Targets, Zones and Asymmetries: A Flexible Nonlinear Model of Recent UK Monetary Policy*

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Abstract

We estimate a flexible model of the behaviour of UK monetary policymakers in the era of inflation targeting based on a new representation of policymaker's preferences. This enables us to address a range of issues that are beyond the scope of the existing literature. We find a complex relationship between interest rates and inflation: interest rates are passive when inflation is close to the target but there is an increasingly vigorous response as inflation deviates further from the target. We also find that the response to the output gap is linear and find no evidence of a nonlinear Phillips curve.

JEL: C51; C52; E52; E58
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1) Introduction

The inflation targeting policy framework that has been used in the UK since late 1992 permits limited fluctuations of inflation around the inflation target. The toleration of small deviations of inflation from the target suggests that policymakers may exhibit "zone-like" behaviour by responding aggressively to inflation when inflation is some way from the target but by responding more passively when inflation is in a zone around the inflation target. In addition, it has been suggested that policymakers may exhibit "asymmetric" behaviour by responding more vigorously when inflation is above the target than when below.

Analysis of the behaviour of policymakers therefore requires a model of monetary policy that allows for zone-like and asymmetric behaviour. In this paper we derive and estimate a nonlinear optimal monetary policy rule that does this. In doing so, we build on earlier work. Many models of monetary policy use the Taylor rule (Taylor, 1993). This assumes a constant proportional response of interest rates to inflation and the output gap and thus has neither zone-like nor asymmetric behaviour. Asymmetric behaviour can be derived from models in which the preferences of policymaker's are described by the linear exponential (linex) function or from models in which the aggregate supply function is convex (eg Chadha and Schellekens, 1998, Schaling, 1999, Ruge-Murcia, 2003, Kim, Osborn and Sensier, 2005, Dolado, Maria-Dolores and Ruge-Murcia 2004, Surico, 2003 and Nobay and Peel, 2003). However these models do not imply zone-like behaviour. Zone-like behaviour can be derived from models in which policymakers have zone-quadratic preferences, being indifferent to inflation in a zone around the inflation target but having quadratic preferences outside the zone (Orphanides and Weiland, 2000). This model, however, does not imply asymmetric behaviour.

We propose a new representation of policymaker's preferences, based on a simple generalisation of the Linex function. We combine this with a convex aggregate supply curve and a conventional linear model of aggregate demand to derive a flexible nonlinear model of optimal monetary policy that allows for both zone-like and asymmetric behaviour. Estimating our model using data for the UK since 1992, we find strong evidence of zone-like behaviour but weaker evidence of asymmetric behaviour. Estimates of our preferred model imply that there is essentially no response of interest rates to inflation when inflation is between 2.3%-2.7% and that the Taylor principle that real interest rates should increase when inflation rises is only satisfied when inflation is less than 2.1% or more than 2.9%. Larger deviations of inflation lead to an increasingly vigorous response as policymakers seek to defend the boundaries of the inflation target. In contrast to this complex response to inflation, we find that the response to the output gap is linear. We also find no evidence of a convex supply curve.

The remainder of the paper is structured as follows. We discuss our model of policymakers' preferences in section 2); we derive our model of optimal monetary policy in section 3), discuss our empirical methodology in section 4), present our estimates in section 5) and offer conclusions in section 6).

2) Policymakers' Preferences

We model the preferences of policy makers using the loss function

(1) $$L = \frac{e^{\alpha_\pi(\pi-\pi^*)^{\beta_\pi}} - \alpha_\pi(\pi-\pi^*)^{\beta_\pi} - 1}{\beta_\pi \alpha_\pi^2} + \lambda \frac{e^{\alpha_y y^{\beta_y}} - \alpha_y y^{\beta_y} - 1}{\beta_y \alpha_y^2} + \frac{\mu}{2}(i - i^*)^2$$

where π is the inflation rate, π^* is the inflation target (we refer to $\pi-\pi^*$ as the inflation gap), y is the output gap, i is the nominal interest rate and i* is the equilibrium interest rate; λ is the relative weight on output and μ is the relative weight on the interest rate. This is a flexible loss function that can exhibit different combinations of asymmetric and zone-like preferences depending on the values of α_π, α_y, β_π and β_y. β_π and β_y are integers that determine the asymmetry and zone-like properties of the loss function while α_π and α_y are parameters that affect the slope of the loss function and the sign of any asymmetry.

