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Summary

This paper investigates the empirical relevance of a new framework for monetary policy analysis in which decision makers are allowed to weight differently positive and negative deviations of inflation and output from the target values. The specification of the central bank objective is general enough to nest the symmetric quadratic form as a special case, thereby making the derived policy rule potentially nonlinear. This forms the basis of our identification strategy which is used to develop a formal hypothesis testing for the presence of asymmetric preferences. Reduced-form estimates of postwar US policy rules indicate that the preferences of the Fed have been highly asymmetric in both inflation and output gaps, with the asymmetries on the latter becoming relatively more pronounced during the post-79 tenures.

Keywords: Nonlinear optimal monetary policy rules, asymmetric loss function, linearized Central Bank Euler equation

JEL: E32, E52

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1 Introduction

The last decade has been characterized by an increasing consensus in monetary policy analysis. One of the most influential paradigm has been the design of policy interventions as the constrained optimum of a well-behaved control problem in which the central bank moves interest rates to minimize some quadratic objective function. The latter defines the ultimate goals of monetary policy and translates the behavior of the target variables into some measure for policy evaluations. When assigned with such a problem, the central bank faces the constraints representing the 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 according to which monetary authorities move policy rates as the optimal response to the developments in the economy.

While the quadratic specification implies that monetary authorities evenly weight positive and negative deviations of inflation and output from the target values, such a modeling choice has been questioned by several practitioners at the policy committees of various central banks on the ground that it has little justification beyond analytical tractability (see Blinder, 1997, and Goodhart, 1999). The few notable exceptions include Rotemberg and Woodford (1999) and Woodford (2002, Ch. 6) who show that the quadratic form can be obtained as a second order approximation of the utility-based welfare function. More generally, a number of quadratic objectives have been recently proposed in the literature as a way to evaluate alternative targeting schemes and the policy recommendations have been implicitly drawn upon the assumption of symmetric central bank preferences.[1]

Several recent studies however explore some novel mechanism through which the cost of the business cycle can be asymmetric and argue that policy makers may incur losses of different orders between positive and negative deviations of the state variables from target. Galì, Gertler and Lopez-Salido (2002) construct a theoretical measure of aggregate inefficiency in a business cycle model with nominal rigidities. Given that price and wage markups make the steady state level of employment inefficiently low, it is shown that business contractions of a given amount generate greater welfare losses than the welfare gains coming from expansions of the same magnitude. Furthermore, when applied to postwar US data, their gap measure indicates that the costs of business fluctuations have been historically large and asymmetric.

An alternative way to think of output asymmetries is provided by a recent strand of literature which considers labor decisions as indivisible. For most of the workforce, employment is an all-or-nothing status and the costs of business cycle fluctuations are mainly paid on the

[1] See for instance Rudebusch and Svensson (1999), Dennis and Söderström (2002), Jensen (2002), Söderström (2001) and Walsh (2002) among many others.

extensive margin rather than on the intensive one (see King and Rebelo, 1999). This means that recessions are characterized by a few individuals becoming unemployed as opposed to the entire labor force working a lower number of hours. Orphanides and Wilcox (1996) argue that as a consequence of such an indivisibility, policy makers who aggregate over individual welfare may suffer a first-order loss even in the case of small departures of output from potential. Moreover, in the absence of complete insurance markets, the concentration of unemployment is most likely to make negative deviations from the target more costly than positive ones, thereby providing a basis for an asymmetric behavior in output.

Another promising avenue of research suggests that heterogeneity in portfolio holdings and transaction patterns are an important mechanism through which inflation may also have distributional effects. By contrast, the conventional representative agent abstraction supports the notion that the negative consequences of inflation are mainly allocative, investment and spending decisions become inefficient and from a welfare point of view it seems reasonable to treat the costs of price instability as convex in the inflation level, at least for small departures from the target. Erosa and Ventura (2002) show that if agents are heterogenous in the sense described above and there exists uninsurable income risks, price changes act as a regressive consumption tax such that the burden of inflation is mostly paid by low income individuals, who mainly use cash for their total transactions. This suggests that when inflation is above the reference value policy makers may incur a first-order loss coming from the asymmetric costs of inflation fluctuations.

Lastly, the literature on the psychology of choice offers a different perspective which dates back to the seminal work by Kahneman and Tversky (1979). By using a revealed preference approach, it is argued that people tend to place a greater weight on the prospect of losses than on the prospect of gains in decision making under uncertainty. Accordingly, an asymmetric behavior arises because most individuals seem to value gains of a given amount less than losses of the same magnitude. As a consequence, policy makers who aggregate over individual welfare may be loss-averse with respect to either inflation or output.

Turning the attention to the implications of asymmetric central bank preferences, a number of papers have recently derived the optimal monetary policy within such a framework. Interestingly, Cukierman (2001), Nobay and Peel (1998) and Ruge-Murcia (2002a and 2002b) show that some of the results coming from the Barro-Gordon tradition (1983) are not invariant to the specification of the policy objectives. In particular, a new source of inflation (deflation) bias can emerge not because monetary authorities target a value of output above potential but because they are perceived by the private sector as responding more aggressively to negative output deviations (positive inflation deviations) from target.

Despite of the possible foundations and the theoretical implications, only few studies have attempted to identify asymmetric central bank behaviors and the empirical relevance of this alternative framework remains to be assessed. Gerlach (2000), Dolado, Maria-Dolores and Naveira (2002), and Martin and Milas (2001) show some international evidence that supports the notion of asymmetric reaction functions. Ruge-Murcia (2002a), and Cukierman and Muscatelli (2002) study analytically the implicit functional form of a nonlinear policy rule and using data for some G7 economies they conclude that the qualitative features of the empirical reaction functions are consistent with an asymmetric objective. Dolado, Maria-Dolores and Ruge-Murcia (2002) estimate a nonlinear policy rule, which is drawn upon the existence of an asymmetric preference on inflation only, and they find that the US monetary policy can be characterized by a nonlinear reaction function after 1983, but not before 1979.

This paper contributes to the theoretical and empirical literature on optimal monetary policy rules in different respects. First, assuming a fairly general specification of both inflation and output objectives, we derive a closed-form solution of the optimal monetary policy within a New-Keynesian model of the business cycle. Since our objective function nests the conventional quadratic form as a special case, the specification of the policy rule is shown to be nonlinear *if and only if* the central bank preferences are asymmetric. This condition delivers a formal theoretical prediction which can be successfully tested for. Second, the analytical approach to the solution of the central bank optimal control problem allows to identify the degree of nonlinearities and asymmetries with respect to both inflation and output gaps, a result that to our knowledge of the existing literature comes as new. Third, our reduced-form specification of the nonlinear policy rule is an augmented version of the popular Taylor rule (1993) since monetary authorities respond not only to the level of inflation and output gaps but also to their squared values. However, as a result of our identification strategy, the rule is *linear* in the feedback parameters. Fourth, reduced-form estimates of US monetary policy indicate that nonlinearity is a robust feature of the data over both the pre- and post-Volcker periods. While this finding enriches the picture provided by Clarida, Galì and Gertler (2000), it suggests that the preferences of the Fed have been highly asymmetric in both inflation and output gaps, with the asymmetries on the latter becoming more pronounced than those on the former during the post-79 tenures.

The road map of the paper is as follows. Section 2 presents the theoretical model and derives the interest rate rule as the first order condition of the central bank optimal control problem. The identification method and the hypothesis testing strategy for the presence of asymmetric preferences are described in Section 3. Reduced-form estimates on postwar US data are reported and discussed in the following part while the last Section concludes.

