Optimal monetary policy reaction function in a model with target zones and asymmetric preferences for South Africa

Ruthira Naraidoo
University of Pretoria
Leroi Raputsoane
University of Pretoria

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Department of Economics
University of Pretoria
0002, Pretoria
South Africa
Tel: +27 12 420 2413

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R Naraidoo

Department of Economics

University of Pretoria, South Africa

e-mail: ruthira.naraidoo@up.ac.za

And

L Raputsoane

Department of Economics

University of Pretoria, South Africa

Abstract

This paper estimates the optimal monetary authorities' response to deviations of inflation and output from their target values for South Africa over the inflation targeting era. This is achieved using an empirical framework that allows the central bank's policy preferences to be zone-like as well as asymmetric. The main findings are that the monetary authorities react in a passive manner when inflation is within the target band and become increasingly aggressive when it deviates from the target band and that they react with the same level of aggressiveness regardless whether inflation overshoots or undershoots the inflation target band, that is, the monetary authorities' response towards inflation is zone symmetric. The second major finding shows that the monetary authorities' response to output fluctuations is asymmetric such that they react more aggressively to negative deviations of output from the potential, therefore weighing more business cycle recessions versus expansions.

1.   Introduction

Policy makers around the world have sought to improve transparency and accountability of their policy objectives by specifying explicit targets for variables such as inflation and output. An important development in the recent past has been the adoption of the inflation targeting framework by a growing number of developed and developing countries (Mishkin and Schmidt-Hebbel, 2001). Under this framework, monetary policy authorities make public announcements of the target inflation rate and use of interest rates to steer actual inflation towards the target with the objective of achieving price stability. This monetary policy framework is characterised by point targeting, which permits inflation to fluctuate by some margin around the specified target. Other central banks, including the SARB, have adopted a zone targeting monetary policy framework that allows some toleration to the fluctuation of inflation within a specified target range.

When the monetary authorities are endowed with inflation and output stabilisation, they may have an inflation bias when inflation overshoots the target and an output bias during productivity declines (Orphanides and Wilcox, 2002). Thus the monetary authorities may behave in ways that reflect asymmetries when confronted by numerous competing objectives. This implies that their responses to inflation and output may be different depending on whether these variables undershoot or overshoot their target values. The monetary authorities may also exhibit zone-like behaviours by penalising more when inflation moves out of the target range and being passive when it is within the target range. Thus an empirical framework that allows for target zones and asymmetries in monetary policy preferences is more relevant to evaluate the monetary authorities' actual practice of monetary policy setting. However, as argued by Orphanides and Wieland (2000), the quantitative evaluations of monetary policy have been based on linear models that use the Taylor (1993) rule and its extensions by Clarida et al. (2000) may not fully capture the actual practice of inflation targeting.

Empirical work on the analysis of monetary policy is dominated by studies which use the linear Taylor rule with relatively few studies which have estimated asymmetric monetary policy reaction functions. Cukierman and Gerlach (2003), Ruge-Murcia (2003), Dolado et al. (2004, 2005), Surico (2007a,b) show evidence supporting asymmetries by adopting a monetary policy reaction function which feature asymmetries in either inflation or the output

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gap for the US, UK, EU and OECD countries. Boinet and Martin (2008) implement a monetary policy rule for the UK and find the evidence of zone-like responses to inflation.

This paper estimates the monetary authorities' response to deviations of inflation and output from their target values using an empirical framework which allows central bank's policy preferences to be zone like and asymmetric. Of particular interest is whether the monetary authorities' preferences are such that they react differently to deviations in inflation and output when they overshoot or are below their target values and/or when inflation is within or outside the target range. The modelling strategy is an adaptation of the New Keynesian framework, which is the intertemporal optimisation problem where the central bank minimises a loss function subject to the constraints given by the structure of the economy. The study is important in that it allows the evaluation of the central bank's monetary policy outcomes using an analytical framework that captures the authentic monetary policy practice given the explicit inflation target objectives under which central banks operate. The paper is the first attempt to model monetary policy using an optimal monetary policy rule with zone-like and asymmetric preferences for the SARB. This monetary policy rule is in line with the actual practice of inflation zone targeting by the SARB where the inflation target is 3 to 6 percent.[1] This paper therefore contributes to the growing number of studies by estimating nonlinear monetary policy reaction function for a developing economy.

The paper is organised as follows. The next section details the theoretical model where the optimal monetary policy rule is derived from the monetary authorities' optimisation problem. Section 3 discusses the data. In section 4, the optimal monetary policy rule is estimated and the results are reported and discussed, while section 5 concludes.

2.   Theoretical model

The central bank's monetary policy design problem is a targeting rule following Svensson (1999) and draws from Boinet and Martin (2008). The monetary policy rule is an adaptation of the New Keynesian setup that is modelled as an intertemporal optimisation problem

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[1] The only piece of work that have attempted estimating nonlinear monetary policy rule in the context of South Africa is Naraidoo and Gupta (2008) who make use of a smooth transition model with a quadratic logistic function to capture inflation zone targeting practice. However the approach taken in the present paper is different as the analysis is based on optimal monetary policy rule.

where the central bank is assumed to use all available information available at any point in time to bring the target variables in line with their reference values.

2.1. Central bank's preferences

The central bank sets the interest rate at the beginning of period t based on the information, which is available at the end of period, $t-1$ and the following timing mechanism captures the intertemporal criterion as in Clarida et al. (1999):

$$\underset{\{i_t\}}{Min}\, E_{t-1} \sum_{\tau=0}^{\infty} \delta^{\tau} L_{t+\tau} \qquad [1]$$

where δ and L is the discount factor and the period loss function, respectively.