This loss function generalises the familiar quadratic loss function, which is obtained when $\alpha_\pi \to 0, \alpha_y \to 0$ and $\beta_\pi = \beta_y = 1$. The function also generalises the asymmetric Linex loss function, which is obtained when $\beta_\pi = 1$ and $\beta_y = 1$. The degree of asymmetry in this case is captured by α, where $\alpha_\pi > 0$ ($\alpha_y > 0$) implies that policymakers are more sensitive to a positive inflation gap (output gap). This is illustrated in figure 1a).

If $\beta_\pi > 1$, there are zone-like preferences over the inflation gap while $\beta_y > 1$ implies zone-like preferences over the output gap. There is very little loss from values of the inflation or output gaps that lie within a zone, the width of which is an increasing function of β_π or β_y, with increasing loss outside the zone. The loss function outside the zone is symmetric if the β parameters are even numbers $(\beta_\pi, \beta_y = 2,4,6,....)$. In this case, the slope of the loss function is an increasing function of the α parameters. The loss function outside the zone is asymmetric if the β parameters are odd numbers greater than 1 $(\beta_\pi, \beta_y = 3,5,7,....)$. If so, the α parameters affect both the slope of the loss function and the sign of the asymmetry as there is greater loss for positive values of the inflation or output gaps if $\alpha_\pi > 0$ or $\alpha_y > 0$. Figures 1b) and 1c) illustrate zone-symmetric and zone-asymmetric preferences. Of course, there is no reason why β_π should equal β_y, so the response to the inflation and output gaps may have different functional forms. Table 1 summarises the possible configurations of the loss function.

3) Optimal Monetary Policy

We assume that aggregate demand is given by

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

where ε_t^d is an i.i.d demand shock. This is a standard forward-looking demand relationship (which can be derived from an Euler equation for consumption, McCallum and Nelson, 1999) in which the output gap is a decreasing function of the real interest rate. Aggregate supply is

(4) $$\pi_t = \frac{ky_t}{1 - k\tau y_t} + \theta E_t \pi_{t+1} + \varepsilon_t^s$$

where ε_t^s is an i.i.d supply shock. If $\tau = 0$ this is a standard New-Keynesian aggregate supply relationship (Clarida et al, 1999) that can be derived, for example, from the Calvo (1983) model of staggered price adjustment. If $\tau > 0$, the aggregate supply relationship is convex, so inflation is more sensitive to the output gap when the output gap is higher (Schaling, 1999, Dolado et al 2004).

We assume that monetary policymakers choose interest rates at the beginning of each period, before the realisation of the shocks. Their optimisation problem is therefore

(5) $$\mathrm{Min}_{\{i_t\}} \; E_{t-1} \sum_{j=0}^{\infty} \delta^j L_{t+j}$$

subject to (3) and (4) and where δ is the discount factor. Assuming that policymakers cannot commit to future values of the interest rate, optimal policy under discretion simplifies to a sequence of static optimisation problems. At each period, therefore, policymakers chooses the interest rate to minimise

(6) $$E_{t-1}\frac{e^{\alpha_\pi(\pi-\pi^*)^{\beta_\pi}}-\alpha_\pi(\pi-\pi^*)^{\beta_\pi}-1}{\beta_\pi\alpha_\pi{}^2}+\lambda E_{t-1}\frac{e^{\alpha_y y^{\beta_y}}-\alpha_y y^{\beta_y}-1}{\beta_y\alpha_y{}^2}+\frac{\mu}{2}(i-i^*)^2+F_t$$

subject to

(7) $$\pi_t=\frac{ky_t}{1-k\tau y_t}+f_t$$

and

(8) $$y_t=-\rho i_t+g_t$$

where $F_t=E_{t-1}\sum_{\upsilon=1}^{\infty}\delta^{\upsilon}L_{t+\upsilon}$, $f_t=\theta E_t\pi_{t+1}+\varepsilon_t{}^s$, $g_t=E_t y_{t+1}+\rho E_t\pi_{t+1}+\varepsilon_t{}^d$. Solving this and assuming, for tractability (following Surico, 2004), that expectations are exogenous, the optimal monetary policy rule is

(9) $$\hat{i}_t=i^*+\frac{k\rho}{\mu(1-k\tau y_t)^2}E_{t-1}\left((\pi-\pi^*)^{\beta_\pi-1}\frac{e^{\alpha_\pi(\pi-\pi^*)^{\beta_\pi}}-1}{\alpha_\pi}\right)+\frac{\lambda\rho}{\mu}E_{t-1}\left(y^{\beta_y-1}\frac{e^{\alpha_y y^{\beta_y}}-1}{\alpha_y}\right)$$

where $\hat{i}$ is the optimal interest rate. This is a general nonlinear monetary policy rule that exhibits both asymmetric and zone-like responses to the inflation and output gaps.