2 Theoretical model: a New-Keynesian perspective

We assume that the central bank conducts monetary policy through a *targeting rule* according to the terminology of Svensson (1999). Thus, all available information are used to bring at each point in time the target variables in line with their targets by penalizing any future deviation of the former from the latter. The policy rule is modeled as the outcome of an intertemporal optimization problem in which decision makers minimize a given criterion under the constraints provided by the structure of the economy. The optimizing device allows us to reversely engineer the objectives of monetary authorities, which are unobservable, 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 for 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 celebrated New-Keynesian model of the business cycle developed in King and Wolman (1996), Yun (1996), Woodford (2002, Ch. 3 and 4) and McCallum and Nelson (1999), among many others, and generally referred to as the New Neoclassical Synthesis (see Goodfriend and King, 1997).

2.1 The structure of the economy

This subsection describes an aggregate version of the New-Keynesian forward-looking model with sticky prices that has been recently summarized by Clarida, Galì and Gertler (1999). The evolution of the state variables is compactly represented by the following two-equation system:

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

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

Equation (1) captures in a log-linear fashion the staggered feature of a Calvo-type world (1983) 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 by 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. Equation (2) is a log-linearized version of 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 output gap a positive function of its expected 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 a well-behaved cost shock and demand shock, respectively.

2.2 An asymmetric specification of the loss function

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

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

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 nonquadratic 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 paradigm 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 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 in (4), which has been originally proposed by Varian (1974) and Zellner (1986) in the context of Bayesian econometric analysis and introduced by Nobay and Peel (1998) in the optimal monetary policy literature, embodies a number of appealing characteristics. First, it allows for departures from the quadratic objective in that policy makers may treat differently positive and negative deviations of the target variables from the reference values. This pattern is shown in Figure 1 which plots the standard quadratic versus the asymmetric function for both inflation (Panel a) and output gap (Panel b).

The key difference between the two specifications is that deviations of the same size yield different losses. Indeed, under the symmetric scenario policy makers are assumed to care only about the magnitude of deviations whereas under asymmetric preferences they care also about the sign. In particular, a positive value of α in Panel (a) implies that, everything equals, deviations of inflation (relative to target) from above are weighted more severely than deviations from below. To see this notice that whenever $\pi_t - \pi^* > 0$ the exponential component of the loss function dominates the linear component while the converse is true for $\pi_t - \pi^* < 0$. The same reasoning holds for the coefficient γ in Panel (b), which captures any asymmetry in the policy preferences for stabilizing the business cycle. However, if monetary authorities are more concerned about undershooting potential output rather than overshooting it, the value of γ would be negative implying that whenever $y < 0$ the loss rises exponentially whereas it does linearly for $y > 0$.

Furthermore, the linex loss function specified above is so general as to collapse to the symmetric quadratic form for some parameter limiting case. Applying twice L'Hôpital's rule on (4), it is possible to show that whenever α and γ tend to zero the central bank objective function reduces to the symmetric parametrization $L_t = \frac{1}{2}\left[(\pi_t - \pi^*)^2 + \lambda y_t^2 + \mu\,(i_t - i^*)^2\right]$. The latter can be obtained as a quadratic 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, 2002, Ch. 6). Accordingly, the policy preferences would be functions of some primitive parameters of the model implying that potential evidence of asymmetries in the central bank objective could be tracked into evidence of asymmetries in the representative agent's utility. Indeed, as argued by Clarida, Galì and Gertler (1999), the representative agent approach can be highly misleading as a guide to welfare analysis and it is likely to be the case that some groups suffer more in recessions or in high inflation periods than others. This suggests that an asymmetric utility-based specification of loss function may be a desirable representation of the social costs of cyclical fluctuations.

2.3 A nonlinear policy rule

We let monetary authorities choose policy rates in a discretionary fashion. Indeed, the case for an optimal monetary policy without commitment seems to be closer to the actual practice of many central banks which rarely tie their hands over the course of future policy actions. Because no endogenous state variable enters the model, the intertemporal policy problem reduces to a sequence of static optimization problem. This amounts to choosing in each period the instrument rate 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

$$\begin{aligned} \pi_t &= k y_t + f_t \\ y_t &= -\varphi i_t + g_t \end{aligned}$$

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 monetary authorities cannot directly manipulate expectations. The first order condition reads

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

which is a closed-form solution for the optimal policy rule. Equation (5) implicitly describes a general reaction function according to which the central bank moves policy rates as the optimal, potentially nonlinear, response to the developments in the economy.[2] The important result which underlies equation (5) is that it nests the conventional linear form as a special case. Indeed, it can be shown by means of L'Hôpital's rule that when both α and γ tend to zero the reaction function (5) collapses to an implicit interest rate rule of the type proposed by Rudebusch (2002), and Clarida, Galì and Gertler (2000):

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

This feature is attractive in that it delivers a joint restriction on policy makers' preferences which can be formally tested for. It follows that the hypothesis of symmetric loss function can be challenged by assessing whether the relevant feedback coefficients are, either jointly or marginally, significantly different from zero. The policy 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 those asymmetries mapping into a nonlinear policy rule. This suggests that were α and γ identified, the hypothesis that central bank preferences are symmetric around the target could be tested simply by evaluating the functional form of the feedback rule as the latter would correspond to test whether α and γ are significantly different from zero. Thus, evidence of nonlinearity in the policy rule would be informative about which type of asymmetry, if any, is relevant to policy makers.

It should be noticed that while the nonlinear components of the policy rule (5) stem from an asymmetric policy makers' objective, we cannot exclude in principle that a nonlinear Phillips

[2] Notice that in contrast to other studies which impose an ad-hoc partial adjustment mechanism, our model-based specification for the central bank reaction function does not include any lagged interest rate terms. This comes from the fact that monetary authorities pursue the stabilization of policy rate *levels* rather than *changes*, a feature which hinges upon the specification of the utility function of the representative agent (see Woodford, 2002, Ch. 6).

curve is indeed responsible for any potential reduced-form evidence of nonlinearity. However, Dolado, Maria-Dolores and Ruge-Murcia (2002) show that the US aggregate supply curve is well approximated by a linear relation over the samples we will focus on, thereby making asymmetric preferences the most empirically relevant source of nonlinearity.

3 Econometric analysis

Before turning to the estimation of the nonlinear policy rule, there are a number of econometric issues we have to deal with. Our favorite specification (5) has similarities with the Smooth Transition Regressive (STR) specifications in that the endogenous variable is determined over a number of different regimes. In particular, two regimes can be associated with small and large values of the transition variable π_t relative to the target π^*, and two other regimes can be associated with the movements of output gap around the threshold value of zero. Accordingly, a more vigorous policy response distinguishes the regime operating during high inflation (output contraction) periods from the one in place during low inflation (output expansions) times. The policy parameters α and γ and the exponential function govern the smoothness of the changes allowing for an asymmetric response of policy rates to positive and negative deviations of the state variables from the target.

Our task consists in estimating the STR reaction function in order to evaluate whether the parameters governing the asymmetries in the policy objective are significantly different from zero. This amounts to test linearity against a STR model, which is complicated by the fact that in small samples the estimation criterion is insensitive to the smoothness coefficients as there exists a large set of α- and γ-values yielding almost the same interest rate behavior (see Granger and Teräsvirta, 1993, Ch. 7). It follows that the asymmetric preference parameters would be inaccurately estimated, thereby making the hypothesis testing for the presence of nonlinearities theoretically flawed. Moreover, the specification in (5) is nonlinear in the relevant parameters and therefore the econometric method of estimation may pick up just one among the numerous local maxima depending on the initial values of the coefficients.

