

## Chapter 3

### **Financial market conditions, target zones and asymmetries: a flexible optimal monetary policy reaction function for South Africa<sup>4</sup>**

#### **3.1 Introduction**

A controversial debate in academic and policy circles concerns whether or not monetary authorities should pay attention to movements in financial market variables. The recent economic crisis has highlighted the importance of the behaviour of certain asset prices such as stock prices, house prices and the exchange rate as well as the concern by central banks over the maintenance of financial stability. If this is the case, it is possible that the monetary authorities will respond to the financial market developments when they reach unsustainable levels as opposed to when they follow their fundamental paths. The proponents against targeting asset prices are most notably the former chairman of the Federal Reserve, Alan Greenspan (2004, 2005, 2008), the current chairman of the Federal Reserve, Bernanke (2002) and the former member of the Board of Governor of the Federal Reserve, Mishkin (2008).

A number of key policy-makers have moved a step closer to acknowledging the importance to react to booming financial asset markets in an attempt to prevent deflationary risk in the events of asset price bubbles bursts. Among them are the president of the San Francisco Federal Reserve, Yellen (2009), the former president of the Minneapolis Federal Reserve, Stern (2008), the president of the Boston Federal Reserve Rosengren (2009), the president of the European Central Bank, Trichet (2005, 2009) and in particular, the former vice president of the European Central Bank, Papademos (2009). The South African financial institutions experienced no direct exposure to the sub-prime crisis in terms of inter-bank or liquidity problems of the type experienced in developed countries (see Mboweni, 2008a, 2008b and Mminele, 2009). However, it is worth noting that the other primary

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goals of the South African Reserve Bank are to protect the value of the currency as well as to achieve and maintain financial stability as defined in the Constitution.

South Africa implemented inflation targeting as a preferred framework for monetary policy in 2000 where the inflation target range of 3 to 6 percent was adopted. The inflation target band practice suggests that policymakers may exhibit zone-like behaviour by responding more to inflation when inflation is some way from the target band and passively when inflation is inside the target band. However, the most widely used model of monetary policy to study the objectives of policy makers, viz., the Taylor rule and its extensions (e.g., Taylor, 1993; Clarida et al., 2000), suggests that the interest rates relate linearly to the gap between actual and desired values of inflation and output. The literature also suggests asymmetries in which case the response of interest rates to inflation and output is different for positive and negative deviations of these variables from their desired levels. The zone targeting and asymmetric framework can also be extended to the financial market developments. In this case, it is possible that the monetary authorities will exhibit zone targeting and asymmetric behaviour when the conditions in the financial market reach unsustainable levels as opposed to when they follow their fundamental paths.

The theoretical basis of the linear Taylor rule comes from the assumption that policymakers have a quadratic loss function and that the aggregate supply or Phillips curve is linear. Recent literature has questioned the linear specification of the monetary policy reaction functions. A nonlinear framework is appropriate if the central bank has asymmetric preferences in the context of a linear function for the monetary authorities' preferences as originally propounded by Nobay and Peel (2003). A number of studies such as Cukierman (2002) and Ruge-Murcia (2003) have used these types of monetary policy preferences. A nonlinear Phillips curve was used in Schaling (2004), while Aksoy et al. (2006) used a nonlinear framework to analyse the opportunistic approach to disinflation (OAD). Dolado et al. (2004) also discusses a model that comprises both asymmetric central bank preferences and a nonlinear Phillips curve. The empirical analysis of asymmetric monetary policy reaction functions have also received attention in Davradakis and Taylor (2006), Assenmacher-Wesche (2006) and Surico (2007a,b), among others. Orphanides and Wieland (2000) analysed the 'zone-like' monetary policy behaviours in the context

of zone quadratic preferences, while Boinet and Martin (2008) extended this model to allow for both zone-like and asymmetric behaviour in investigating monetary policy in the United Kingdom.

This chapter contributes to the debate on whether monetary authorities should react to movements in financial asset markets by deriving and estimating a nonlinear flexible optimal monetary policy rule that allows for both zone-like and asymmetric behaviours. To contribute to the discussion on financial asset prices, we also investigate whether the optimal monetary policy rule could be augmented with an alternative variable that collects and synthesises the information from the financial assets market in vein with Castro (2008). Zone targeting and asymmetric preferences as well as the impact of the unsustainable developments in financial markets on the economy are all important and are currently debated in the case of South Africa and several other central banks. The reason is that many countries have undergone important changes to conduct of monetary policy over the last two decades. To the best of our knowledge, the attempt to model the South African monetary policy using a nonlinear optimal model of the interest rate rule of this nature is the first.

The next section is the description of the theoretical model, which is an intertemporal optimisation problem that is augmented with an index describing financial market conditions. Section 3 is the data description. Section 4 discusses the empirical results with emphasis on the role of financial market conditions in monetary policy conduct. Section 5 is the conclusion.

### **3.2 Theoretical model**

The monetary authorities' policy preferences are modelled as an intertemporal optimisation problem following Svensson (1999), Surico (2007a,b) and Boinet and Martin (2008). The monetary policy design problem involves minimising a loss function with the structure of the economy forming a set of constraints. This is the adaptation of the New Keynesian model derived in Yun (1996) and Woodford (2003).

### 3.2.1 Central bank's preferences

The monetary authorities use all information that is available at the end of period  $t-1$  to set the nominal interest rates at the beginning of period  $t$ . This is captured by the following intertemporal criterion where  $\delta$  and  $L$  are the discount factor and the period loss function, respectively:

$$\text{Min}_{\{i_t\}} E_{t-1} \sum_{\tau=0}^{\infty} \delta^{\tau} L_{t+\tau} \quad [1]$$

The period loss function is specified such that it captures asymmetries by allowing monetary authorities to treat target variables differently when they overshoot or undershoot their reference values following Boinet and Martin (2008). It also exhibits target zones by allowing monetary authorities to treat target variables differently depending on whether they fluctuate within or outside the given target bands. This feature was introduced by Orphanides and Wieland (2000). The period loss function is specified as follows:

$$L_t = \frac{e^{\alpha_{\pi}(\pi_t - \pi^*)^{\beta_{\pi}}} - \alpha_{\pi}(\pi_t - \pi^*)^{\beta_{\pi}} - 1}{\beta_{\pi} \alpha_{\pi}^2} + \lambda_y \frac{e^{\alpha_y(y_t)^{\beta_y}} - \alpha_y(y_t)^{\beta_y} - 1}{\beta_y \alpha_y^2} \quad [2]$$