There are a number of interesting special cases of (9). When $\beta_\pi = \beta_y = 1$ and α_π, α_y and τ all tend to zero, the policy rule collapses to a linear Taylor rule (Taylor, 1993)

(10) $$\hat{i}_t = i^* + \frac{k\rho}{\mu} E_{t-1}(\pi - \pi^*) + \frac{\lambda\rho}{\mu} E_{t-1} y$$

When $\beta_\pi = \beta_y = 1$, α_π and α_y tend to zero and we approximate around $\tau = 0$ we obtain

(11) $$\hat{i}_t = i^* + \frac{k\rho}{\mu} E_{t-1}\left(\pi_t - \pi^*\right) + \frac{\lambda\rho}{\mu} E_{t-1} y_t + \frac{2k^2\tau\rho}{\mu} E_{t-1}\left(\left(\pi_t - \pi^*\right) y_t\right)$$

which is similar to models that allow for a nonlinear Phillips curve that have been estimated by Kim, Osborn and Sensier (2005), Dolado, Maria-Dolores and Ruge-Murcia (2004) and Dolado, Maria-Dolores and Naveira (2005).

The response of monetary policy to the inflation gap is asymmetric if $\beta_\pi = 1$ and the response to the output gap is asymmetric if $\beta_y = 1$. However there is no zone-like behaviour. Figure 2a) shows this case. There is a stronger response to positive values of the gaps if α_π or α_y is positive. If $\alpha_\pi > 0$, for example, interest rates are increasingly responsive to inflation if $\pi > \pi^*$ but not if $\pi < \pi^*$, since policymakers are sensitive to high inflation but relatively indifferent to low inflation. Although this case does not seem well suited to the UK case where policymakers must ensure inflation cannot rise too high or fall too low, it may be appropriate for one-sided inflation targets that only prescribe an upper bound for inflation. The situation is reversed if $\alpha_\pi < 0$, where a greater sensitivity to low inflation implies a stronger response if $\pi < \pi^*$.

Figure 2b) depicts the policy rule if $\beta_\pi = 2$ or $\beta_y = 2$. There is zone-like behaviour but no asymmetry. There is a zone within which interest rates do not respond to non-zero values of the inflation or output gaps, so policymakers tolerate small deviations from the inflation or output targets, but there is an increasingly aggressive response to larger misalignments. The response of interest rates outside the zone is symmetric and is stronger for larger (absolute) values of α. Figure 2c) depicts the monetary policy rule when $\beta_\pi = 3$ or $\beta_y = 3$. In this case there is both asymmetry and zone-like behaviour. There is again a zone within which interest rates are unresponsive and an increasingly aggressive response outside the zone. However in this case, the response outside the zone is asymmetric and displays a stronger response to positive values of the gap if α_π or α_y are positive. The policy rule if $\beta_\pi = 4$ or $\beta_y = 4$ is similar to that for $\beta_\pi = 2$ or $\beta_y = 2$ but in this case the zone is wider and the response of interest rates outside the zone is stronger. Similarly, the policy rule if $\beta_\pi = 5$ or $\beta_y = 5$ is similar to that for $\beta_\pi = 3$ or $\beta_y = 3$ but with a wider zone and a stronger response outside the zone.

This model allows us to test for zone-like and asymmetric behaviour. A zone-like response to inflation implies $\beta_\pi > 1$, while an asymmetric response implies β_π is an odd number. In this case $\alpha_\pi > 0$ would indicate a greater aversion to inflation being above rather than below the target. The imperative of keeping inflation within the target range suggests that α_π might be relatively large (in absolute value), since this implies a stronger response to inflation close to the boundaries of the inflation target. We can also examine the response to the output gap. Zone-like behaviour would imply $\beta_y > 1$ while asymmetry implies β_y is an odd number with $\alpha_y > 0$ indicating a greater aversion to positive output gaps. A convex supply curve implies $\tau > 0$[1].