A simple way to overcome these issues is to follow Luukkonen, Saikkonen and Teräsvirta (1988), and van Dijk, Teräsvirta and Franses (2002), and take a first order Taylor expansion of the STR reaction function around $\alpha = 0$ and $\gamma = 0$. This amounts to linearize the nonlinear policy rule with respect to the smoothness coefficients in order to obtain a more tractable specification which can be successfully estimated through conventional linear methods. It should be noticed that under the null hypothesis of linearity such an approximation does come at no cost in terms of properties of the reaction function. Indeed, when the null holds true the remainder of the Taylor expansion is zero and therefore also the properties of the error term are not affected by the linearization. The main implication is that the conventional statistical theory is still available for obtaining the asymptotic null distribution of any classical test, which can be used in turn to evaluate the statistical significance of the preference parameters $\{\alpha, \gamma\}$.

We approximate the reaction function in (5) by means of a first order Taylor series expansion around $\alpha = \gamma = 0$. The policy rule now reads

$$-k\varphi E_{t-1}(\pi_t - \pi^*) - \lambda\varphi E_{t-1}(y_t) - \frac{\alpha k\varphi}{2} E_{t-1}\left[(\pi_t - \pi^*)^2\right] +$$
$$-\frac{\lambda\varphi\gamma}{2} E_{t-1}\left(y_t^2\right) + \mu(i_t - i^*) + e_t = 0 \tag{6}$$

with e_t being the remainder of the Taylor series approximation.

This condition relates in a nonlinear manner the policy rates with the expected future values of the state variables conditioned upon the information available at time $t-1$. We solve equation (6) for i_t and prior to estimation we replace expected inflation and output gaps with actual values assuming that policy makers know the model parameters with certainty (i.e. there is no multiplicative uncertainty). Accordingly, we focus on the following policy rule:

$$i_t = c_{onst} + c_1\pi_t + c_2 y_t + c_3(\pi_t)^2 + c_4(y_t)^2 + v_t \tag{7}$$

which is linear in the coefficients

$$c_{onst} \equiv i^* - c_1\pi^* - c_3(\pi^*)^2$$

$$c_1 \equiv \frac{k\varphi}{\mu} - 2c_3\pi^*$$

$$c_2 \equiv \frac{\lambda\varphi}{\mu}$$

$$c_3 \equiv \frac{\alpha k\varphi}{2\mu}$$

$$c_4 \equiv \frac{\lambda\varphi\gamma}{2\mu}$$

and whose error term is defined as

$$v_t \equiv -\left\{\begin{array}{c} c_1(\pi_t - E_{t-1}\pi_t) + c_2(y_t - E_{t-1}y_t) + \\ +c_3\left[\pi_t^2 - E_{t-1}(\pi_t)^2\right] + c_4\left[y_t^2 - E_{t-1}(y_t)^2\right] \end{array}\right\} + \frac{e_t}{\mu}$$

The term in curly brackets is a linear combination of forecast errors and therefore v_t is orthogonal to any variable in the information set available at time $t-1$.

Equation (7) makes clear that by assuming an optimizing central bank behavior the reaction function parameters can only be interpreted as convolutions of the coefficients representing policy makers' preferences and those describing the structure of the economy. While recovering all structural parameters is beyond the scope of this paper, a single-equation estimation of the derived policy rule is all we need to identify the asymmetric preferences. Indeed, the feedback coefficients c_3 and c_4 embody the relevant information we are interested in such that the joint restriction $\alpha = \gamma = 0$ implies $c_1 \neq 0$, $c_2 \neq 0$ and $c_3 = c_4 = 0$. Hence, testing the null hypothesis $H_0 : \alpha = \gamma = 0$ in (5) is equivalent to testing the null hypothesis $H_0' : c_3 = c_4 = 0$ in (7).[3] The latter however has the remarkable advantage of testing for *linearity*, which fully corresponds to test for symmetric preferences, without requiring the estimation of a *nonlinear* model. Under the null of linear-reaction-function/symmetric-preferences the test statistics has an asymptotic χ^2 distribution with as many degrees of freedom as the number of restrictions. Such an hypothesis can be successfully evaluated through a standard Wald test and since we are considering the auxiliary null $H_0' : c_3 = c_4 = 0$ rather than the original hypothesis $H_0 : \alpha = \gamma = 0$, the statistics is usually referred to as Wald-*type*.[4]

Finally, while our strategy allows to identify the asymmetric preference on output gap, γ, from the coefficients c_4 and c_2 only, it does not allow to recover the other key preference parameter, α, unless some additional restriction are imposed to the policy rule. Nevertheless, were c_3 and c_4 jointly significant the hypothesis on symmetric preferences would be rejected. We will return on the issue in the next section.

The derived monetary policy rule (7) represents a generalized version of the popular Taylor rule (1993) as the monetary authorities respond not only to the level of the state variables but also to their squared values. Thus, the policy response is nonlinear in the size of the target variable deviations and asymmetric with respect to their signs. Moreover, as the parameters in the central bank Euler equation have been linearized, a reaction function like (7) may potentially capture a number of alternative functional forms for the central bank objective relative to the linex specification. Accordingly, the policy rule coefficients would be some *unknown* convolution of the parameters of the economy and policy makers' preferences, and it would not be possible to distinguish among the two. Nevertheless, the hypothesis testing for the presence of nonlinearities, which makes the main argument of the paper, would still be valid as a number of nonquadratic specifications of the objective function can be shown to translate into some nonlinear quadratic approximation of the policy rule.

[3] It is worthwhile to notice that the power of the test upon the auxiliary regression (7) crucially depends on the significance of c_1 and c_2 as it may be the case that H_0' cannot be rejected simply because c_1 and c_2 are not statistically different from zero.

[4] As we are estimating a model which is *linear* in the parameters, the critique that the Wald test for *nonlinear* specifications is not invariant to the parametrization of the model simply does not apply here.

4 Empirical results

This section reports the estimates and the relevant tests of the policy reaction function (7). The analysis is conducted on US quarterly data spanning the period 1960:1-2001:4. The data set has been obtained from the web site of the Federal Reserve Bank of St. Louis and embodies alternative measures of both inflation and output gap. In particular, the baseline measure of inflation is constructed from the (log) GDP chain-weighted price index while the one for output gap is taken from the Congressional Budget Office. As a way of providing a robustness check, we also report the results for two alternative measures of the state variables, namely the commodity price index inflation and the detrended output obtained as the residuals from regressing output on a constant and a quadratic trend.

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, Galì and Gertler, 2000, Judd and Rudebusch, 1998, and Dennis, 2002 among others). Moreover, we remove from the second sub-sample the period 1979:3- 1982:3 when the operating procedure of the Fed temporarily switched from Fed funds rate to non-borrowed reserves (see Bernanke and Mihov, 1998). Finally, we address the issue of subsample stability by re-evaluating the model over the Greenspan era only, 1987:3-2001:4.

The empirical analysis maintains the assumption that the model variables are stationary. Although the null of unit root is often hard to reject, the well known low power of those tests and the documented change of policy regime make it a reasonable hypothesis for the postwar US (see Clarida, Galì and Gertler, 2000).