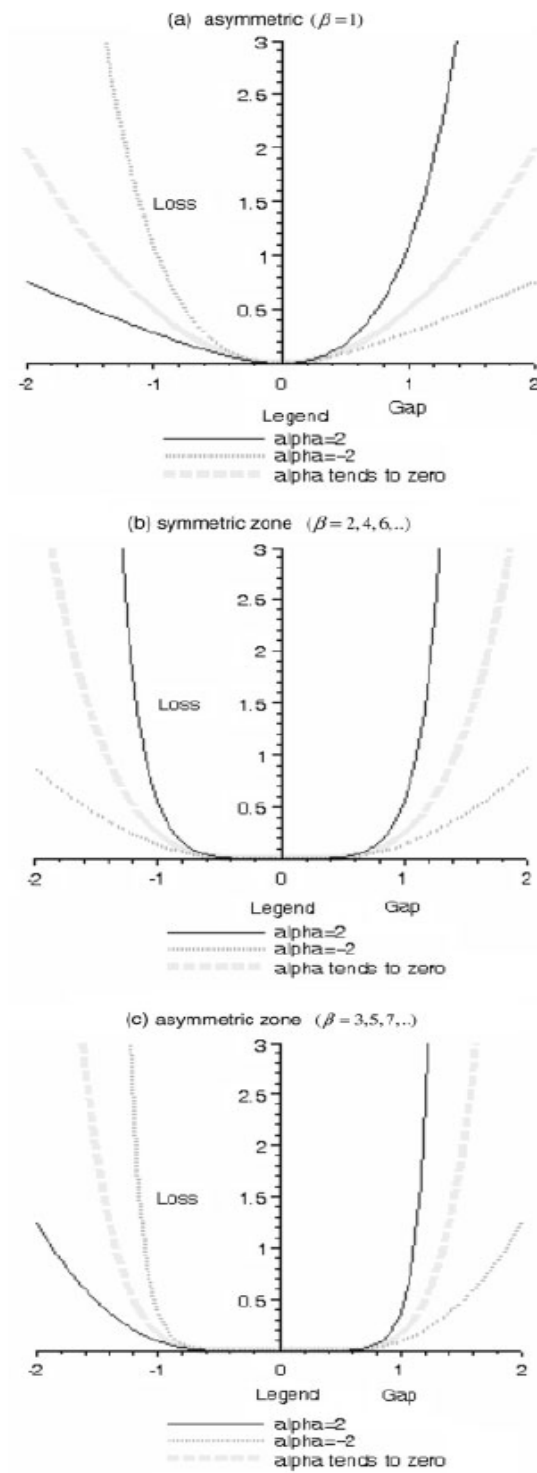
$$+ \lambda_z \frac{e^{\alpha_z(z_t)^{\beta_z}} - \alpha_z(z_t)^{\beta_z} - 1}{\beta_z \alpha_z^2} + \frac{\lambda_i}{2} (i_t - i^*)^2$$

where  $\pi_t$  is the inflation rate,  $y_t$  is the output gap,  $z_t$  is the index of financial conditions and  $i_t$  is the nominal interest rate.  $i^*$  and  $\pi^*$  are the desired level of interest rate and the inflation target, respectively.  $\alpha_{\pi}$ ,  $\alpha_y$  and  $\alpha_z$  capture the asymmetries, while  $\beta_{\pi}$ ,  $\beta_y$  and  $\beta_z$  capture the zone-like properties in the monetary authorities' preferences.  $\lambda_y$ ,  $\lambda_z$  and  $\lambda_i$  are coefficients which measure the monetary authorities' aversion to fluctuations in the level of output, financial conditions and interest rates. These coefficients are assumed to be greater than zero and are expressed in relative terms so that the policy preference towards inflation stability is normalised to 1.

The period loss functions nest the linear, quadratic, linex and the zone-like functional forms. When  $\beta_\pi$ ,  $\beta_y$  and  $\beta_z$  equal 1, the period loss function generalises to a linex loss function. Using L'Hopital's rule when  $\alpha_\pi$ ,  $\alpha_y$  and  $\alpha_z$  approach zero, the period loss function generalises to a quadratic loss function. The period loss function also nests numerous configurations of linearities, asymmetries and zone-like features and can take different forms depending on the combinations of the values  $\beta_\pi$ ,  $\beta_y$  and  $\beta_z$  as well as  $\alpha_\pi$ ,  $\alpha_y$  and  $\alpha_z$  as illustrated in Figure 3.1. When  $\alpha_\pi$ ,  $\alpha_y$  and  $\alpha_z$  is greater than zero, the monetary authorities are more aggressive if inflation, output and financial conditions overshoot than when they undershoot their desired values by the same magnitude. On the flipside, the monetary authorities are more aggressive if output, Inflation and financial conditions undershoot than when they overshoot their desired values by the same magnitude when  $\alpha_\pi$ ,  $\alpha_y$  and  $\alpha_z$  are less than zero.

When  $\beta_\pi$ ,  $\beta_y$  and  $\beta_z$  equal 1, the period loss function exhibits asymmetries and it exhibits zone-like properties when  $\beta_\pi$ ,  $\beta_y$  and  $\beta_z$  are greater than 1, where it becomes zone symmetric when  $\beta_\pi$ ,  $\beta_y$  and  $\beta_z$  equal 2,4,6,..., while the values of  $\beta_\pi$ ,  $\beta_y$  and  $\beta_z$  equal 3,5,7,... imply a zone asymmetric period loss function. Thus, the monetary authorities behave differently when the target variables are inside and when they are outside this zone. This is because the marginal loss from deviations of target variables is negligible within the target zone, while it increases when these variables move outside their target zones. It is important to note that the monetary authorities' response to the fluctuations of target variables may be different so that  $\alpha_\pi$ ,  $\alpha_y$  and  $\alpha_z$  and  $\beta_\pi$ ,  $\beta_y$  and  $\beta_z$  need not assume equal values in any particular instance.

**Figure 3.1 The loss functions**



Note: The Figures illustrate the preferences over inflation, output and financial conditions under different assumptions on  $\alpha$  and  $\beta$ . The Figure is adopted from Boinet and Martin (2008).