4) Empirical Methodology

To transform our optimal monetary policy rule into an empirical model, we approximate (9) by means of a second-order Taylor series expansion around $\alpha_\pi = \alpha_y = \tau = 0$ (following, eg, Ruge-Murcia, 2003). Doing so, we find

(12)
$$\hat{i}_t = i^* + \frac{k\rho}{\mu} E_{t-1}\left(\pi_t - \pi^*\right)^{2\beta_\pi - 1} + \frac{\lambda\rho}{\mu} E_{t-1} y_t^{2\beta_y - 1} + \frac{\alpha_\pi k\rho}{2\mu} E_{t-1}\left(\pi_t - \pi^*\right)^{3\beta_\pi - 1} + \frac{\alpha_y \lambda\rho}{2\mu} E_{t-1} y_t^{3\beta_y - 1} + \frac{2k^2\tau\rho}{\mu} E_{t-1}\left(\left(\pi_t - \pi^*\right)^{2\beta_\pi - 1} y_t\right)$$

which can be expressed as

[1] In the model, optimal monetary policy rules are asymmetric if policymakers have asymmetric preferences or if the aggregate supply curve is asymmetric, while policy rules exhibit zone-like behaviour only if policymakers have zone-like preferences. Although we might conjecture that zone-like behaviour might also arise if the aggregate supply curve has zone-like features, the literature on this is not sufficiently developed for this to be incorporated into our model.

(13)

$$\hat{i}_t = i^* + \omega_1 \left(\left(\pi_t - \pi^*\right)^{2\beta_\pi - 1} + \frac{\alpha_\pi}{2}\left(\pi_t - \pi^*\right)^{3\beta_\pi - 1} \right) + \omega_2 \left(y_t^{2\beta_y - 1} + \frac{\alpha_y}{2} y_t^{3\beta_y - 1} \right)$$
$$+ 2\omega_1\omega_3 \left(\pi_t - \pi^*\right)^{2\beta_\pi - 1} y_t + \varepsilon_t$$

where $\omega_1 = \frac{k\rho}{\mu},\ \omega_2 = \frac{\lambda\rho}{\mu},\ \omega_3 = k\tau$ and where the error term is defined as

$$\varepsilon_t = -\omega_1 \left(\left(\pi_t^{2\beta_\pi - 1} - E_{t-1}\pi^{2\beta_\pi - 1}\right) + \frac{\alpha_\pi}{2}\left(\pi_t^{3\beta_\pi - 1} - E_{t-1}\pi^{3\beta_\pi - 1}\right) \right) - \omega_2 \left(\left(y_t^{2\beta_y - 1} - E_{t-1} y_t^{2\beta_y - 1}\right) \right.$$
$$\left. + \frac{\alpha_y}{2}\left(y_t^{3\beta_y - 1} - E_{t-1} y_t^{3\beta_y - 1}\right) \right) - 2\omega_1\omega_3 \left(\left(\left(\pi_t - \pi^*\right)^{2\beta_\pi - 1} y_t \right) - E_{t-1}\left(\left(\pi_t - \pi^*\right)^{2\beta_\pi - 1} y_t \right) \right)$$

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

In common with much of the literature (eg Clarida et al, 2000), we allow for interest rate persistence by adding an ad-hoc partial adjustment mechanism to our model, so

(14) $$i_t = \rho(L) i_{t-1} + \left(1 - \rho(L)\right)\hat{i}_t$$

where i_t is the observed nominal interest rate and $\rho(L)$ is a polynomial in the lag operator, L. This yields

(15)

$$i_t = \rho(L) i_{t-1} + (1-\rho(L))\left[\omega_0 + \omega_1\left(\left(\pi_t - \pi^*\right)^{2\beta_\pi - 1} + \frac{\alpha_\pi}{2}\left(\pi_t - \pi^*\right)^{3\beta_\pi - 1}\right)\right.$$
$$\left. + \omega_2\left(y_t^{2\beta_y - 1} + \frac{\alpha_y}{2} y_t^{3\beta_y - 1}\right) + 2\omega_1\omega_3\left(\pi_t - \pi^*\right)^{2\beta_y - 1} y_t\right] + \varepsilon_t$$

We estimate equation (15) using a variety of values for the integer parameters β_π and β_y, evaluating a range of alternative models of monetary policy. We assume that the inflation target, $\pi*$, equals 2.5%, but we also experiment with other values. Alternatively, we could have followed much of the literature (eg Clarida et al, 1999) in assuming that the inflation target equals the average observed inflation rate. This would not have much effect on our estimates as the average inflation rate in our sample is close to 2.5%.

5) Results

We use quarterly data for the UK for 1992Q4-2003Q1. The interest rate is the 3-month treasury bill rate, inflation is the annual change in the retail price index and output is real GDP. We model the output gap as the difference between output and a Hodrick-Prescott trend. We find that inflation and the output gap are stationary but that the order of integration of the interest rate is more ambiguous; we assume that all variables are stationary (see also Dolado et al, 2004 and Clarida et al, 2000, for a discussion of similar issues).