We estimate equation (7) over the three periods 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 four lag Newey-West estimate of the covariance matrix. Four lags of the explanatory variables, the interest rates and the measure of inflation left out from the regression are included as instruments corresponding to a set of 20 overidentifying restrictions that can be tested for.[5]

In the absence of further assumptions our approach only identifies the policy parameter on output gap asymmetries, γ, but neither the one on inflation, α, nor the inflation target, π^*,

[5]Notice that because no lagged interest rate terms appear in (7) as explanatory variable, the error component is likely to be serially correlated. This is more that a standard error issue as it implies a violation of the orthogonality conditions stemming from the New-Keynesian transmission mechanism. We solve the issue by removing from the set of instruments so many lags as to make the residuals nonsystematic. This amounts to replace the first lag of each instrument in the pre-79 period and the first three lags in the post-79 period with their own earlier lags. While such a choice has only a minor impact on the goodness of the instruments, it does not affect the overall fit of the model.

separately. Since the focus of our analysis is on the former parameters, we impose prior to estimation the additional restriction that the observed subsample average of inflation provides a reasonable approximation of the target. This assumption, which is consistent with the estimates provided by Judd and Rudebusch (1998), and Clarida, Galì and Gertler (2000), allows to jointly identify γ and α while depurating the feedback coefficients from π^*.[6] On the contrary, no additional restrictions are needed for our hypothesis testing strategy on symmetric central bank preferences.

4.1 Baseline estimates

Table 1 reports the GMM estimates of the feedback coefficients as well as the relevant parameters on asymmetric behavior for the baseline case corresponding to GDP deflator inflation and CBO output gap. The policy preferences γ and α, which feature a nonsymmetric specification of the central bank objective, have the expected signs and they are marginally significant throughout the table with the exception of α for the second subsample. A remarkable shift in output gap asymmetries is observed between the pre-79 (first column) and the post-79 (second column) tenures in that γ moves to an absolute value bigger than one in the latter period (we will return on the third column in the following subsection). All feedback coefficients but the one on squared inflation in the second subsample are significantly different from zero and they allow us to perform the crucial hypothesis testing of our analysis.

The first row of Table 2 shows that the null hypothesis of linearity for the reaction function, which corresponds to the joint null of symmetry for the central bank preferences, is strongly rejected over the two periods with the Wald statistics being much larger than the relevant critical value[7] (disregard the last two columns for the time being). It is important to stress that the validity of our hypothesis testing strategy relies on the fact that under the null of linearity the remainder of the Taylor expansion is zero. Under the alternative however this does not hold true anymore and therefore the error term might turn out to be correlated with the regressors. While this suggests some caution about interpreting the point estimates, as long as a first order Taylor expansion is accepted as providing a reasonable approximation such a bias would be fairly small.

[6] Indeed, under asymmetric central bank preferences the inflation conditional mean may be either below or above the inflation target depending, inter alia, on the relative size of the policy parameters on inflation and output gaps (see Nobay and Peel, 1998, Ruge-Murcia, 2002a and 2002b, and Cukierman, 2001, for a formal derivation of this novel inflation bias). However, under the null of symmetric preferences such a bias disappears (i.e. average inflation equals inflation target), thereby preserving the validity of our hypothesis testing strategy.

[7] The results are not affected by using F-versions of the Wald statistics as opposed to the χ^2 variants which may be oversized in small samples.

4.1.1 Comparison to other empirical estimates and subsample stability

It is useful at this point to compare our results with the empirical estimates obtained in other recent studies in order to gauge their plausibility. In the pre-Volcker period, Clarida, Galì and Gertler (2000) estimate a forward-looking linear reaction function with an ad-hoc adjustment mechanism and find values of 0.83 for the coefficient on inflation (s.e.= 0.07) and 0.27 for the coefficient on output (s.e.= 0.08). The significant difference comes from the output gap parameter which suggests that neglecting the quadratic term, which enters our empirical specification with a negative sing, introduces a downward bias in the linear estimate. Turning to a nonlinear specification, Dolado, Maria-Dolores and Ruge-Murcia (2002) use a Clarida, Galì and Gertler-type rule augmented with a generated regressor for the conditional variance of inflation and estimate the marginal impact of inflation at 1.14 (s.e.= 0.12) and the one of output at 0.31 (s.e.= 0.11). In addition to the downward bias for the output level, their findings suggest that neglecting the quadratic terms introduce also an upward bias for the coefficient on inflation level, which is consistent with the positive estimate we get for the squared inflation. The picture is completed by the post-Volcker estimates. Both coefficients on inflation level and output level display differences of expected sign relative to the values reported in Clarida, Galì and Gertler (2000), who find in particular that the output parameter is not statistically different from zero over the post-82 sample, while they are consistent with those provided by Dolado, Maria-Dolores and Ruge-Murcia (2002). Lastly, we line up with early contributions in that the coefficient on the inflation level becomes bigger than one moving from the pre- to the post-Volcker era.

It should be noticed that as no lagged policy rate terms enter the forecast-based nonlinear policy rule (7), our estimates should be interpreted as long-run responses. Interestingly, they can also be interpreted as short-run coefficients if one is willing to consider monetary policy inertia as an illusion reflecting the episodic unforecastable persistent shocks that central banks face. In this vein, Rudebusch (2002) use our baseline measure of inflation and output gap over the period 1987:4-1999:4 to estimate with instrumental variables a linear forward-looking US monetary policy rule which is all alike equation (7) but the squared variables. In order to make our estimates directly comparable with those in Rudebusch (2002), we re-evaluate the nonlinear policy rule over the Greenspan sample. In so doing, we can assess the robustness of our results to subsample stability as well.

The estimates are reported in the third column of Table 1 and they reinforce the findings obtained so far. Indeed, not only all parameters are statistically different from zero and take the expected sign but also the coefficient on inflation asymmetries becomes now significant. The value of γ keeps growing over time confirming a significant shift in the Fed output preferences across the pre- and post-Volcker tenures, while the Wald statistics rejects the null of symmetric preferences with a value of 83.883.

Turning to the comparison to other empirical estimates, we observe that neglecting the squared variables introduces once more a significant omitted variable bias. In particular, the estimates provided in Rudebusch (2002) read the parameter on inflation levels at 2.00 (with s.e. = 0.66) and the one on output gap levels at 0.39 (with s.e. = 0.24). By contrast, the results we report in Table 1 shows that the point estimate of c_1 is significantly reduced whenever the policy rule incorporates a squared inflation term whereas c_2 becomes higher whenever a squared output gap term is allowed for. While part of the differences can be attributed to both the longer sample and the non-annualized quarterly inflation we use, our results seem to suggest a significant role for the nonlinear components of US monetary policy rules. Such a conclusion mirrors the estimates by Cukierman and Muscatelli (2002) who, employing an ad-hoc specification for the reaction function over a slightly longer sample, find a positive and significant coefficient for the nonlinear inflation term and a negative and significant coefficient for the nonlinear output component.

4.2 Robustness analysis

We assess now in turn the robustness of our findings to alternative measures of inflation and output gap. Table 3 reports the estimates obtained with GMM using, everything equals, the commodity price changes as measure of inflation. All preference parameters on asymmetries have the expected sign. In analogy to the results in Table 1, the coefficient γ on output gap displays a substantial growth over time in absolute values, although it is less pronounced than in the case of GDP deflator inflation. All reaction function coefficients are significant but c_4 in the pre-Volcker period, which nevertheless does not translate in values of γ and α inconsistent with an asymmetric objective. Moreover, the estimates in Table 3 deliver the Wald statistics displayed in the second row of Table 2. The null hypothesis of a linear policy rules is once more strongly rejected over the two samples implying that central bank preferences are indeed asymmetric.