When values  $\beta_\pi$ ,  $\beta_y$  and  $\beta_z$  equal one and those of  $\alpha_\pi$ ,  $\alpha_y$  and  $\alpha_z$  approach zero, the period loss function is symmetric. Thus, the monetary authorities give equal weight to positive and negative deviations of target variables from their desired values. The period loss function becomes asymmetric when values  $\beta_\pi$ ,  $\beta_y$  and  $\beta_z$  equal one and those of  $\alpha_\pi$ ,  $\alpha_y$  and  $\alpha_z$  are greater than zero. In this instance, the monetary authorities are more aggressive when the target variables overshoot their desired values, while they become relatively passive in the event that  $\alpha_\pi$ ,  $\alpha_y$  and  $\alpha_z$  are less than zero.

The monetary authorities can also be passive when the target variables fluctuate within a target zone but become more aggressive when they fluctuate outside this zone. Thus, the monetary authorities are equally aggressive regardless of whether the target variables overshoot or undershoot the target zone so that their preferences can be described as being symmetric and zone-like. In this particular case, the values of  $\beta_\pi$ ,  $\beta_y$  and  $\beta_z$  are even and the higher these values, the wider the width of the zone. The values of  $\alpha_\pi$ ,  $\alpha_y$  and  $\alpha_z$  can either be less, greater or equal to zero and they govern the slope of the loss function.

In the event that the values of  $\beta_\pi$ ,  $\beta_y$  and  $\beta_z$  are odd, the period loss function is asymmetric. As above, the monetary authorities' reaction inside the target zone is relatively passive but increasingly aggressive when they fluctuate outside this zone. The difference here is that the monetary authorities' aggressiveness is not the same when the target variables overshoot and when they undershoot the target zone by the same magnitudes so that their preferences are described as being asymmetric and zone-like. The values of  $\alpha_\pi$ ,  $\alpha_y$  and  $\alpha_z$  can still be less, greater or equal to zero but in this case they govern both the slope and sign of asymmetry of the loss function.

### 3.2.2 Structure of the economy

The structure of the economy is represented by a system of equations comprising the aggregate demand and the aggregate supply curves following Clarida et al.

(1999) as well as McCallum and Nelson (1999). The aggregate demand is the forward-looking demand relationship derived from the Euler equation for consumption specified as

$$y_t = \eta_y E_t y_{t+1} - \psi_y (i_{t-1} - E_{t-1} \pi_t) + \varepsilon_t^y \quad [3]$$

Where  $\eta_y > 0$  and  $\psi_y > 0$  are the coefficients and  $\varepsilon_t^y$  is the independent and identically distributed demand shock. The aggregate supply captures, in a log-linearised manner, the staggered feature derived from the Calvo (1983) model of staggered price adjustment

$$\pi_t = \eta_\pi E_t \pi_{t+1} + k y_t + \varepsilon_t^\pi \quad [4]$$

where  $\eta_\pi > 0$  and  $k > 0$  are the coefficients, while  $\varepsilon_t^\pi$  is the Independent and identically distributed supply shock.

The conditions in the financial market are captured by the following equation

$$z_t = \eta_z E_t z_{t+1} - \psi_z (i_{t-1} - E_{t-1} \pi_t) + \varepsilon_t^z \quad [5]$$

Where  $\eta_z > 0$  and  $\psi_z > 0$  are the coefficients and  $\varepsilon_t^z$  is the Independent and identically distributed shock to the conditions in the financial market. As in Martin and Milas (2010b), equation [5] assumes that financial stability can be increased by reducing nominal interest rates allowing financial institutions to re-capitalize at a lower cost. The forward looking forward looking version for financial market conditions equation resembling the aggregate demand function in equation [3] is specified given that this market is driven to a large extent by market expectations.

Goodhart and Hoofmann (2001) and Montagnoli and Napolitano (2005) and Castro (2008) include the financial market conditions variable in the aggregate demand curve. Thus, the conditions in the financial market act as a shift variable for aggregate demand and do not allow the policy instrument to affect the financial



market directly. We have chosen instead to adopt ideas from Martin and Milas (2010c), where the monetary authorities' preferences differ between the times of financial crisis and the times when no crisis exists. During the times of no crisis, stabilising inflation and output become important and less so during the financial crisis period such that stabilising the conditions in the financial market become more important. Therefore, the financial market becomes important at certain times and hence the inclusion in an additional equation describing the conditions in that market.

### 3.2.3 Optimal monetary policy

The monetary authorities choose the per-period instrument  $i_t$  under discretion to minimise the following objective function

$$\begin{aligned}
 & E_{t-1} \left( \frac{e^{\alpha_\pi (\pi_{t+1} - \pi^*)^{\beta_\pi}} - \alpha_\pi (\pi_{t+1} - \pi^*)^{\beta_\pi} - 1}{\beta_\pi \alpha^2} \right) + \lambda_y E_{t-1} \left( \frac{e^{\alpha_y (y_{t+1})^{\beta_y}} - \alpha_y (y_{t+1})^{\beta_y} - 1}{\beta_y \alpha^2} \right) \\
 & + \lambda_z E_{t-1} \left( \frac{e^{\alpha_z (z_{t+1})^{\beta_z}} - \alpha_z (z_{t+1})^{\beta_z} - 1}{\beta_z \alpha^2} \right) + \frac{\lambda_i}{2} (i_t - i^*)^2 + F_t
 \end{aligned} \tag{6}$$

subject to the structure of the economy where  $F_t \equiv E_{t-1} \sum_{\tau=1}^{\infty} \delta^\tau L_{t+\tau}$ . The model is solved assuming that the Central bank takes the expectations as given. This is because the monetary authorities cannot directly manipulate the economic agents' expectations.