For both the inflation and output gaps, we considered four cases: linear $(\beta = 1;\ \alpha \to 0)$, asymmetric $(\beta = 1;\ \alpha \neq 0)$, zone symmetric $(\beta = 2)$ and zone asymmetric $(\beta = 3)$. We estimated models with both linear and nonlinear Philips curves (this latter assuming $\omega_3 = 0$). This gives a total of 32 estimated models [2]. Values of the estimated standard errors for models with a nonlinear Philips Curve are presented in table 2a) and those for models with a linear Philips Curve are presented in table 2b). The lowest standard errors are obtained for models with a linear Phillips Curve. In addition, the only model with a nonlinear Philips Curve with a significant estimate of ω_3 (that for $\beta_\pi = 3;\ \beta_y = 2$) has an insignificant estimate of ω_1, suggesting, implausibly, that interest rates do not respond to the inflation gap[3]. Taken together, this evidence suggests that the Phillips Curve is linear and we therefore focus on this case in the remainder of the paper.

Considering the estimates in table 2b), models with $\beta_\pi = 1$ or $\beta_\pi = 4$ perform poorly as do models with $\beta_y = 2$, 3 or 4. Two models clearly dominate, those for ($\beta_\pi = 2;\ \beta_y = 1;\ \alpha \to 0$) and ($\beta_\pi = 3;\ \beta_y = 1;\ \alpha \to 0$). Estimates of these models are presented in columns (i) and (ii) of table 3), while column (iii) presents estimates of the linear Taylor rule in (10), which serves as a benchmark. We note that the estimates in columns (i) and (ii) are quite similar, that the estimates of ω_0 and the ρ parameters are similar across table 3, and that the estimates of Taylor rule are similar to others in the literature (see Nelson, 2003, Martin and Milas, 2004 and Adam et al, 2003, for estimates on UK data). The estimates of ω_2 and ω_1 imply that the ratio of λ to κ is less than 0.1. Since κ is unlikely to be much greater than unity, this

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[2] We also estimated models for larger values of β_π and β_y. None of these models were superior to those reported in Table 2). We should note that the model becomes increasingly nonlinear as β increases and that estimates of some models failed to converge.

[3] Estimates for these and other models that are not reported in the paper are available from the authors.

suggests that λ is small. The loss function of policymakers seems, therefore, to put little weight on the output gap. This is consistent with a policy regime that specifies a target for inflation but not for output. We also investigated different values of the inflation target $\pi*$, considering values of $\pi*$ ranging from 1.5% to 3.0%. Doing so, we obtained the best model when $\beta_\pi = 3$, $\beta_y = 1$ and $\pi* = 2.55\%$. Estimates of this model are presented in column (iv) of table 3 and are similar to those in column (i).

These estimates provide clear evidence of a zone-like response to inflation. The zone asymmetric model is slightly superior to the zone symmetric model in terms of statistical criteria, suggesting that there is some, albeit not strong, evidence of asymmetry. We estimate $\alpha_\pi < 0$ in column (i), implying, perhaps surprisingly, a stronger response to lower rates of inflation. By contrast, we find a simple, linear response to the output gap.

Figure 3) plots the implied optimal monetary policy rules, obtained by substituting the estimates in table 3) into (9). Compared to the linear response in column (iii), where a 1% increase in the inflation gap is always met by a 1.7% increase in the interest rate, the nonlinear reaction functions implied by the estimates in columns (i) and (ii) are more subtle and arguably more plausible. Considering the zone asymmetric model in column (i), there is a negligible response to inflation when inflation is between 2.3%-2.7%. The Taylor principle that real interest rates should increase when inflation rises is satisfied when the inflation gap exceeds 0.56% or is less than 0.52%. The response to inflation is stronger than in the Taylor rule when inflation is above 3.14% or below 1.92%. The effect of the requirement that inflation not differ from the target by more than 1% is clear. Interest rates are increased by 6%

above the equilibrium when inflation equals the upper threshold of 3.5%; since we estimate that the equilibrium rate is around 5.8%, this suggests that policymakers will set interest rates at nearly 12% in order to protect the inflation target[4]. Policymakers also act to defend the lower bound to the inflation target as interest rates are cut aggressively once inflation falls below 2% (we do not consider the zero lower bound to nominal interest rates as this is beyond the scope of the paper; this may moderate the response somewhat). The zone symmetric reaction function has a somewhat narrower zone, reflecting the lower value of β_π, and a slightly flatter slope, reflecting the slightly smaller (absolute) value of α_π. Despite this, the estimated reaction functions are quite similar, suggesting that the effects of asymmetry are quite weak.