The period loss function is a linex specification and was first introduced in the monetary policy literature by Nobay and Peel (2003). It departs from the conventional quadratic specification in that the central bank is allowed to treat differently the positive and negative deviations of inflation and output from their targets. The central bank is also indifferent between inflation rates and output within these target zones as in Boinet and Martin (2008). It extends on Surico (2007a,b), in that the linex specification is general in that it approximates a number of different functions. The range of values for the rate of inflation for which the loss function is constant forms the target zone for inflation. Therefore, the period loss function is specified as follows:

$$L_t = \frac{e^{\alpha_{\pi}(\pi-\pi^*)^{\beta_{\pi}}} - \alpha_{\pi}(\pi_t - \pi^*)^{\beta_{\pi}} - 1}{\beta_{\pi}\alpha_{\pi}^2} + \lambda \left(\frac{e^{\alpha_y(y_t)^{\beta_y}} - \alpha_y(y_t)^{\beta_y} - 1}{\beta_y\alpha_y^2} \right) + \frac{\mu}{2}(i_t - i^*)^2 \qquad [2]$$

where α_{π} and α_y capture the asymmetries, while β_{π} and β_y capture the zone-like properties in the central bank's preferences. i^* is the desired level of interest rate, while π^* is the inflation target. $\lambda > 0$ is a coefficient, which measures the central bank's aversion to output level fluctuation relative to the potential level, while $\mu > 0$ is a coefficient, which measures the central bank's aversion to interest rate fluctuations around the desired level. The policy preference towards inflation stability is normalised to 1 so that λ and μ are expressed in relative terms.

The loss function embodies numerous characteristics of linearities, asymmetries and zone-like central bank's preferences depending on the values of α_π, α_y, β_π and β_y. As special cases, whenever β_π and β_y approach one, the period loss function generalises to a linex function, while applying L'Hopital's rule on the loss function and allowing α_π and α_y approach zero and β_π and β_y approach one simultaneously achieves a quadratic loss function. Figure 1 illustrates the monetary authorities' preferences assuming that the central bank is more concerned about inflation overshooting its target and output undershooting its potential. Under these assumptions, high inflation relative to the target is more costly to the monetary authorities than low inflation, while low output relative to the potential is weighted more severely than higher output.

As illustrated in Figure 1 (a) and (b), when α_π and α_y approach zero, the loss function is symmetric. In this particular case, the deviation of inflation from its target and output fluctuations from the potential are weighted equally by the monetary authorities and the loss function exhibits zone-like properties when β_π and β_y are greater than one. Given a positive value of α_π, as illustrated in figure 1 (c) and (d), whenever π_t is greater than zero, the linear component of the loss function is dominated by the exponential component. Thus the central bank penalises higher inflation relative to the target more severely than lower inflation. In similar manner, given the negative value of α_y, as illustrated in figure 1 (e) and (f), the exponential component dominates the linear component of the loss function whenever y_t is less than zero, while the opposite is true for output values greater than zero. In this particular instance, the central bank weighs output contraction relative to the potential level more heavily than output expansions of the same level.

Whenever β_π and β_y are greater than one, the central bank's preferences are zone-like, a feature which was introduced by Orphanides and Wieland (2000). Within the target zones, the central bank's marginal loss is zero. Whenever β_π and β_y are even, the inflation and output targets are symmetric so that the loss from inflation and output outside their targets are symmetric, while both the inflation and output target zone and the loss from inflation and output outside the target zone are asymmetric whenever β_π and β_y are odd. Higher values

of β_π and β_y widen the target zone. The responses to inflation and output gaps may be different so that β_π and β_y may not be equal.

The shape of the linex specification depends on the signs of α_π and α_y. Thus the central bank may weigh deflation more severely than inflation in which case α_π would be negative. α_y can also be positive in which case the central bank is averse to output contractions than expansions. Thus under asymmetric setting, the central bank is concerned about the magnitudes as well as the signs whereas under the symmetric setting, the only concern is the magnitude of deviations of target variables from their reference values. For a detailed discussion on all the possible configurations of the loss function, see Martin and Boinet (2008).

2.2. Structure of the economy

The framework of the evolution of monetary policy is the New-Keynesian sticky price forward looking model of the business cycle. The model is derived in Yun (1996) and Woodford (2003). The economy is represented by a two equation system comprising the aggregate demand and aggregate supply (Phillip's curve) functions. The aggregate demand is a log-linearised version of the standard Euler equation for consumption combined with the relevant market clearing condition:

$$y_t = E_t y_{t+1} - \varphi(i_t - E_t \pi_{t+1}) + \varepsilon_t^d \qquad [3]$$

where y_t is the output gap, i_t is the nominal interest rate, π_t is the inflation rate, while $\varphi > 0$ is the coefficient and ε_t^d is a demand shock. The aggregate supply curve incorporates consumption smoothing into the aggregate demand formulation where the output gap increases with its future value, while it decreases with the real interest rate $i_t - E_t \pi_{t+1}$ (Clarida et al., 1999). The aggregate supply (Phillips curve) captures, in a log-linearised manner, the staggered feature of the Calvo type contract:

$$\pi_t = \theta E_t \pi_{t+1} + k y_t + \varepsilon_t^s \qquad [4]$$

where $\theta > 0$ and $k > 0$ are the coefficients, while ε_t^s is the i.i.d supply shock.