### 3.2.4 Central bank's reaction function

The reaction function according to which the monetary authorities chooses policy rates in response to developments in the economy is given by the following first order condition describing the monetary authorities' optimal monetary policy rule

$$\begin{aligned} & \delta E_{t-1} f'(\pi_{t+1}) \frac{\partial \pi_{t+1}}{\partial y_{t+1}} \frac{\partial y_{t+1}}{\partial i_t} + \delta \lambda_y E_{t-1} f'(y_{t+1}) \frac{\partial y_{t+1}}{\partial i_t} \\ & + \delta \lambda_z E_{t-1} f'(z_{t+1}) \frac{\partial z_{t+1}}{\partial i_t} + \lambda_i (i_t - i^*) = 0 \end{aligned} \quad [7]$$

Where  $f(a_t; \alpha, \beta) = \left( \frac{e^{\alpha a_t^\beta} - \alpha a_t^\beta - 1}{\beta \alpha^2} \right)$  and  $f'(\cdot)$  is the first derivative. Solving the first order condition achieves the reduced form central bank's reaction function

$$\begin{aligned} \hat{i}_t = & i^* + \omega_\pi E_{t-1} f'(\pi_{t+1} - \pi^*) (\pi_{t+1} - \pi^*) \\ & + \omega_y E_{t-1} f'(y_{t+1}) (y_{t+1}) + \omega_z E_{t-1} f'(z_{t+1}) (z_{t+1}) \end{aligned} \quad [8]$$

where  $\omega_\pi = -\frac{\kappa \psi_y \delta}{\lambda_i}$ ,  $\omega_y = -\frac{\lambda_y \psi_y \delta}{\lambda_i}$ ,  $\omega_z = -\frac{\lambda_z \psi_y \delta}{\lambda_i}$  are convolutions of parameters

representing the monetary authorities' preferences and the structure of the economy,

$f'(a_t; \alpha, \beta) = x_t^{\beta-1} \left( \frac{e^{\alpha a_t^\beta} - 1}{\alpha} \right)$  and  $\hat{i}$  is the optimal interest rate. Using L'Hopital's rule

on equation [8] as  $\beta_\pi$ ,  $\beta_y$  and  $\beta_z$  equal 1 and  $\alpha_\pi$ ,  $\alpha_y$  and  $\alpha_z$  approaches zero,

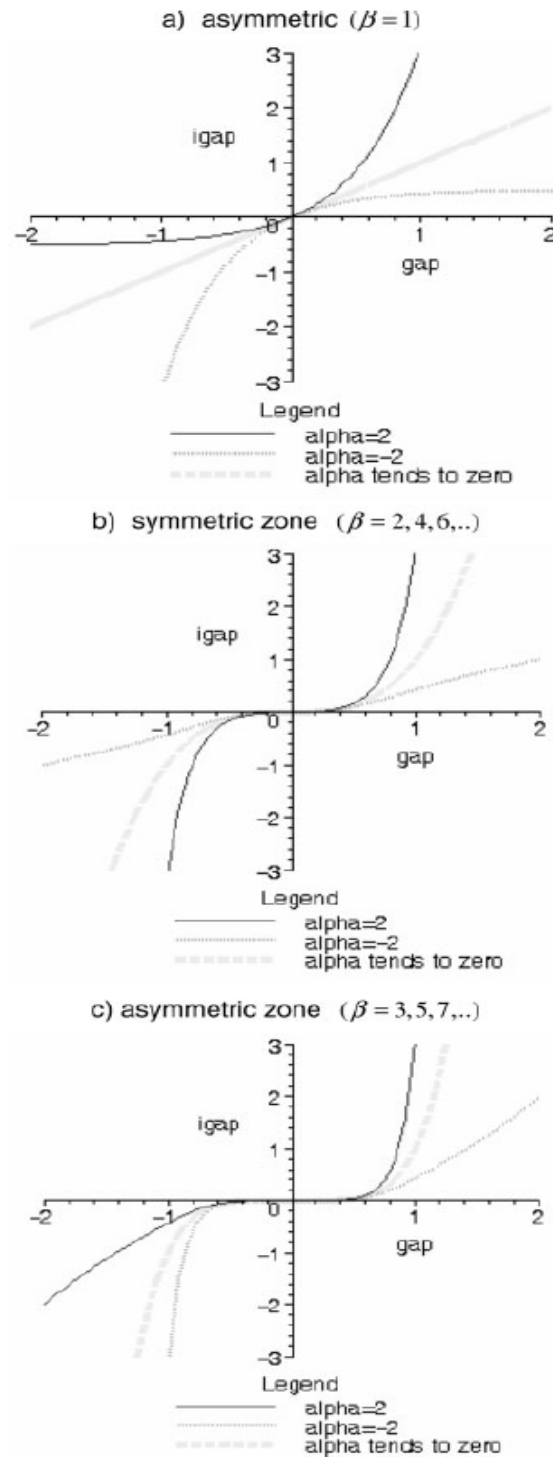
$f'(\cdot)$  tends to unity and the central bank's monetary policy rule generalises to a

linear Taylor (1993) rule.

As shown in Figure 3.2, the optimal monetary policy rule can take different forms depending on the values  $\beta_\pi$ ,  $\beta_y$  and  $\beta_z$  and  $\alpha_\pi$ ,  $\alpha_y$  and  $\alpha_z$ . When  $\alpha_\pi$ ,  $\alpha_y$  and  $\alpha_z$  equal zero, monetary authorities react linearly to deviations of inflation, output and financial conditions from their target values. Thus, they place equal weight to negative and positive deviations of inflation, output and financial conditions from their target values. When  $\alpha_\pi$ ,  $\alpha_y$  and  $\alpha_z$  are equal to zero, monetary authorities weigh inflation, output and financial conditions more severely when they overshoot their target values and become less aggressive interest rates. The opposite is true for  $\alpha_\pi$ ,  $\alpha_y$  and  $\alpha_z$  are less than zero where the monetary authorities move interest rates more aggressively when the target variables undershoot their reference values than

when they overshoot them. Surico (2007a) made similar findings for preferences over output expansion in the context of the Federal Reserve's monetary policy rule.

**Figure 3.2 Optimal monetary policy rules**



Note: The Figures illustrate the gap between the steady-state and equilibrium interest rates, denoted by  $igap$ , calculated using equation [8]. The Figure is adopted from Boinet and Martin (2008).