6) Conclusions

This paper has developed a flexible nonlinear model of monetary policy behaviour based on a new representation of policymaker's preferences and incorporating a convex supply curve. The model has allowed us to address a range of issues that are beyond the scope of the existing literature since the model allows there to be little or no response when inflation is close to the target or output is close to equilibrium but an increasingly aggressive

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[4] However we would stress that there are few observations for which inflation is close to 1.5%, the lowest permissible rate of inflation in the inflation targeting regime, none for which inflation is close to 3.5%, the highest permissible rate and none for which inflation is outside these bounds. Therefore our conclusions about the behaviour of policymakers at these extremes must necessarily be tenuous.

response when these variables move away from their desired levels. The model also allows for asymmetric responses to output and inflation.

We have found a subtle nonlinear response to inflation in which there is almost no response when inflation is 0.2% of the target, the Taylor principle is only satisfied when inflation deviates from the target by almost 0.5%, but that interest rates are raised by almost 6% above equilibrium to defend the boundaries of the inflation target. The response to the output gap is linear and we find no evidence of a nonlinear Philips curve.

Our work can be extended in a number of ways. This approach can be applied to other countries in order to see whether the finding of a nonlinear response of interest rates to inflation is robust. It would also be interesting to extend our analysis to allow for responses to other macroeconomic variables such as exchange rates and house prices. We hope to address these issues in future work.

Table 1
Forms of the Loss Function

INFLATION GAP COMPONENT/ OUTPUT GAP COMPONENT	$\beta_\pi = 1; \alpha_\pi \to 0$	$\beta_\pi = 1; \alpha_\pi \neq 0$	$\beta_\pi = 2$	$\beta_\pi = 3$	$\beta_\pi = 4$
$\beta_y = 1;$ $\alpha_y \to 0$	Quadratic/ Quadratic	Asymmetric/ Quadratic	Symmetric zone/ Quadratic	Asymmetric zone/ Quadratic	Symmetric zone/ Quadratic
$\beta_y = 1;$ $\alpha_y \neq 0$	Quadratic/ Asymmetric	Asymmetric/ Asymmetric	Symmetric zone/ Asymmetric	Asymmetric zone/ Asymmetric	Symmetric zone/ Asymmetric
$\beta_y = 2$	Quadratic/ Symmetric zone	Asymmetric/ Symmetric zone	Symmetric zone/ Symmetric zone	Asymmetric zone/ Symmetric zone	Symmetric zone/ Symmetric zone
$\beta_y = 3$	Quadratic/ Asymmetric zone	Asymmetric/ Asymmetric zone	Symmetric zone/ Asymmetric zone	Asymmetric zone/ Asymmetric zone	Symmetric zone/ Asymmetric zone
$\beta_y = 4$	Quadratic/ Symmetric zone	Asymmetric/ Asymmetric zone	Symmetric zone/ Asymmetric zone	Asymmetric zone/ Asymmetric zone	Symmetric zone/ Symmetric zone

Table 2
Estimated standard error for various values of β_π and β_y

a) Nonlinear Philips Curve

		INFLATION GAP EFFECT			
		Quadratic $\beta_\pi = 1;$ $\alpha_\pi \to 0$	Asymmetric $\beta_\pi = 1;$ $\alpha_\pi \neq 0$	Zone symmetric $\beta_\pi = 2$	Zone asymmetric $\beta_\pi = 3$
OUTPUT GP EFFECT	Quadratic $\beta_y = 1;$ $\alpha_y \to 0$	0.406	0.481	0.442	0.430
	Asymmetric $\beta_y = 1;$ $\alpha_y \neq 0$	0.389	0.466	0.871	0.825
	Zone symmetric $\beta_y = 2$	0.525	0.523	0.395	0.387 (*)
	Zone asymmetric $\beta_y = 3$	0.686	0.660	0.45	0.428

Note: (*) indicates that ω_3 is significant at the 5% level

b) Linear Philips Curve

		INFLATION GAP EFFECT			
		Quadratic $\beta_\pi = 1;$ $\alpha_\pi \to 0$	Asymmetric $\beta_\pi = 1;$ $\alpha_\pi \neq 0$	Zone symmetric $\beta_\pi = 2$	Zone asymmetric $\beta_\pi = 3$
OUTPUT GP EFFECT	Quadratic $\beta_y = 1;$ $\alpha_y \to 0$	0.392	0.463	0.351	0.348
	Asymmetric $\beta_y = 1;$ $\alpha_y \neq 0$	0.386	0.449	0.487	0.499
	Zone symmetric $\beta_y = 2$	0.551	0.545	0.404	0.472
	Zone asymmetric $\beta_y = 3$	0.804	0.712	0.455	0.539