2.3. Optimal monetary policy

The central bank chooses monetary policy rates under discretion. The per period instrument i_t is chosen to minimise the following objective function:

$$E_{t-1}\left(\frac{e^{\alpha_\pi(\pi_t-\pi^*)^{\beta_\pi}}-\alpha_\pi(\pi_t-\pi^*)^{\beta_\pi}-1}{\beta_\pi\alpha_\pi^2}\right)+\lambda E_{t-1}\left(\frac{e^{\alpha_y(y_t)^{\beta_y}}-\alpha_y(y_t)^{\beta_y}-1}{\beta_y\alpha_y^2}\right)+\frac{\mu}{2}(i_t-i^*)^2+F_t \qquad [5]$$

Subject to $y_t = -\varphi i_t + g_t$ and $\pi_t = ky_t + f_t$ where $F_t \equiv E_{t-1}\sum_{\tau=0}^{\infty}\delta^\tau L_{t+\tau}$,

$g_t \equiv E_t y_{t+1} - \varphi E_t \pi_{t+1} + \varepsilon_t^d$ and $f_t \equiv \theta E_t \pi_{t+1} + \varepsilon_t^s$. The central bank cannot directly manipulate expectation. As a result, F_t, g_t and f_t are taken as given.

2.4. Central bank's reaction function

The reaction function according to which the central bank chooses monetary policy rates in response to developments in the economy is achieved by solving the central bank's optimisation problem above. This translates into the following first order condition, which describes the central bank's optimal monetary policy rule.

$$\delta E_{t-1} f'\left(\pi_{t+1}-\pi^*\right)\frac{\partial \pi_{t+1}}{\partial y_{t+1}}\frac{\partial y_{t+1}}{\partial i_t}+\delta E_{t-1}f'\left(y_{t+1}\right)\frac{\partial y_{t+1}}{\partial i_t}+\mu(i_t-i^*)=0 \qquad [6]$$

where $f\left(x_t;\alpha,\beta\right)=\left(\frac{e^{\alpha x_t^\beta}-\alpha x_t^\beta-1}{\beta\alpha^2}\right)$ and $f'(.)$ is the first derivative of this function. The parameter α and the exponential function determine the asymmetric response of monetary policy rates to departure of target variables from their reference values, while β captures the zone-like properties.

Solving equation [6] achieves the reduced form central bank's reaction function

$$\hat{i}_t = i^* + \omega_\pi E_{t-1} f'\left(\pi_{t+1} - \pi_t^*\right)\left(\pi_{t+1} - \pi_t^*\right) + \omega_y E_{t-1} f'\left(y_{t+1}\right)\left(y_{t+1}\right) \tag{7}$$

where $\hat{i}$ is the optimal interest rate, $\omega_\pi = \left(\dfrac{k\varphi\delta}{\mu}\right)$ and $\omega_y = \left(\dfrac{\lambda\varphi\delta}{\mu}\right)$ are convolutions of parameters representing the central bank's preferences and the structure of the economy and $f'\left(x_t; \alpha, \beta\right) = x_t^{\beta-1}\left(\dfrac{e^{\alpha x_t^\beta} - 1}{\alpha}\right)$. The weight on inflation is given by $\omega_\pi E_{t-1} f'\left(\pi_{t+1} - \pi_t^*\right)$ while the weight on output stabilisation is $\omega_y E_{t-1} f'\left(y_{t+1}\right)$.

As a special case, the central bank's reaction function above embodies the linear form whenever the αs approach zero. Using L'Hopital's rule on equation [7] as α_π and α_y approach zero and β_π and β_y approach one, $f'(.)$ tends to unity and the central bank's monetary policy rule generalises to a linear Taylor rule (Taylor, 1993)

$$\hat{i}_t = i^* + \omega_\pi E_{t-1}\left(\pi_{t+1} - \pi_t\right) + \omega_y E_{t-1}\left(y_{t+1}\right) \tag{8}$$

The monetary authorities have linex preferences whenever β_π and β_y are equal to one. This monetary reaction function is similar to those in Nobay and Peel (2003), Ruge-Murcia (2003) and Surico (2007a,b). As illustrated in Figure 2 (a) and (b), respectively, the monetary policy reaction function generalise to a linear Taylor rule whenever α_π and α_y approach zero, while it is symmetric whenever β_π and β_y are greater than one. The monetary policy reaction function reveals asymmetries to inflation and output whenever α_π and α_y are greater than zero. Assuming that the monetary authority dislikes high inflation, whenever α_π is greater than zero, monetary authorities are more aggressive when inflation overshoots the target but less responsive when inflation undershoots the target as shown in Figure 2 (c) and (d). Further, assuming that monetary authorities are averse to output contractions, as shown in Figure 2 (e) and (f), the asymmetry is reversed whenever α_y is less than zero so that monetary authorities are more aggressive when output undershoots the target and relatively passive when it overshoots the target.

Whenever β_π and β_y are even, the monetary policy reaction function exhibits zone-like preferences similar to that proposed by Orphanides and Wieland (2000). In this case, monetary authorities are passive or do not respond to fluctuations in inflation and output inside the zone. However, the monetary authorities' reaction becomes increasingly aggressive whenever inflation and output moves outside this zone. Their reaction outside the zone is symmetric and increasingly aggressive for the larger values of α_π and α_y.