When  $\beta_\pi$ ,  $\beta_y$  and  $\beta_z$  equal 1, the monetary authorities have quadratic preferences so that the optimal monetary policy rule follows the linear function as proposed by Nobay and Peel (2003) as well as Surico (2007a,b). The response of monetary authorities to the fluctuations of the target variables from their desired values is asymmetric and their aggressiveness to deviations of the target variables from their desired values depends on the values of  $\alpha_\pi$ ,  $\alpha_y$  and  $\alpha_z$ . When  $\beta_\pi$ ,  $\beta_y$  and  $\beta_z$  equal 2,4,6,..., the monetary authorities have zone-like preferences as proposed by Orphanides and Wieland (2000). In this case, monetary authorities are passive when target variables fluctuate within a target zone and become increasingly aggressive when the target variables fluctuate outside these zones. The response of monetary authorities to the fluctuations of the target variables is symmetric and their aggressiveness outside this zone increases with the larger values of  $\alpha_\pi$ ,  $\alpha_y$  and  $\alpha_z$ . For values of  $\beta_\pi$ ,  $\beta_y$  and  $\beta_z$  equal 3,5,7,..., the monetary authorities' response to fluctuations of target variables is both zone-like and asymmetric. Thus, the specified monetary policy response functions nest two very important features where monetary authorities' policy preferences can be asymmetric and zone-like in their responses.

### 3.2.5 Empirical model

Testing the statistical significance of the parameters of the central bank's reaction function involves estimating equation [8]. However, this amounts to testing linearity against a non-linear model. To overcome this problem, the central bank's reaction function is linearised to eliminate the exponential terms. This is achieved by approximating equation [8] using a first order Taylor series expansion when  $\alpha_\pi$ ,  $\alpha_y$  and  $\alpha_z$  tend to zero. Thus by using a first order Taylor series expansion and replacing the expectations terms with realised values, the reduced form central bank's reaction function now becomes

$$\begin{aligned} \hat{i}_t = i^* + \omega_\pi (\pi_{t+1} - \pi^*)^{2\beta-1} \left( 1 + \frac{\alpha_\pi}{2} (\pi_{t+1} - \pi^*)^{\beta_\pi} \right) \\ + \omega_y (y_{t+1})^{2\beta-1} \left( 1 + \frac{\alpha_y}{2} (y_{t+1})^{\beta_y} \right) + \omega_z (z_{t+1})^{2\beta-1} \left( 1 + \frac{\alpha_z}{2} (z_{t+1})^{\beta_z} \right) + \varepsilon_t^i \end{aligned} \quad [9]$$

When  $\beta_x$ ,  $\beta_y$  and  $\beta_z$  equal 1 the monetary authorities has linex preferences and the monetary policy reaction function generalises to a linear Taylor rule when  $\alpha_\pi$ ,  $\alpha_y$  and  $\alpha_z$  approach zero.

Adding a partial adjustment mechanism  $i_t = \rho(L)i_{t-1} + (1-\rho(L))\hat{i}_t$  to allow for interest rate persistence following Clarida et al. (1999) achieves the following reduced form central bank's reaction function

$$i_t = \rho(L)i_{t-1} + (1-\rho(L)) \left( \begin{aligned} &\omega_0 + \omega_\pi (\pi_{t+1} - \pi^*)^{2\beta-1} \left( 1 + \frac{\alpha_\pi}{2} (\pi_{t+1} - \pi^*)^{\beta_\pi} \right) \\ &+ \omega_y (y_{t+1})^{2\beta-1} \left( 1 + \frac{\alpha_y}{2} (y_{t+1})^{\beta_y} \right) + \omega_z (z_{t+1})^{2\beta-1} \left( 1 + \frac{\alpha_z}{2} (z_{t+1})^{\beta_z} \right) \end{aligned} \right) + \varepsilon_t^i \quad [10]$$

Where  $\varepsilon_t^i$  is the residual of the Taylor's series expansion.

### 3.3 Data description

The data used in the analysis is sourced from the South African Reserve Bank database. All data is denominated in monthly frequency and the sample ranges from January 2000 to December 2008 covering the inflation targeting era in South Africa. The 91-day Treasury bill rate measures the nominal interest rate. The Treasury bill rate has commonly been used as a proxy for official policy rate, particularly in studies for the United Kingdom such as Martin and Boinet (2008), Nelson (2003) and others. The correlation between the repurchase rate and treasury bill rate during the sample period is sufficiently high at about 98 percent and drops to about 96 percent after 2007 due to the disruption of the close relationship between policy rates and money market interest rates during the recent financial crisis. Inflation is approximated by the annual change in the consumer price index.

Output is measured using the coincident business cycle indicator. We measure the output gap as the deviation of coincident business cycle indicator from a Hodrick and Prescott (1997) trend. Industrial production is often used as the measure of the

output gap at the monthly frequency. However, this runs into operational problems because although Industrial production is obtainable from the South African Reserve bank, industrial production is not official data in South Africa. We also found that the coincident business cycle indicator is a better proxy because it has a higher correlation with gross domestic product than industrial production at levels and in deviations from trend. The coincident business cycle indicator is the composite index comprising five equally weighted components including Gross value added and Industrial production index making a broader measure of economic activity. Although the Hodrick Prescott filter is used to compute the output gap, other methods do exist in the literature including the Blanchard-Quah decomposition, the Kalman filter and the production function. However, the Hodrick Prescott filter is the most commonly used approach in the literature, particularly in similar studies such as in Surico (2007a, b), Boinet and Martin (2008).

Financial variables and asset prices represent another group of variables that have recently been considered in the specification of the monetary policy reaction functions for the analysis of the behaviour of central banks. Rudebusch (2002) raises the issue of an omitted variables problem by pointing out that the significance of interest rate persistence in the policy rule could be due to omitting a financial spread variable from the estimated regression. Gerlach-Kristen (2004) and English et al. (2003) find that inclusion of a financial spread reduces the empirical importance of interest rate smoothing. Among others, Estrella and Mishkin (1997) analyse the influence of a term structure variable in policy rules. In the South African context, the asset prices most likely used in empirical models of monetary policy have been the exchange rate (Woglom, 2003), the real exchange rate in Ortiz and Sturzenegger (2007). Following the above studies and Castro (2008) in particular, the financial index variable pools together relevant information provided by a number of financial variables.

The range of potential financial variables to include in the index of financial conditions is vast due to the plethora of financial measures that influence the supply and demand of financial instruments relevant for economic activity. The index used here is constructed as a weighted average of the following variables; (i) the real house price index where the house price index is an average price of all houses

compiled by the ABSA bank, deflated by the consumer price index. (ii) the real stock price, which is measured by the Johannesburg Stock Exchange All Share index, deflated by the consumer price index. (iii) the real effective exchange rate with the foreign exchange rate in the denominator. (iv) the credit spread, which is the spread between the yield on the 10-year government bond and the yield on A rated corporate bonds, and (v) the future spread which is the change of spread between the 3-month interest rate futures contracts in the previous quarter and the current short-term interest rate.