Lastly, we re-estimate the policy rule(7) using GDP deflator inflation and detrended output as measures of the state variables where the latter is obtained as the residuals from regressing output on a constant and a quadratic trend. The results are shown in Table 4 and they mirror those of previous tables over the pre-Volcker period. In particular, significant values of the feedback coefficients map into significant values of the asymmetric parameters, which once more display the expected signs. Turning to the post-79 subsamples, a different picture emerges. While the preference parameter γ is still negative and significant and confirms in absolute values its growing path over time, the coefficient α on inflation asymmetries takes now a negative and significant value. However, the relevance of the latter result has to be weighted by the fact that detrended output may be not an appropriate measure of the business cycle.[8]

4.3 Interest rate smoothing

We complete the empirical analysis by introducing an interest rate smoothing argument into the nonlinear policy rule. Several studies have shown that the Fed tends to smooth changes in interest rates and the omission of some lagged policy rate term may turn out to be responsible for a seemingly nonlinear behavior. Rather than imposing some ad-hoc adjustment mechanism, we derive the nonlinear monetary policy rule in a framework where policy makers have an explicit objective to smooth policy rates.[9] Accordingly, we write the period loss function as:

$$L_t = \frac{e^{[\alpha(\pi_t - \pi^*)]} - \alpha(\pi_t - \pi^*) - 1}{\alpha^2} + \lambda \left[\frac{e^{(\gamma y_t)} - \gamma y_t - 1}{\gamma^2} \right] + \frac{\mu'}{2}(i_t - i_{t-1})^2 \tag{8}$$

The coefficients μ' represent the central bank aversion towards interest rate fluctuations and unlike the specification (4), which expresses a concern to reduce the variability of interest rate *level*s, it specifies a concern with the variability of *changes.*

Following the identification strategy of Section 3, we first minimize with respect to i_t the criterion (3) and (8) under the constraints provided by (1) and (2), and then we take a Taylor series expansion of the resulting Euler equation around $\alpha = \gamma = 0$. Solving for the control variable, we obtain an augmented quadratic policy rule:

$$i_t = c_{onst} + \frac{1}{1+\delta} i_{t-1} + \frac{\delta}{1+\delta} i_{t+1} + d_1 \pi_t + d_2 y_t + d_3 (\pi_t)^2 + d_4 (y_t)^2 + v'_t \tag{9}$$

which is linear in the coefficients:

$$c_{onst} \equiv -d_1 \pi^* - d_3 (\pi^*)^2$$

$$d_1 \equiv \frac{k\varphi}{\mu'(1+\delta)} - 2 d_3 \pi^*$$

$$d_2 \equiv \frac{\lambda\varphi}{\mu'(1+\delta)}$$

[8]Indeed, as argued by McCallum and Nelson (1999), not only the fitted trend displays a significantly more volatile path than the congressional budget office time series, especially in the post-Volcker period, but also it does not capture the conventional wisdom that output has been unusually high relative to potential in the mid-90s.

[9]Whether this smoothing should enter or not the central bank objective function is beyond the scope of this paper. An interesting explanation of 'why yes' is provided by Woodford (2002, Ch. 7) who uses an optimal delegation argument to show that the appointment of a central banker with an alternative objective relative to the true social one may be welfare improving.

$$d_3 \equiv \frac{\alpha k \varphi}{2\mu' (1+\delta)}$$

$$d_4 \equiv \frac{\lambda \varphi \gamma}{2\mu' (1+\delta)}$$

and whose error term is defined as

$$v'_t \equiv - \left\{ \begin{array}{c} \frac{\delta}{1+\delta} (i_{t+1} - E_{t-1} i_{t+1}) + d_1 (\pi_t - E_{t-1}\pi_t) + d_2 (y_t - E_{t-1} y_t) + \\ +d_3 \left[\pi_t^2 - E_{t-1} (\pi_t)^2\right] + d_4 \left[y_t^2 - E_{t-1} (y_t)^2\right] \end{array} \right\} + \frac{e_t}{\mu' (1+\delta)}$$

The term in curly brackets is a linear combination of forecast errors and therefore v'_t is orthogonal to any variable in the information set available at time $t-1$.

Equation (9) is all alike the policy rule (7) but the one lead-one lag smoothing components and therefore it can be used to evaluate whether the squared variables capture a genuine nonlinear behavior or rather they mimic some omitted lagged policy rate.

The GMM estimates using the baseline measure of inflation and output gap are reported in Table 5. The set of instruments is made up of four lags of GDP inflation, CBO output gap and their squared values, the fed funds rate and CPI inflation. The discount factor, δ, is restricted to 0.98 as the unrestricted estimate is rather imprecise; the imposed value does not affect the overall fit of the model. All feedback coefficients are small in absolute value because the sluggish components capture most of the policy rate behavior. Nevertheless, they are significant and translate into meaningful asymmetric preference estimates. On the one hand, the deep parameter on output is always negative and statistically different from zero, and displays a growing path over time. On the other hand, the asymmetric coefficient on inflation is always positive and, consistently with the baseline estimates, it is significant only over the pre-Volcker era. Moreover, the last row of Table 2 shows that the null of symmetric preferences is once again strongly rejected over both samples. This finding suggests that squared inflation and squared output gap capture a genuine nonlinear behavior and therefore they have a place on their own right in US monetary policy rules.[10]

4.4 Discussion

A number of different results stem from the estimates reported above. On the one hand, the preference parameter on output asymmetries, whose identification does not require any additional assumption on the model coefficients, takes always negative and significant values. Such an evidence is robust across alternative measures of inflation and output gaps as well

[10]Surico (2002) shows that these results are robust to both a backward-looking structure of the economy à la Rudebusch and Svensson (1999) and to a nonparametric specification of the central bank loss function. In particular, the nonparametric estimates suggest that the nonlinearities found in US monetary policy rules are consistent with an objective function that is both nonquadratic and asymmetric.

as over the three subsamples being consistent with an asymmetric specification of the central bank objectives. In addition, the significant increase of γ over time appears to be a robust feature of the data corroborating the view that a regime shift has occurred between the pre- and the post-1979 Chairmen. On the other hand, the estimates on the inflation preference parameter, α, are in most cases significantly different from zero and take a positive sign.

These findings enrich the picture provided in Clarida, Galì and Gertler (2000) and indicate that the nonlinear components have significantly characterized the policy stance of the Fed, especially after 1983. Indeed, equation (7) makes clear that under asymmetric preferences the interest rate responses are not anymore time invariant but rather they depend on the *level* of inflation and output gaps. Accordingly, large deviations of the target variables require vigorous movements of policy rates whereas small deviations require only limited changes. This point is illustrated in Figure 2 and 3 which compare our baseline estimates with those obtained using a linear specification of the policy rule (i.e. forcing c_3 and c_4 to be zero). The vertical axis displays the interest rate responses (relative to target) implied by the estimates of the two rules while the horizontal axis reports the actual movements over the Greenspan sample for inflation and output gaps respectively. The graphs show not only that US monetary policy has been significantly nonlinear and asymmetric but also that large gaps have been penalized more than small gaps with the exception of the negative deviations of inflation.

Furthermore, Figure 3 shows that only according to the nonlinear policy rule interest rates have been lowered in response to both positive and negative output gaps with the former mostly corresponding to the period 1997:1-2001:1. Interestingly, this observation is consistent with the view that the Fed has taken advantage of the benign macroeconomic conditions of the late 90s to accommodate the favorable supply shocks that the 'New Economy' has brought about.[11] It should be noticed that the reverse U-shape policy response displayed in Figure 3 is a feature of the post-Volcker era only since over the first sample the relative size of c_2 over c_4 is considerably higher in absolute value than its post-79 counterpart (see Table 1). Indeed, while the squared term translates into a significant asymmetric behavior also over the pre-79 sample, the coefficient on levels, which is now bigger than one, makes the nonlinear relation between interest rates and output gap positive over the entire domain.