Whenever β_π and β_y are odd, the monetary policy reaction function is asymmetric and exhibits zone-like preferences' similar to that proposed by Boinet and Martin (2008). Similar to the previous case, monetary authorities are passive or do not respond to fluctuations in inflation and output inside the zone. Assuming that monetary authorities' dislike high inflation and output contractions, their response to inflation is somewhat passive when inflation moves below the target zone but becomes increasingly aggressive when inflation moves above the target zone and the response is also aggressive when output undershoots the target zone but less so when it overshoots it.

Thus it is apparent from the preceding discussion that the monetary policy reaction function is flexible in that it can embody linearities and nonlinearities, symmetries and asymmetries as well as zone-like responses to inflation and output depending on the assumptions concerning the monetary authorities' preferences. As a result, determining which specification best fits the data allows the evaluation of the monetary authorities' preferences', which adequately capture the key features in monetary policy conduct.

2.5. Empirical model

Estimating the central bank's reaction function in equation [7] to test the statistical significance of the parameters amounts to testing linearity against a non-linear model. To overcome this problem, the central bank's reaction function is linearised to eliminate the expectation terms by approximating equation [7] using a first order Taylor series expansion when α_π and α_y tend to zero. Replacing the expectations with realised values, the reduced form central bank's reaction function now becomes:

$$\hat{i}_t = i^* + \omega_\pi \left(\pi_{t+1} - \pi^*\right)^{2\beta_\pi - 1} \left(1 + \frac{\alpha_\pi}{2}\left(\pi_{t+1} - \pi^*\right)^{\beta_\pi}\right) + \omega_y \left(y_{t+1}\right)^{2\beta_y - 1} \left(1 + \frac{\alpha_y}{2}\left(y_{t+1}\right)^{\beta_y}\right)$$

[9]

When $\beta_\pi ; \beta_y = 1$ the monetary authorities have linex preferences and the monetary policy reaction function generalises to a linear Taylor rule when $\alpha_\pi ; \alpha_y \to 0$. Adding a partial adjustment mechanism $i_t = \rho(L)i_{t-1} + (1-\rho(L))\hat{i}_t$ to allow for interest rate persistence as in Clarida et al. (1999) achieves the following reduced form central bank's reaction function:

$$i_t = \rho(L)i_{t-1} + (1-\rho(L))\left(\omega_0 + \omega_\pi \left(\pi_{t+1} - \pi^*\right)^{2\beta_\pi - 1}\left(1 + \frac{\alpha_\pi}{2}\left(\pi_{t+1} - \pi^*\right)^{\beta_\pi}\right) + \omega_y \left(y_{t+1}\right)^{2\beta_y - 1}\left(1 + \frac{\alpha_y}{2}\left(y_{t+1}\right)^{\beta_y}\right)\right) + \varepsilon_t \quad [10]$$

Where ε_t is the residual of the Taylor's series expansion defined as:

$$\varepsilon_t = -\omega_\pi \left(1 - \rho(L)\right)\left(\left(\left(\pi_{t+1} - \pi^*\right)^{2\beta_\pi - 1} - E_{t-1}\left(\pi_{t+1} - \pi^*\right)^{2\beta_\pi - 1}\right) + \frac{\alpha_\pi}{2}\left(\left(\pi_{t+1} - \pi^*\right)^{3\beta_\pi - 1} - E_{t-1}\left(\pi_{t+1} - \pi^*\right)^{3\beta\beta_\pi - 1}\right)\right)$$
$$-\omega_y \left(1 - \rho(L)\right)\left(\left(\left(y_{t+1}\right)^{2\beta_y - 1} - E_{t-1}\left(y_{t+1}\right)^{2\beta_y - 1}\right) + \frac{\alpha_y}{2}\left(\left(y_{t+1}\right)^{3\beta_y - 1} - E_{t-1}\left(y_{t+1}\right)^{3\beta_y - 1}\right)\right)$$

3.   Data description

Monthly data for South Africa is used for the analysis. The data spans the period January 2000 to December 2008. The three month treasury bill rate is used to measure the rate of interest. We prefer using this interest rate rather than the key policy rate, the repo rate given that it contains more variation. Inflation gap is measured by the difference between the annual change in consumer price index and 4.5, which is the mid point of the inflation target in south Africa. Output gap is measured by the difference between (in logarithms) coincident business cycle indicator and its Hodrick and Prescott (1997) trend. The instrument set includes the lags of the independent variables, the long term government bond yield, annual change in M3 and the index of financial conditions gap. All the data is sourced from the South African Reserve Bank database.

To tackle the end-point problem in calculating the HP trend (see Mise et al., 2005a,b), we applied an autoregressive (AR(n)) model (with n set at 4 to eliminate serial correlation) to the output measure. The AR model was used to forecast twelve additional months that were then added to the series before applying the HP filter. The main variables are depicted in Figure 3. The inflation rate is showing a persistent increase towards the end of the sample

together with an accompanying increase in interest rate. The output gap is showing a severe downturn by the end of 2008.

4.   Empirical results

The orthogonality conditions in the central bank's reaction function allow the use of Generalised Method of Moments (GMM) in estimation. Equation [10] is estimated using a mixture of integer values of β_π and β_y when $\alpha_\pi; \alpha_y \to 0$ and $\alpha_\pi; \alpha_y \neq 0$. The optimal monetary policy reaction functions are estimated in a forward looking manner with a preferred specification that allows a lead structure of six on inflation gap and one on the output gap. The optimal monetary policy rule is achieved by selecting the model with the lowest standard error among all the alternatives under the different assumptions for inflation and output. As discussed above, the inflation and output gaps can be assumed to be linear, asymmetric, zone symmetric and zone asymmetric.