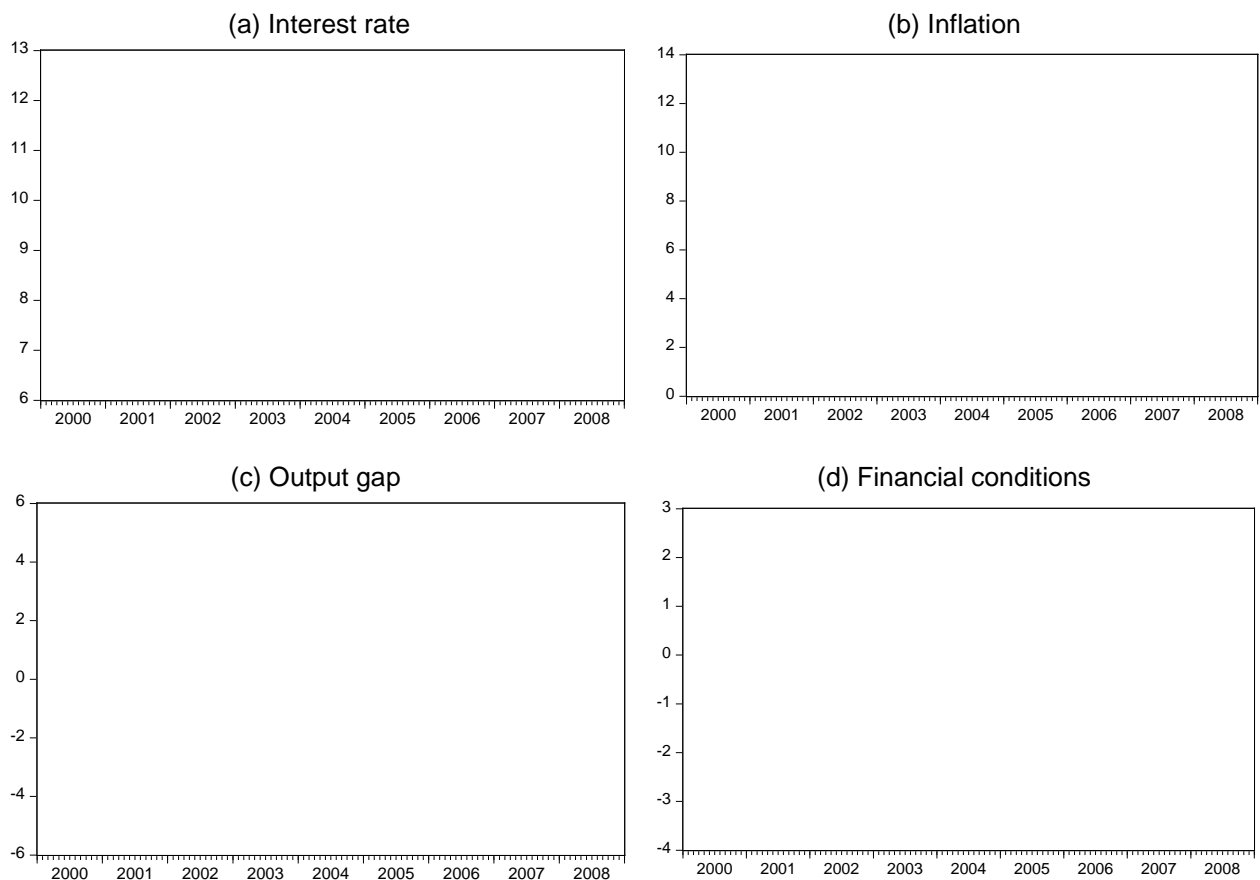
According to Castro (2008), these variables contain valuable information from the monetary authorities' point of view in that they provide an indication of financial markets stability and expectations about the monetary policy stance. In particular, the credit spread is a good proxy for the business cycle and financial stress, while future interest rates spread is a good indicator of expected interest rates by the economic agents. The index of financial conditions recognises the importance of the transmission of monetary policy through the asset prices and the credit channels over and above the interest rate channel (Mishkin, 1996 and Bernanke and Gertler, 2000).

The stock price, real effective exchange rate and house price variables are detrended using the Hodrick Prescott filter. The autoregressive ( $n$ ) model is applied to the output measure and the components of the financial index to tackle the end-point problem in calculating the Hodrick Prescott trend as proposed by Mise et al. (2005a,b).  $n$  is set to 4 to eliminate serial correlation and heteroscedasticity. A similar application of an autoregressive (4) model to the end points criticism of the Hodrick Prescott filter can be found in Martin and Milas (2010a). The autoregressive model was used to forecast twelve additional months that were then added to each of the series before applying the Hodrick Prescott filter.

Equal weights are used in the computation of the index of financial conditions. It is expressed in standardised form, relative to the mean value in 2000 so that the vertical scale measures deviations from the mean. Therefore, a value of 1 represents a 1-standard deviation difference from the mean. Castro (2008) uses time-varying weights based on the extended model of Rudebusch and Svensson's (1999). The

preferred choice lies in the fact that the time-varying weights are based on a backward-looking Phillips and IS curves. This is distinct from the model of the economy that we assumed in this chapter, which is the forward looking model by Clarida et al. (1999). Additionally, all data are seasonally adjusted and is similar to the financial conditions index provided by the Bank of England (Bank of England, 2007). The evolution of the main variables is shown in Figure 3.3.

**Figure 3.3 Evolution of the main variables**



Note: Own calculations with data sourced from the South African Reserve bank

As illustrated, inflation has had a sustained fall in 2003 and at the end of the sample period and is showing a persistent increase from 2004 to 2007 together with an accompanying increase in interest rate. The output gap was largely range bound but increased notably from 2005 before the severe downturn by the end of 2008. The movements in the financial conditions index track the main milestones in the South African financial sector. This is because its turning points, particularly the downturns,



are consistent with the technology market bubble in 2000, the September 11 terrorist attacks in the United States and the rapid depreciation of the South African currency in 2001. The turning points are also consistent with the US attack on Iraq in 2003 and the onset of the financial crisis via the subprime crisis in late 2007 and the collapse of the global financial market in late 2008 due to the bankruptcy of Lehman brothers. The volatility in 2003-2004 reflects the tight liquidity conditions due to high interest rates and low economic sentiment in emerging economies consistent with the war in Iraq in 2003 and the ultimate rally in financial markets as the tide of stringent liquidity conditions turned and investor sentiment towards emerging economies improved in 2004

### 3.4 Empirical results

The orthogonality conditions in the central bank's reaction function allow the use of Generalised Method of Moments in estimation. The specifications for the preferred optimal policy rule allow for one lag of the interest rate, with the lead structure of 6 months on inflation gap, one month on the output gap and one month on the financial conditions index. The estimations were also tried using the repurchase rate as a measure of the interest rate where the models perform perhaps due to the lack of variability in the repurchase rate. Additionally, Boinet and Martin (2008) use the 3 month treasury bill rate in a similar study despite the repurchase rate being the monetary policy interest rate in the United Kingdom. Assuming perfect foresight for inflation, we replace forecasts of inflation gap, output gap and financial conditions index by their respective future realizations.

