflation target based on such restriction bearing in mind two caveats. First, assuming that i^* is equal to the mean of the nominal interest rate is likely to bias the estimates of π^* toward the sub-sample averages of inflation. Second, the implicit interest rate and inflation targets may be in facts time-varying and possibly endogenous. While these issues are beyond the scope of the paper, it is interesting to note that using a random walk specification for the process of the inflation target and a full information approach, Ireland (2005) finds that there exists considerable uncertainty about the sources of movements in the inflation target.

It is worth emphasizing that our analysis focuses on the *average* inflation bias induced by asymmetric preferences. While a time-varying measure of the bias requires modeling (and possibly endogenizing) also the volatility of the output gap, Ruge-Murcia (2003) and Surico (2003) find empirical support for asymmetric preferences on

U.S. data using, as additional regressor in the policy rule, the conditional (exogenous) variance of the output gap generated from a GARCH model.

We derive a measure of the inflation bias using formula (10) and the estimates of Table 2 for the PCE inflation.[11] The values of the implicit inflation targets are backed out from the estimates of Eq. (9) using the restriction on the interest rate target. Table 3 presents the results. The average inflation bias, which is reported in the second row, was sizable and statistically different from zero only in the pre-Volcker period with a point estimate of 1.48%. The inflation target also declined moving from the pre- to the post-1979 period, though considerable uncertainty surrounds these estimates.

A shift in the policy preferences on output stabilization seems to account for a larger fraction of the difference in the sub-samples mean of inflation relative to a reduction in the implicit inflation target. The results in Table 3 suggest that while a more favorable macroeconomic environment, as summarized by the decline in the standard deviation of the output gap, had also played a role, a change in the policy preference on output, from asymmetric to symmetric, had remarkably contributed to the fact that U.S. inflation was higher on average during the 1960s and 1970s than during the 1980s and 1990s.

5. Conclusions

The contribution of this paper is twofold. At the theoretical level, it derives the analytical solution of the central bank optimization problem when policy preferences are asymmetric in *both* inflation and output gaps, and the monetary transmission mechanism is New-Keynesian. The specification of the policy objectives is general enough to nest the quadratic form as a special case and translates into a potentially nonlinear targeting rule. This feature forms the basis of our hypothesis testing for the presence of asymmetric preferences as it allows us to reversely engineer potential evidence of nonlinearities in the reaction function into evidence of asymmetries in the policy objective.

At the empirical level, this paper shows that U.S. monetary policy can be effectively characterized by a nonlinear policy rule during the pre-Volcker regime only, with the interest rate response to the output gap being the dominant type of nonlinearity. In particular, the Fed attached a larger weight to output contractions than to output expansions of the same magnitude such as to induce an average inflation bias of about 1.5%. The latter can account for a sizable fraction of the decline in the inflation mean moving from the pre- to the post-1979 period.

This paper focuses on the notion of *average* inflation bias and hence offers a new explanation for the fact that the inflation mean fell *across* monetary policy regimes. An interesting avenue for future research is to investigate further the properties of the implicit inflation target by modeling also its time variation *within* regimes. The random walk assumption put forward by Smets and Wouters (2003a) and Ireland (2005) is a promising step in this direction.

[11]Similar results are obtained using GDP deflator inflation.

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