Table 1 shows the standard errors for all the estimated models under different assumptions for inflation and output. Among the alternatives, the model with a symmetric zone inflation gap and an asymmetric output gap is the preferred model with the lowest standard error. This implies that the monetary authorities react in a passive manner when inflation is within the target band and become increasingly aggressive when it deviates from the target band where they react with the same level of aggressiveness regardless whether inflation overshoots or undershoots the inflation target band. In addition, the monetary authorities react differently to negative and positive deviations of output from the potential.

The estimated results for the preferred model with a symmetric zone inflation gap and an asymmetric output gap are presented in table 2 together with the estimated results for the linear Taylor rule, which is a benchmark for the estimated monetary policy reaction functions. To determine the validity of the set of instruments, the Hansen's J- test is carried out under the null hypothesis that the over identifying restrictions are satisfied. The null hypothesis is accepted for both the preferred model and the benchmark model. However, the preferred model provides slightly better fit to the data compared with the benchmark model and relatively better model diagnostics.

The results for both models show statistically significant coefficients for inflation gap and the output gap. The optimal monetary policy preferences implied by these estimates are illustrated in Figure 4. The preferred model shows a negligible response to inflation when it deviates by about 0.5 percent from the inflation target mid-point of 4.5 percent. The results show that the monetary authorities increase the nominal interest rates by 0.4 percent when inflation hits the upper threshold of the inflation target band so that the desired nominal interest rate is at 8.7 percent compared with the equilibrium interest rate of 8.4 percent. When inflation deviates by one percent outside the upper bound of the inflation target, the monetary authorities increase the nominal interest rates by 2.9 percent so that the desired nominal interest rate is 11.4 percent.

The benchmark model implies a constant response of interest rates to changes in inflation regardless of its deviation from the target. The results show that the monetary authorities move interest rates by 0.8 percent when inflation deviates from the inflation target range mid-point of 4.5 percent by 1 percent. The response of nominal interest rates to changes in inflation implied by the benchmark model is stronger than that which is implied by the preferred model when inflation is between 1.6 and 7.4 percent.

With regard to output, the estimated optimal monetary policy rule for the preferred model shows that the monetary authorities cut nominal interest rates by 1 percent when output undershoots the potential by 0.8 percent. The negative coefficient on the parameter that governs asymmetry implies that monetary authorities' are more aggressive when output falls below that when it overshoots the potential. This implies that monetary authorities' preferences' are biased towards output expansions in that they weigh negative deviations of output more heavily than output expansions. The results for the benchmark model show a constant response to output contractions and expansions as discussed above. The estimated results show that the monetary authorities move the nominal interest rates by 0.4 percent when output deviates from the desired level by 1 percent. The preferred model implies a stronger reaction to output fluctuations compared with the benchmark model whenever output is below its potential.

The results for the benchmark monetary policy rule show lower coefficients compared to the recommended size of the coefficients for the Taylor rule. Thus the estimated benchmark model does not adhere to the Taylor principle that the monetary authorities should move interest rates by more than one to one. This is particularly the case with regard to inflation whereas it is not much the case concerning the output gap. The type of model that is implied

by the preferred model has not been estimated for South Africa. As a result, there are no studies to compare the results that are obtained in this analysis with. However, our paper draws from Boinet and Martin (2008) who estimate the optimal monetary policy reaction function for the UK. They find similar results in terms of symmetric zone inflation but linearity in terms of the output gap. The estimated coefficients in Boinet and Martin (2008) for the monetary authorities' response to inflation in the UK are larger than the estimated coefficients for the case of South Africa. One of the possible reasons for this is because the inflation target for the UK is 2.5 percent, which is much lower than that of South Africa. This calls for a more aggressive policy response on the part of the monetary authorities in the UK.

5.   Conclusion

In this paper, the monetary authorities' response to deviations of inflation and output from their target values is estimated using an empirical framework which allows central bank's policy preferences to be zone like and asymmetric. Of particular interest is whether the monetary authorities' preferences are such that they behave differently to deviations in inflation and output when they overshoot or are below their target values and/or when inflation is within or outside the target range. Monthly data for South Africa spanning the period since inflation targeting framework was adopted is used in the analysis. The optimal monetary policy response functions are estimated in a forward looking manner for linearities and nonlinearities, symmetries and asymmetries as well as zone-like responses to inflation and output gaps.

The results show that the monetary authorities react in a passive manner when inflation is about 0.5 percent from the inflation target mid-point of 4.5 percent and become increasingly aggressive when it deviates from the target band. The monetary authorities increase the nominal interest rates by 0.4 percent when inflation hits the upper threshold of the inflation target band and they increase the nominal interest rates by 2.9 percent when inflation deviates by one percent outside the upper bound of the inflation target. The results also show that the monetary authorities react with the same level of aggressiveness regardless whether inflation overshoots or undershoots the inflation target band. With regard to output, the monetary authorities cut nominal interest rates by 1 percent when output undershoots the potential by 0.8 percent and they react differently to negative and positive deviations of output from the potential showing that they are more aggressive when output falls below that when it overshoots the potential. Future research can extend this analysis by evaluating the

monetary authorities' reaction to other macroeconomic and financial variables such as asset prices and exchange rates.