As discussed above, the instrument set includes the lags of independent variables, long term government bond yield, and annual growth in M3. For the purpose of the selection of the best model, equation [10] is estimated for various assumptions concerning  $\beta_\pi$ ,  $\beta_y$  and  $\beta_z$ . This results in 64 estimated models for the cases where inflation, output gap and financial conditions are linear, asymmetric, zone symmetric and zone asymmetric. The estimated standard errors of the regression equations are presented in Table 3.1. The results show the lowest standard error for the model with zone symmetric inflation, asymmetric output gap and linear financial conditions.

**Table 3.1 Standard errors for the values of  $\beta_\pi$ ,  $\beta_y$  and  $\beta_z$**

Linear financial conditions: $\alpha_z \rightarrow 0; \beta_z = 1$				
	Linear $\alpha_\pi \rightarrow 0; \beta_\pi = 1$	Asymmetric $\alpha_\pi \neq 0; \beta_\pi = 1$	Zone Symmetric $\alpha_\pi \neq 0; \beta_\pi = 2$	Zone Asymmetric $\alpha_\pi \neq 0; \beta_\pi = 3$
Linear $\alpha_y \rightarrow 0; \beta_y = 1$	0.314689	0.308391	0.314172	0.315627
Asymmetric $\alpha_y \neq 0; \beta_y = 1$	0.302862	0.303284	0.297457	0.310285
Zone symmetric $\alpha_y \neq 0; \beta_y = 2$	0.320607	0.312832	0.316278	0.317292
Zone Asymmetric $\alpha_y \neq 0; \beta_y = 3$	0.314185	0.307910	0.309356	0.308664
Asymmetric financial conditions: $\alpha_z \neq 0; \beta_z = 1$				
	Linear $\alpha_\pi \rightarrow 0; \beta_\pi = 1$	Asymmetric $\alpha_\pi \neq 0; \beta_\pi = 1$	Zone Symmetric $\alpha_\pi \neq 0; \beta_\pi = 2$	Zone Asymmetric $\alpha_\pi \neq 0; \beta_\pi = 3$
Linear $\alpha_y \rightarrow 0; \beta_y = 1$	0.318243	0.308653	0.316046	0.319528
Asymmetric $\alpha_y \neq 0; \beta_y = 1$	0.302139	0.301873	0.297827	0.304986
Zone symmetric $\alpha_y \neq 0; \beta_y = 2$	0.323654	0.313151	0.318329	0.320061
Zone Asymmetric $\alpha_y \neq 0; \beta_y = 3$	0.323654	0.313151	0.318329	0.320091
Zone symmetric financial conditions: $\alpha_z \neq 0; \beta_z = 2$				
	Linear $\alpha_\pi \rightarrow 0; \beta_\pi = 1$	Asymmetric $\alpha_\pi \neq 0; \beta_\pi = 1$	Zone Symmetric $\alpha_\pi \neq 0; \beta_\pi = 2$	Zone Asymmetric $\alpha_\pi \neq 0; \beta_\pi = 3$
Linear $\alpha_y \rightarrow 0; \beta_y = 1$	0.318233	0.308653	0.316046	0.321598
Asymmetric $\alpha_y \neq 0; \beta_y = 1$	0.306474	0.306951	0.300983	0.300396
Zone symmetric $\alpha_y \neq 0; \beta_y = 2$	0.325196	0.316229	0.319986	0.323798
Zone Asymmetric $\alpha_y \neq 0; \beta_y = 3$	0.319746	0.313013	0.313846	0.316622
Zone asymmetric financial conditions: $\alpha_z \neq 0; \beta_z = 3$				
	Linear $\alpha_\pi \rightarrow 0; \beta_\pi = 1$	Asymmetric $\alpha_\pi \neq 0; \beta_\pi = 1$	Zone Symmetric $\alpha_\pi \neq 0; \beta_\pi = 2$	Zone Asymmetric $\alpha_\pi \neq 0; \beta_\pi = 3$
Linear $\alpha_y \rightarrow 0; \beta_y = 1$	0.319457	0.312405	0.318609	0.318672
Asymmetric $\alpha_y \neq 0; \beta_y = 1$	0.317553	0.307958	0.300282	0.300258
Zone symmetric $\alpha_y \neq 0; \beta_y = 2$	0.327429	0.318748	0.320263	0.325099
Zone Asymmetric $\alpha_y \neq 0; \beta_y = 3$	0.322155	0.314588	0.315419	0.319071

The preferred model based on the lowest standard error indicates that the monetary authorities' response towards inflation is zone-like. This is consistent with the inflation targeting framework in South Africa where inflation is allowed to fluctuate within a specified band of 3 to 6 percent. This model also indicates that the monetary authorities' response towards output is asymmetric. This means that the monetary authorities weigh differently negative and positive output deviations from its potential. Finally, the model indicates that the monetary authorities' response to financial conditions is linear so that the monetary authorities do not weigh the deviations of financial conditions differently regardless of whether they overshoot or undershoot their desired values. The estimates of the preferred model based on the lowest standard error are presented in Table 3.2. The results are compared with those from the model with linear inflation, output gap and financial conditions, which is the benchmark for estimated monetary policy rules. The Hansen's J-test is carried out to determine the validity of instruments under the null hypothesis of that the over identifying restrictions are satisfied. The validity of the instruments used is confirmed by the reported p-values for the Hansen's J-statistics for the benchmark monetary policy rule and the preferred model.