Lastly, a comparison of α and γ across samples shows that output asymmetries have become relatively more pronounced during the post-Volcker tenures. While the existence of highly asymmetric preferences on output helps rationalizing the sequences of downwards movements

[11] Notice that by using the (CBO) output gap as opposed to the unemployment rate we have implicitely specified a time-varying target for the stabilization of the business cycle. Moreover, since the potential output series is constructed upon revised data, the argument that a shift in the NAIRU estimates may have warranted such a seemingly nonlinear behavior does not apply here.

through which the Fed has considerably cut interest rates during 2001, it also supports the notion of a new source of inflation bias. Indeed, Cukierman (2001) demonstrates that monetary authorities can end up generating a resurgence in inflation expectations (even targeting output to potential) if they are perceived by the private sector as reacting more aggressively to output contractions than to output expansions.

Altogether, these findings suggest that rationalizing the asymmetric policy preferences on inflation and output gaps beyond the simple ad-hoc linex specification we have assumed here is crucial to deepen our knowledge of the postwar US monetary policy stances.

5 Conclusions

The contribution of this paper is twofold. At the theoretical level it derives a general closed-form solution for interest rate rules when central bank preferences are asymmetric in both inflation and output gaps, and the monetary transmission mechanism is New-Keynesian. The specification of the policy objectives nests the quadratic form as a special case and therefore it translates into a *potentially* nonlinear monetary policy rule. This modeling feature forms the basis of our hypothesis testing strategy for the presence of asymmetric preferences as it allows to reversely engineer potential evidence of nonlinearities in the reaction functions into evidence of asymmetries in the policy objectives.

At the empirical level this paper shows that US monetary policy can be characterized by a nonlinear policy rule during both the pre- and post-Volcker eras and that this nonlinearity has been more prominent over the second sample. Moreover, our identification method indicates that the preferences of the Fed have been highly asymmetric in both inflation and output gaps, though the asymmetries on the latter have become relatively more pronounced during the post-79 tenures. These findings are robust across alternative measures of inflation and output gap as well as to an interest rate smoothing goal in the central bank loss function.

Altogether, this paper develops a formal hypothesis testing for the presence of asymmetric preferences. As the null of the test features the conventional quadratic form used in earlier contributions, our results suggest some caution about using symmetric loss functions as a guide to policy analysis. Indeed, very promising strands of literature have recently emphasized that labor market frictions and heterogeneity in portfolio holdings can make the welfare costs of unemployment and inflation asymmetric. Along these lines, a stimulating avenue for future research is to derive an utility-based welfare function within richer models of the business cycle in order to provide a formal microfoundation for an asymmetric central bank objective.

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Table 1: Reaction Function and Policy Preferences Estimates
- baseline measures of inflation and output gap -

	1960:1 – 1979:2	*1982:4 2001:4*	*1987:3 – 2001:4*
const	4.214 (0.241)	7.145 (0.293)	6.305 (0.235)
c1	0.853 (0.061)	1.742 (0.185)	1.213 (0.191)
c2	1.108 (0.095)	0.621 (0.101)	0.549 (0.077)
c3	0.093 (0.023)	0.047 (0.203)	0.475 (0.174)
c4	-0.138 (0.017)	-0.455 (0.078)	-0.474 (0.052)
π^*	4.432 -	2.585 -	2.423 -
γ	-0.249 (0.001)	-1.464 (0.113)	-1.725 (0.137)
α	0.218 (0.004)	0.054 (0.055)	0.784 (0.153)
J(20)	8.947	9.299	6.111

Standard errors using a four lag Newey-West covariance matrix are reported in brackets. Inflation is measured in GDP deflator index and output gap is obtained from the CBO. Four lags of gdp inflation, squared gdp inflation, cbo output gap, squared cbo output gap, the fed funds rate and commodity price inflation are included as instruments. 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.

Table 2: Testing for symmetric policy preferences
- Wald-*type* test of the joint null hypothesis α=γ=0 -

W(2)	*60:1–79:2*	*82:4-01:4*
Baseline Estimates	72.400	34.383
Cpi Inflation	39.731	33.510
Detrended Output gap	95.844	73.214
Interest Rate Smoothing	46.425	32.529

W(*n*) is the Wald test for *n* parameter restrictions, which is distributed as a $\chi^2(n)$ under the joint null hypothesis c4=c5=0. The latter is equivalent to the original null of symmetric central bank preferences, γ=α=0. The jont null is rejected at the 1% significance level whenever W(2)>9.210 and at the 5% whenever W(2)>5.991.

Table 3: Reaction Function and Policy Preferences Estimates
- alternative measure of inflation -

	1960:1 – 1979:2	*1982:4 2001:4*
const	4.898 (0.100)	6.267 (0.207)
c1	0.648 (0.019)	1.095 (0.221)
c2	0.267 (0.026)	0.543 (0.084)
c3	0.027 (0.005)	0.117 (0.073)
c4	-0.007 (0.008)	-0.160 (0.075)
π^*	4.432 -	2.585 -
γ	-0.050 (0.004)	-0.590 (0.100)
α	0.082 (0.001)	0.214 (0.022)
J(20)	10.980	10.123

Standard errors using a four lag Newey-West covariance matrix are reported in brackets. Inflation is measured in commodity price index and output gap is obtained from the CBO. Four lags of cpi inflation, squared cpi inflation, cbo output gap, squared cbo output gap, the fed funds rate and gdp deflator inflation are included as instruments. 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.

Table 4: Reaction Function and Policy Preferences Estimates
- alternative measure of output gap -

	1960:1 – 1979:2	*1982:4 2001:4*
const	4.787 (0.143)	7.694 (0.254)
c1	0.681 (0.039)	1.417 (0.185)
c2	0.245 (0.026)	0.411 (0.038)
c3	0.130 (0.013)	-0.364 (0.150)
c4	-0.035 (0.018)	-0.215 (0.026)
π^*	4.432 -	2.585 -
γ	-0.290 (0.021)	-1.048 (0.023)
α	0.382 (0.002)	-0.514 (0.029)
J(20)	8.260	8.879

Standard errors using a four lag Newey-West covariance matrix are reported in brackets. Inflation is measured in GDP deflator index and output gap is obtained from regressing output on a constant and a quadratic trend. Four lags of gdp inflation, squared gdp inflation, detrended output gap, squared detrended output gap, the fed funds rate and commodity price inflation are included as instruments. 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.

Table 5: Reaction Function and Policy Preferences Estimates
- interest rate smoothing -

	1960:1 – 1979:2	*1982:4 2001:4*
const	0.030 (0.048)	-1.634 (0.289)
d1	-0.060 (0.010)	-0.171 (0.082)
d2	0.088 (0.012)	-0.186 (0.043)
d3	-0.016 (0.005)	-0.031 (0.043)
d4	-0.028 (0.005)	0.084 (0.015)
π^*	4.432 -	2.585 -
γ	-0.645 (0.011)	-0.907 (0.098)
α	0.537 (0.043)	0.362 (0.437)
J(20)	11.201	10.313

Standard errors using a four lag Newey-West covariance matrix are reported in brackets. Inflation is measured in GDP deflator index and output gap is obtained from the CBO. Four lags of gdp inflation, squared gdp inflation, cbo output gap, squared cbo output gap, the fed funds rate and commodity price inflation are included as instruments. 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. W(*n*) corresponds to the Wald statistics for *n* coefficient restrictions which is distributed as a $\chi^2(n)$ under the joint null hypothesis d6=d8=0. The discount factor, δ, has been imposed to 0.98.