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Table 1 **Standard errors for values of β_π and β_y**

	Linear $\alpha_\pi \to 0; \beta_\pi = 1$	Asymmetric $\alpha_\pi \neq 0; \beta_\pi = 1$	Symmetric Zone $\alpha_\pi \neq 0; \beta_\pi = 2$	Asymmetric Zone $\alpha_\pi \neq 0; \beta_\pi = 3$
Linear $\alpha_y \to 0; \beta_y = 1$	0.320672	0.3117229	0.321301	0.325426
Asymmetric $\alpha_y \neq 0; \beta_y = 1$	0.310730	0.312119	0.304125	0.318219
Symmetric Zone $\alpha_y \neq 0; \beta_y = 2$	0.326905	0.322175	0.322711	0.322974
Asymmetric Zone $\alpha_y \neq 0; \beta_y = 3$	0.321068	0.317063	0.318193	0.319374

Table 2 **GMM estimates for the non-linear monetary policy rules**

	Linear inflation and linear output gap $\alpha_\pi \to 0; \alpha_y \to 0;$ $\beta_\pi = 1; \beta_y = 1$		Zone symmetric inflation and asymmetric output gap $\alpha_\pi \neq 0; \alpha_y \neq 0;$ $\beta_\pi = 2; \beta_y = 1$	
	Coefficient	Std error	Coefficient	Std error
ρ	0.938862*	0.007366	0.952855*	0.005851
ω_0	7.827308*	0.194708	8.392031*	0.289229
ω_π	0.804001*	0.118355	0.108174*	0.015844
α_π			-0.025877*	0.000660
ω_y	0.398205*	0.164511	0.779056*	0.181125
α_y			-0.805241*	0.158182
$\bar{R}^2$	0.970032		0.973045	
$Std.Error$	0.320672		0.304125	
$J - statistic$	0.984520		0.989988	

Notes: $i_t = \rho(L)i_{t-1} + (1 - \rho(L))\left(\omega_0 + \omega_\pi \left(\pi_{t+1} - \pi^* \right)^{2\beta_\pi - 1} \left(1 + \frac{\alpha_\pi}{2} \left(\pi_{t+1} - \pi^* \right)^{\beta_\pi} \right) + \omega_y \left(y_{t+1} \right)^{2\beta_y - 1} \left(1 + \frac{\alpha_y}{2} \left(y_{t+1} \right)^{\beta_y} \right) \right) + \varepsilon_t$

* denotes statistical significance at 5 percent level

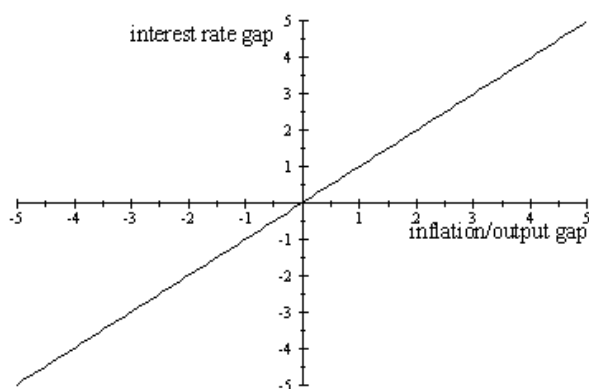j-statistic reports Hansen's test for over-identifying restrictions