Table 3

GMM Estimates of Nonlinear Monetary Policy Rules 1992Q4-2003Q

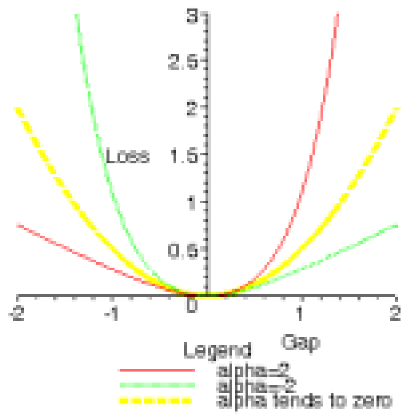
$$i_t = \rho(L) i_{t-1} + (1-\rho(L))\left[\omega_0 + \omega_1\left(E_{t-1}(\pi_t - \pi^*)^{2\beta_\pi - 1} + \frac{\alpha_\pi}{2} E_{t-1}(\pi_t - \pi^*)^{3\beta_\pi - 1}\right) + \omega_2\left(E_{t-1} y_t^{2\beta_y - 1} + \frac{\alpha_y}{2} E_{t-1} y_t^{3\beta_y - 1}\right)\right] + \varepsilon_t$$

	(I)	(II)	(III)	(IV)
	Asymmetric zone inflation gap, linear output gap $\beta_\pi = 3;$ $\beta_y = 1;$ $\alpha_y \to 0$ $\pi^* = 2.5\%$	Symmetric zone inflation gap, linear output gap $\beta_\pi = 2;$ $\beta_y = 1;$ $\alpha_y \to 0;$ $\pi^* = 2.5\%$	Taylor Rule $\beta_\pi = 1;$ $\beta_y = 1;$ $\alpha_y \to 0;$ $\alpha_y \to 0;$ $\pi^* = 2.5\%$	Asymmetric zone inflation gap, linear output gap $\beta_\pi = 3;$ $\beta_y = 1;$ $\alpha_y \to 0$ $\pi^* = 2.55\%$
α_π	-1.518 (0.089)	-1.622 (0.108)		-1.920 (0.177)
ω_0	5.743 (0.171)	5.758 (0.43)	5.451 (0.114)	5.937 (0.184)
ω_1	12.227(2.084)	9.769 (1.677)	1.713 (0.365)	13.768 (3.334)
ω_2	0.495 (0.222)	0.726 (0.174)	1.147 (0.216)	0.431 (0.281)
ρ_1	1.360 (0.046)	1.291 (0.056)	1.134 (0.120)	1.371 (0.051)
ρ_2	-0.596 (0.055)	-0.567 (0.051)	-0.499 (0.079)	-0.557 (0.056)
R^2	0.895	0.893	0.862	0.896
s.e.	0.348	0.351	0.392	0.346
J statistic	0.091	0.095	0.122	0.072

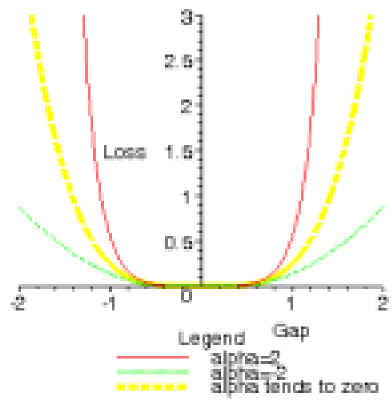
Figure 1

The Loss Function

a) asymmetric $(\beta = 1)$



b) symmetric zone $(\beta = 2, 4, 6, ..)$



c) asymmetric zone $(\beta = 3, 5, 7, ..)$

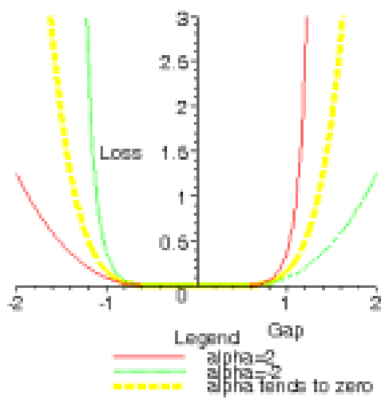
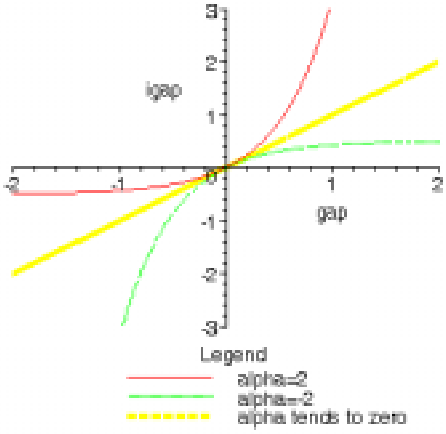