Figure 1a: Preference over Inflation Stabilization

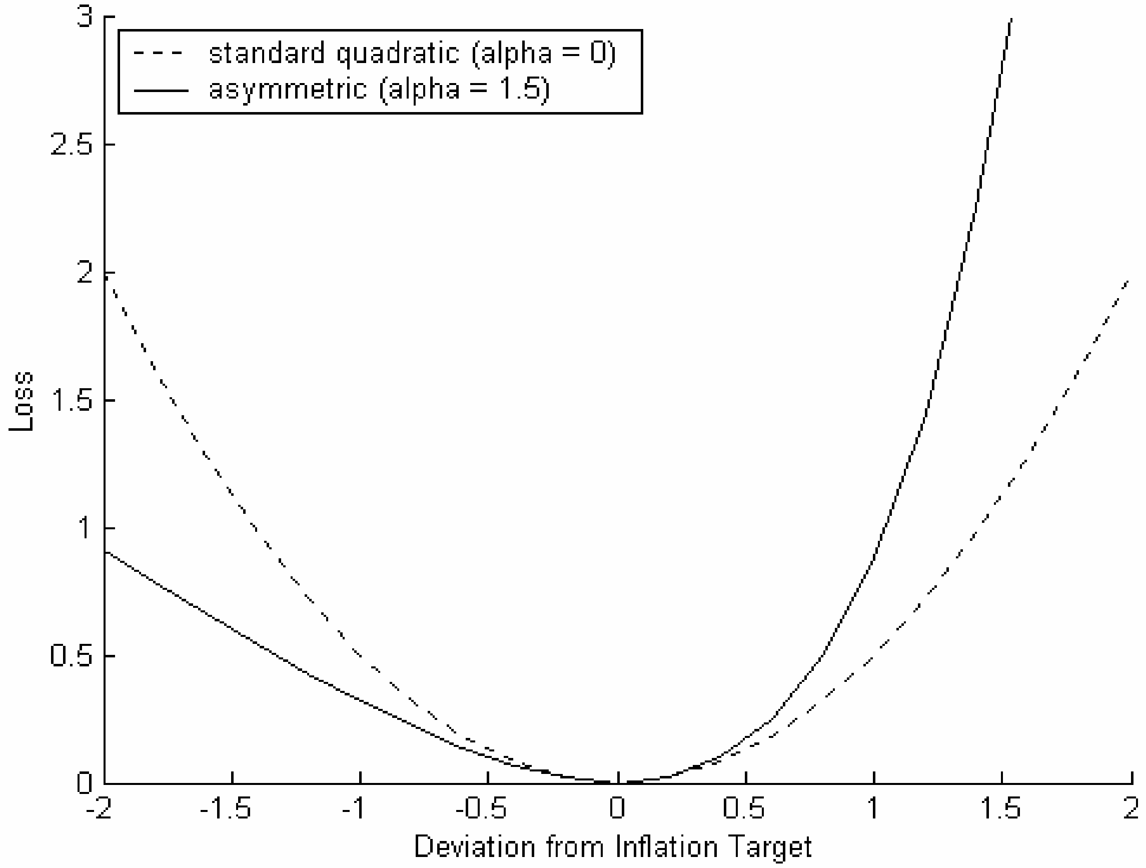


Figure 1b: Preference over Output Stabilization

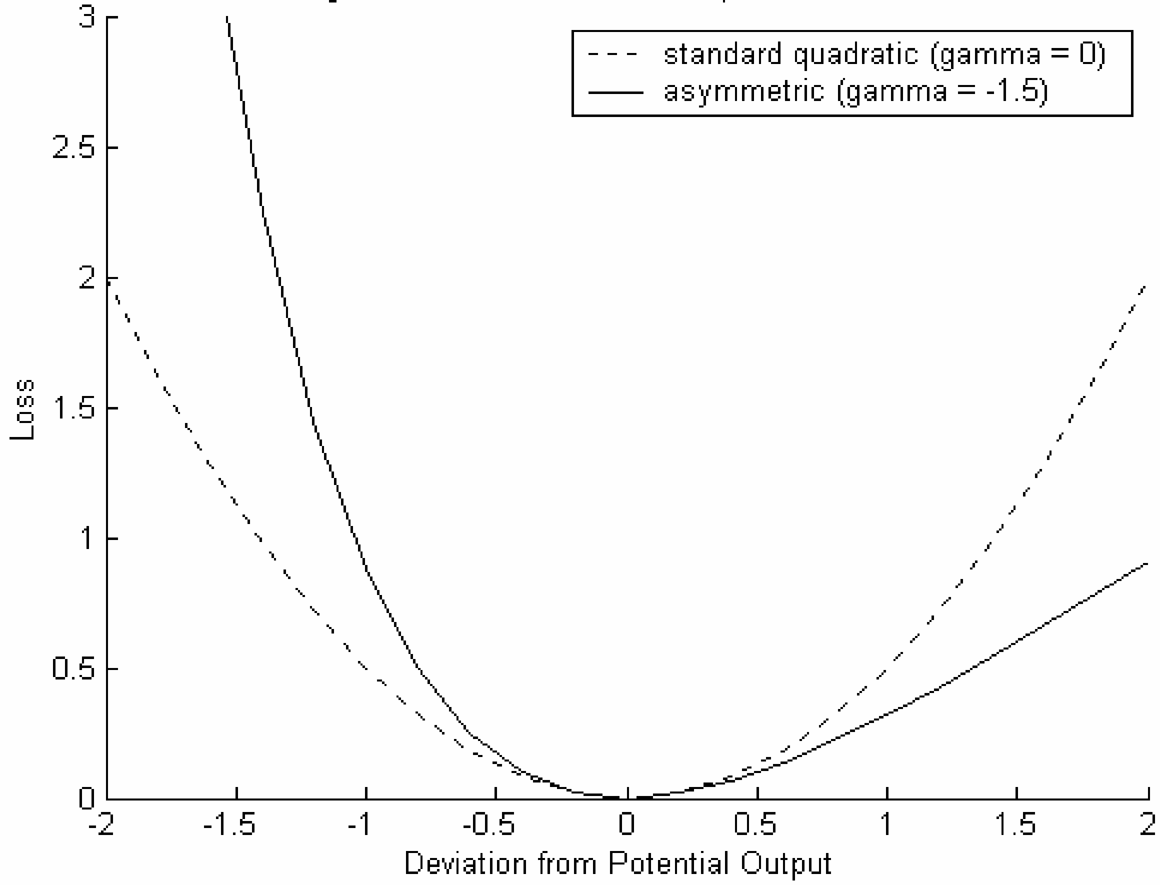
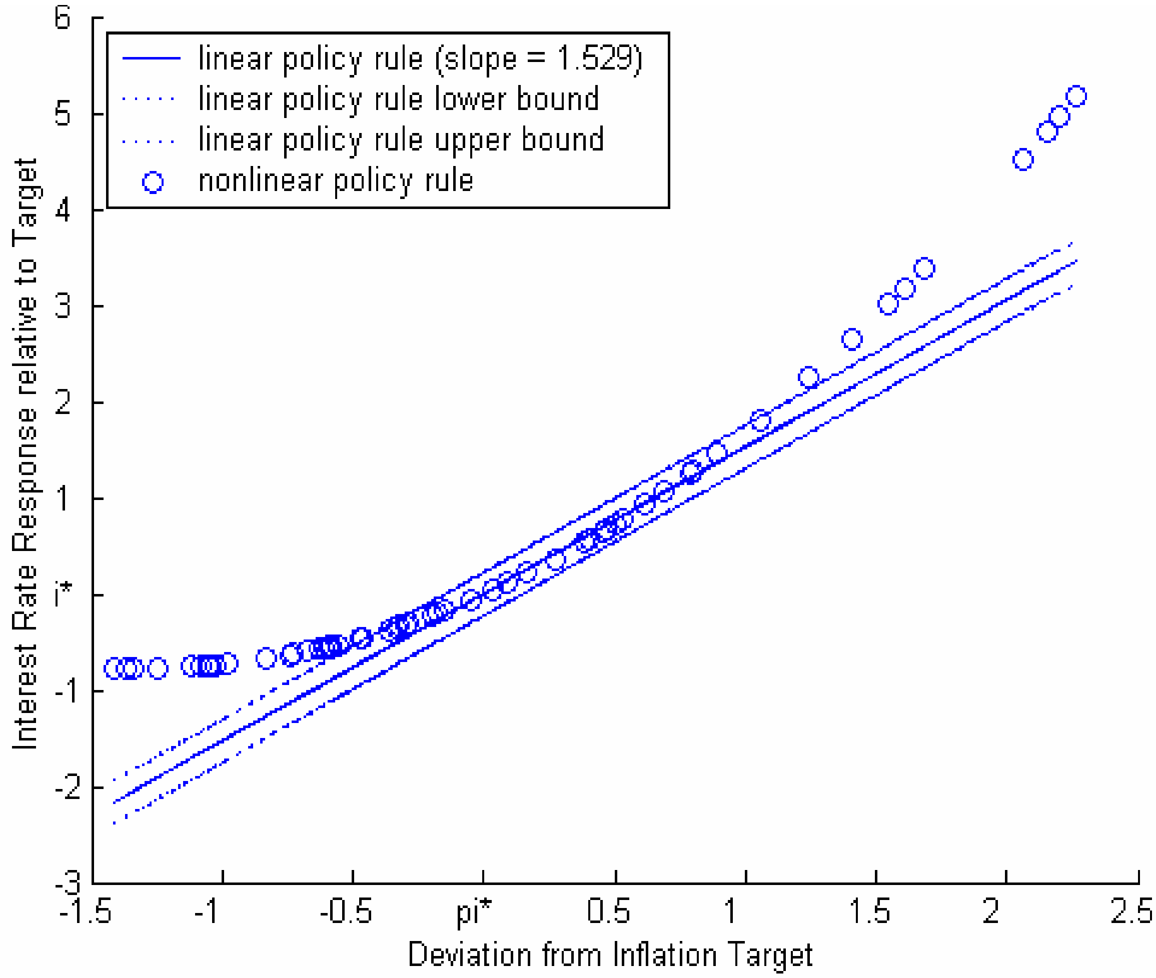
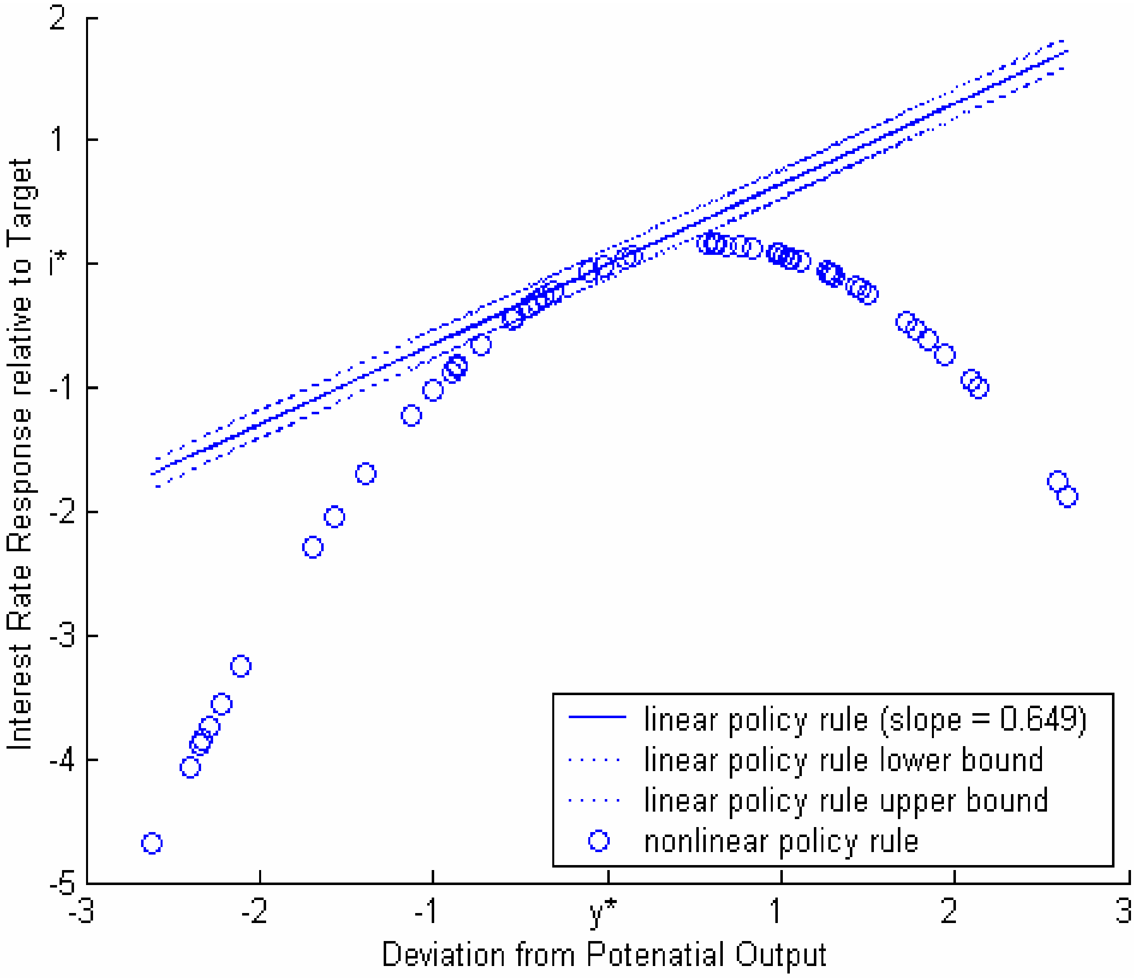


Figure 2: The Policy Response to Inflation over the Greenspan era



The linear policy rule, $i_t = const + c_1(\pi_t - \pi^*) + c_2 y_t + v_t$, has been estimated with GMM using all instruments employed for the nonlinear rule but the squared variables. The estimates are const = 5.694 with s.e. = 0.128, c1 = 1.529 with s.e. = 0.112 and c2 = 0.694 with s.e. = 0.057. The deviation from inflation target refers to the actual values of GDP deflator index inflation observed over the period 1987:3 – 2001:4 using the sample mean, 2.423, as the target value.

Figure 3: The Policy Response to Output Gap over the Greenspan era



The linear policy rule, $i_t = const + c_1(\pi_t - \pi^*) + c_2\, y_t + v_t$, has been estimated with GMM using all instruments employed for the nonlinear rule but the squared variables. The estimates are const = 5.694 with s.e. = 0.128, c1 = 1.529 with s.e. = 0.112 and c2 = 0.694 with s.e. = 0.057. The deviation from potential output refers to the actual values of the Congressional Budget Office series observed over the period 1987:3 – 2001:4

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