Figure 1   The loss functions

(a) $\alpha_{\pi;y} \to 0; \beta_{\pi;y} = 1$

(b) $\alpha_{\pi;y} \to 0; \beta_{\pi;y} = 2,3,4,...$

(c) $\alpha_{\pi} > 0; \beta_{\pi} = 1$

(d) $\alpha_{\pi} > 0; \beta_{\pi} = 3,5,7,...$

(e) $\alpha_y < 0; \beta_y = 1$
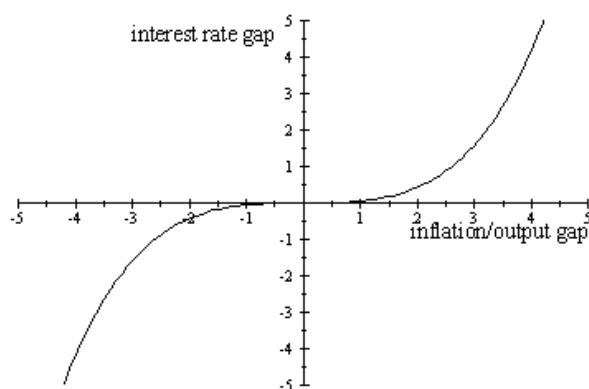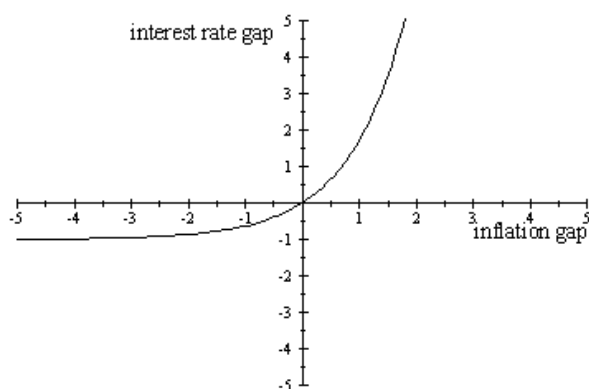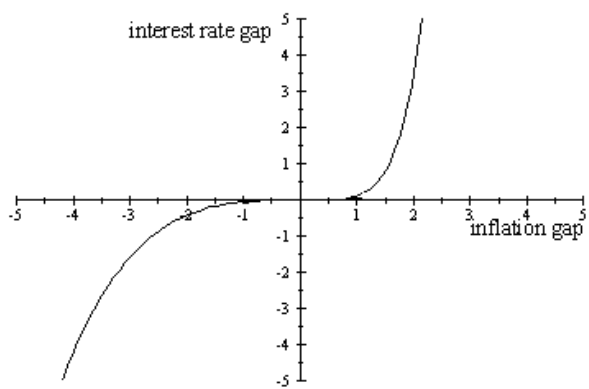
(f) $\alpha_y < 0; \beta_y = 3,5,7,...$
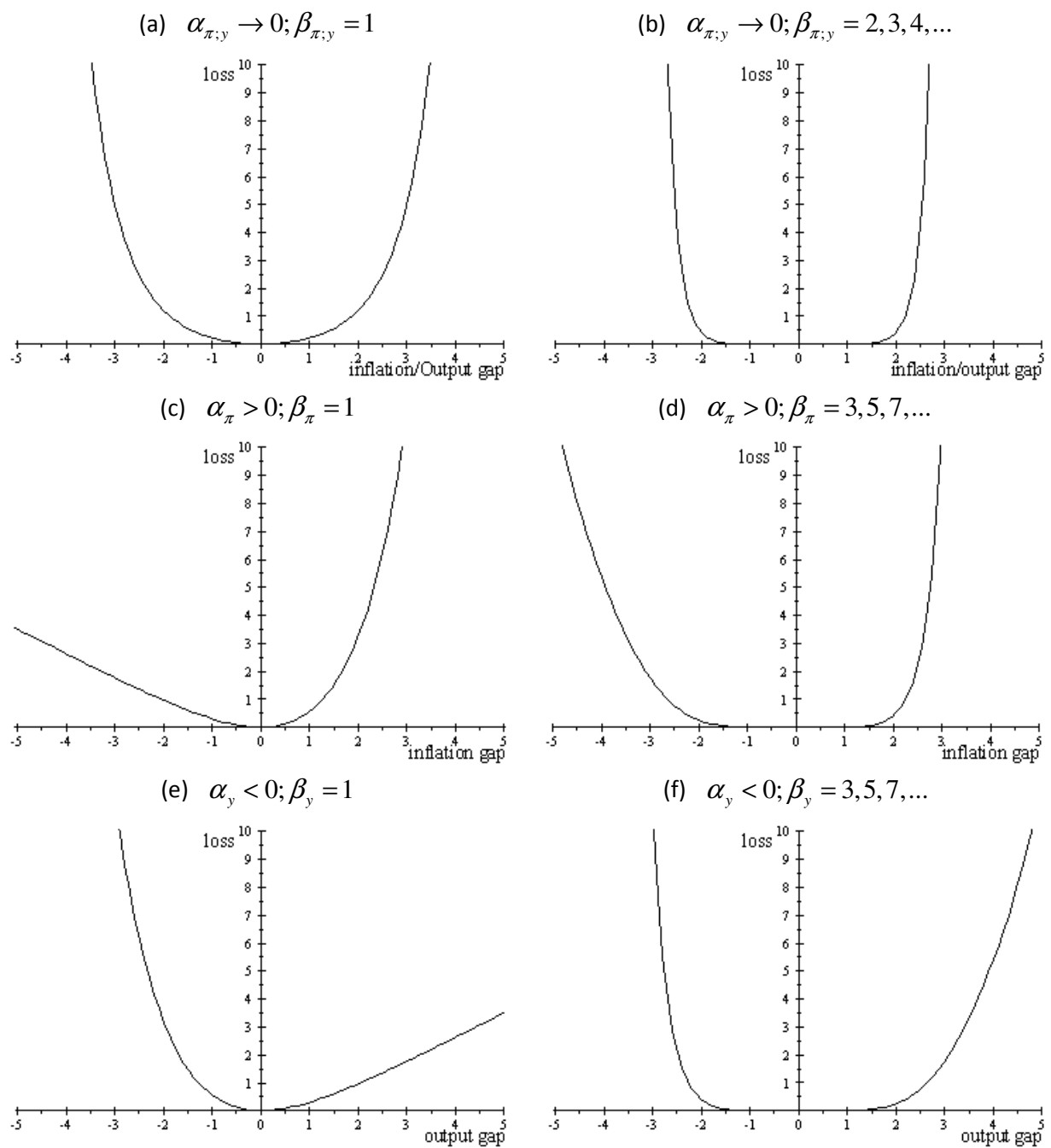
Note: The figure illustrates the preferences over inflation and output embodied by the loss function assuming that monetary authorities have deflationary bias and dislike output contractions