Figure 2

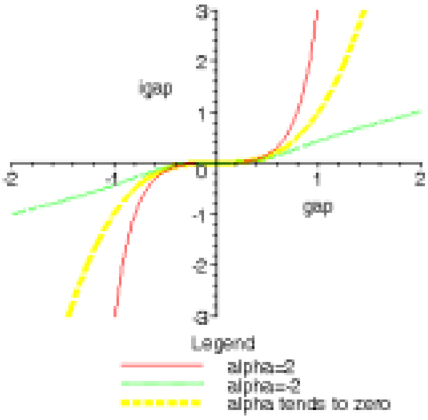
Optimal Monetary Policy Rules

a) asymmetric $(\beta = 1)$

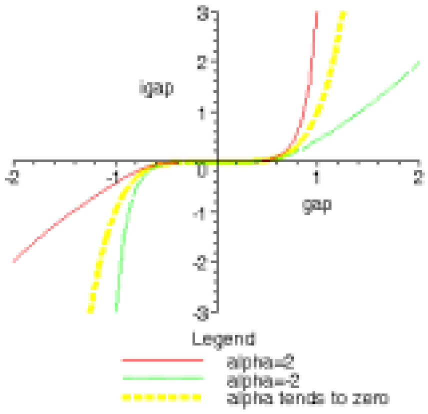
b)



b) symmetric zone $(\beta = 2, 4, 6, ..)$



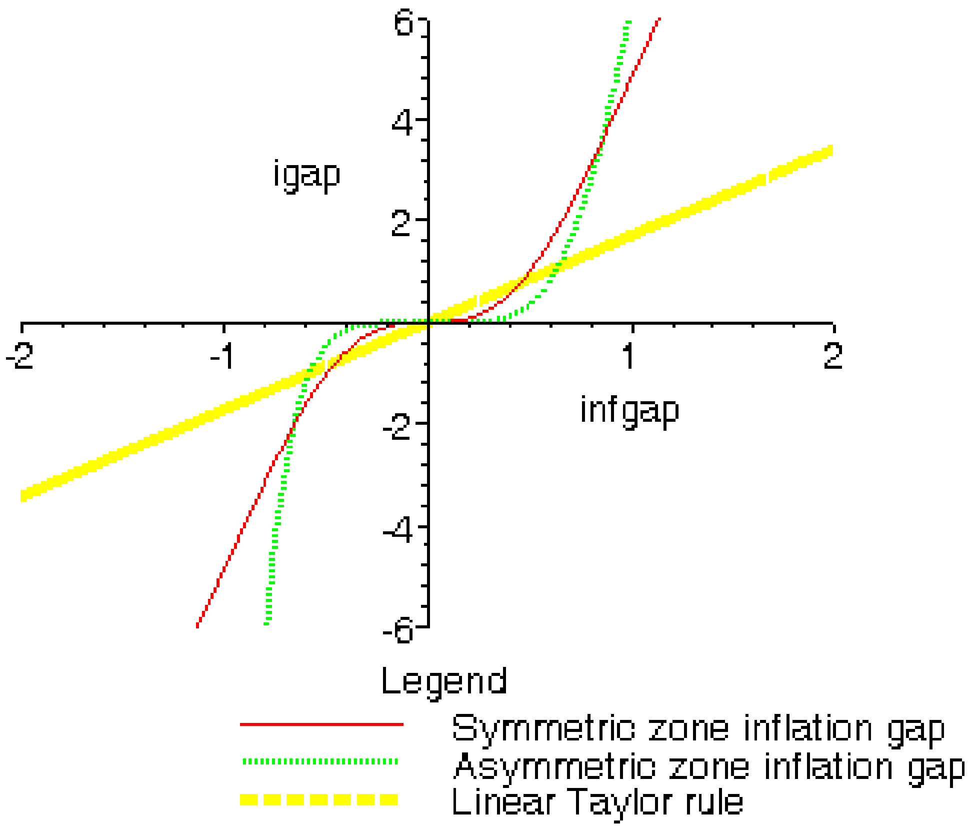
c) asymmetric zone $(\beta = 3, 5, 7, ..)$



note: The figure depicts the gap between the steady-state and equilibrium interest rates, denoted by igap, calculated using (9)

Figure 3

Estimated Optimal Monetary Policy Response to Inflation



note: The figure depicts the gap between the steady-state and equilibrium interest rates, denoted by igap, that is implied by our estimates. It is obtained by substituting the estimates in table 3) into (9)

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