Figure 2   **Optimal monetary policy rules**

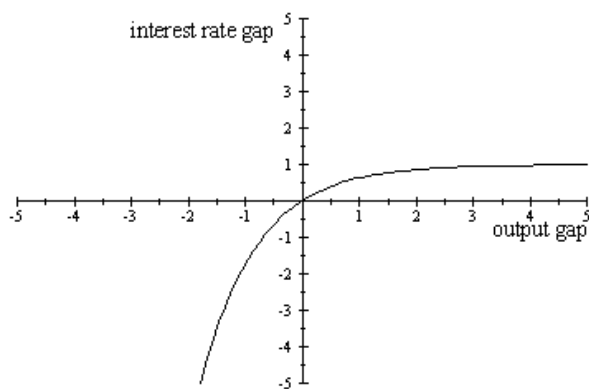(a) $\alpha_{\pi;y} \to 0; \beta_{\pi;y} = 1$ (b) $\alpha_{\pi;y} \neq 0; \beta_{\pi;y} = 2, 4, 6, ...$
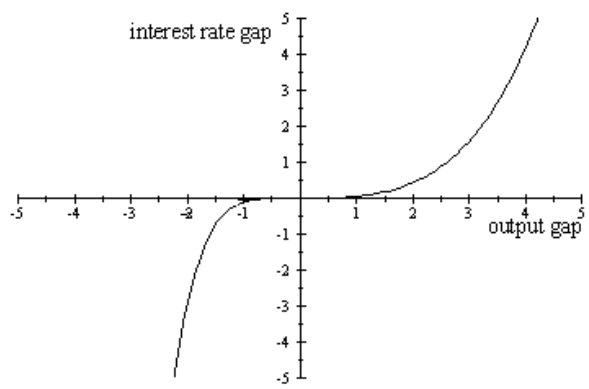
(c) $\alpha_{\pi} > 0; \beta_{\pi} = 1$ (d) $\alpha_{\pi} > 0; \beta_{\pi} = 3, 5, 7, ...$

(e) $\alpha_{y} < 0; \beta_{y} = 1$ (f) $\alpha_{y} < 0; \beta_{y} = 3, 5, 7, ...$
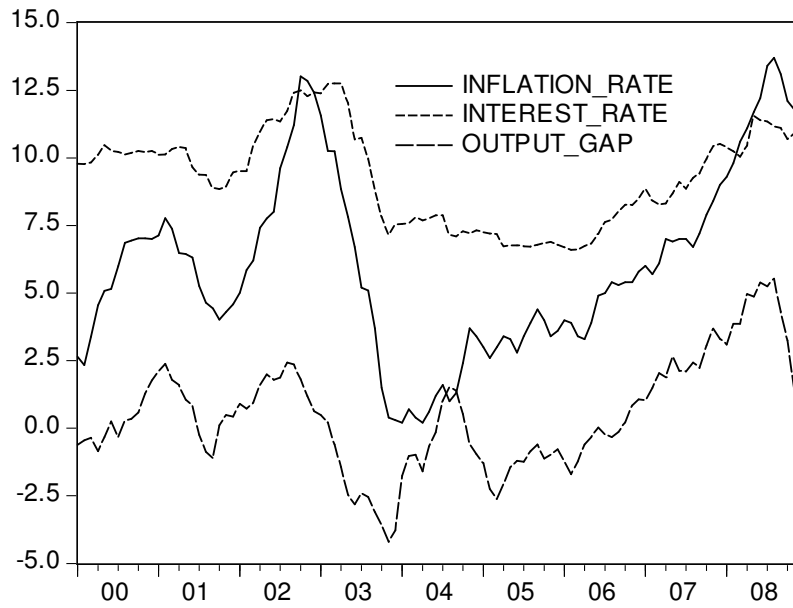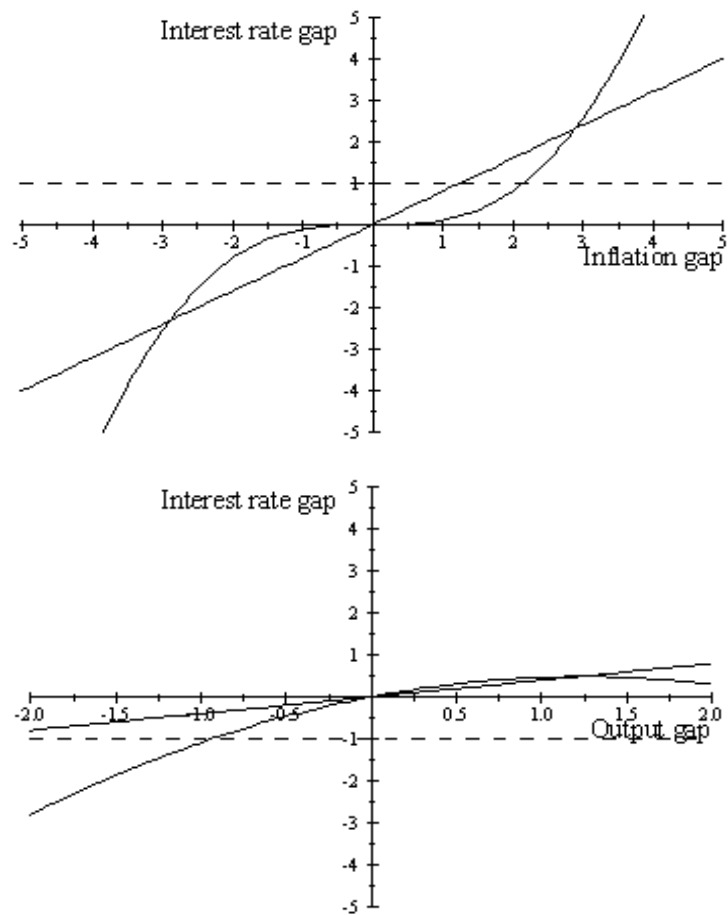

Note: The figure illustrates the gap between the steady-state and equilibrium interest rates calculated using equation [7] assuming that monetary authorities dislike inflation and output contractions.

Figure 3   **Evolution of the main variables**

Figure 4   **Estimated optimal monetary policy responses to inflation and output**

Note: the figures are obtained by substituting the estimates of inflation and output in equation [7] for the both the linear and the non-linear monetary policy rules