It is worth noting that the augmented linear monetary policy rule performs poorly in terms of robustness compared to the preferred model with zone symmetric inflation, asymmetric output gap and linear financial conditions. However, the results of the linear monetary policy rule show that all the coefficients are statistically significant except the coefficient on the output gap. The coefficients show a positive response to the interest rate changes implying that interest rate hikes are associated with rising inflation, output gap and the financial conditions. The results show that the monetary authorities increase interest rates by 1.19 percent when inflation overshoots its long term trend by one percent. Irrespective of the deviation of inflation from the target, there is a constant proportional response of interest rates to inflation and the response implied by the linear model for inflation is stronger than that of the preferred model when inflation is between 7.56 and 1.44 percent. In particular, the linear model records a statistically significant response to the index of financial conditions. A one standard deviation increase in the index relative to its mean triggers an interest rate increase of 1.94 per cent which is in excess of one percent required by the Taylor principle.

**Table 3.2 Estimates of the non-linear monetary policy rule**

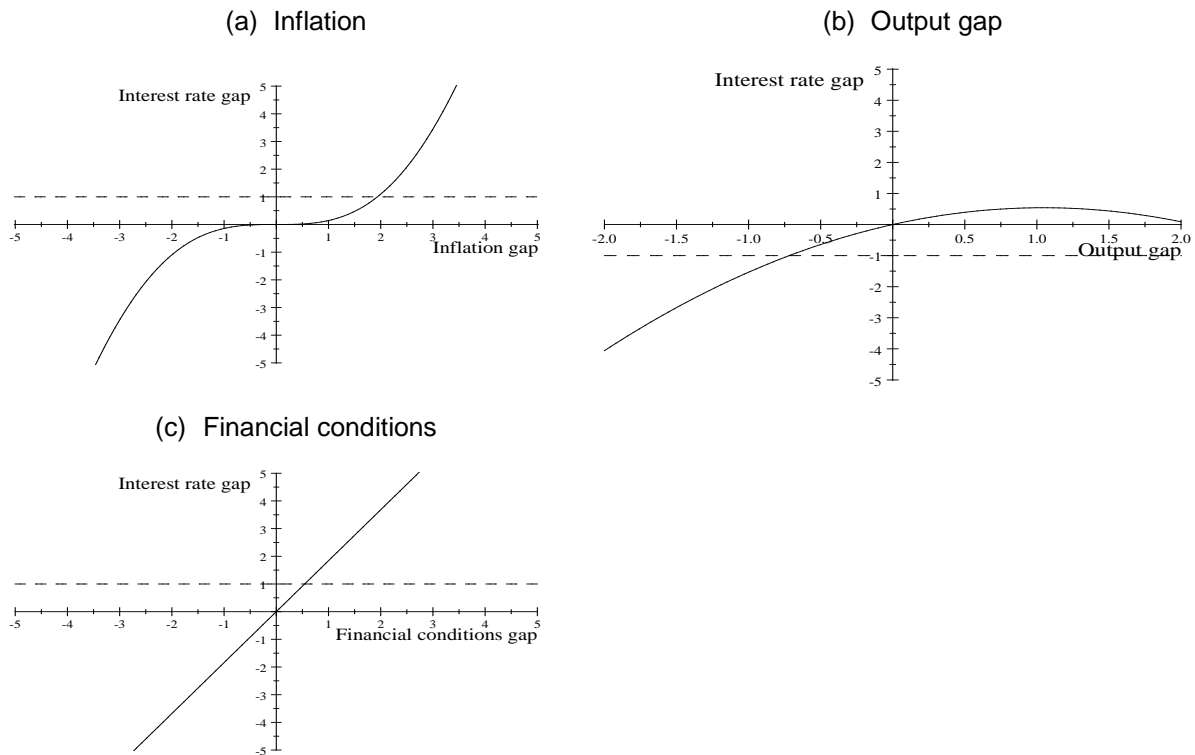
	Linear inflation, linear output gap and linear financial conditions $\alpha_\pi \rightarrow 0; \alpha_y \rightarrow 0; \alpha_z \rightarrow 0;$ $\beta_\pi = 1; \beta_y = 1; \beta_z = 1$		Zone symmetric inflation, asymmetric output gap and linear financial conditions $\alpha_\pi \neq 0; \alpha_y \neq 0; \alpha_z \rightarrow 0;$ $\beta_\pi = 2; \beta_y = 1; \beta_z = 1;$	
	Coefficient	Std error	Coefficient	Std error
$\rho_1$	0.959768*	0.009797	0.968038*	0.007557
$\omega_0$	7.145260*	0.381297	8.377442*	0.413661
$\omega_\pi$	1.192263*	0.273845	0.144554*	0.035553
$\alpha_\pi$			-0.025840*	0.000686
$\omega_y$	0.223371	0.221525	1.036774*	0.315709
$\alpha_y$			-0.957549*	0.260831
$\omega_z$	1.938763*	0.823699	1.840314*	0.789281
$\bar{R}^2$	0.971140		0.974214	
<i>Std.Error</i>	0.314689		0.297457	
<i>J – statistic</i>	0.978468		0.988056	

Note: \* denotes statistical significance at 5 percent level. *J – statistic* reports the p-value of Hansen's test for over identifying restrictions.

The preferred model with zone symmetric inflation, asymmetric output gap and linear financial conditions performs better than all the alternatives in terms of robustness and all the coefficients are statistically significant. Figure 3.4 shows the plots of the monetary authorities' responses to inflation, the output gap and financial conditions. It is obtained by substituting the estimated coefficients into equation [10]. The preferred model shows negligible response to inflation when it is between 4 and 5 percent. This implies that the monetary authorities are almost entirely passive when inflation is within 0.5 percent of the inflation target mid-point of 4.5 percent. The Taylor principle requires that monetary authorities raise the nominal interest rate by more than one-to-one when inflation exceeds its target rate. According to the results, the monetary authorities satisfy the Taylor principle by raising the nominal interest rates by 1 percent when inflation is outside the range 2.56 to 6.44 percent so that the inflation gap is about 1.94 percent from an assumed target of 4.5 percent. When inflation reaches the upper threshold of the inflation target of 6 percent, the monetary

authorities increase desired interest rate by 0.47 percent above the equilibrium interest rate of 8.34 percent.

**Figure 3.4 Estimated optimal monetary policy responses to inflation, output gap and financial conditions**



Note: The Figure illustrates the gap between desired and equilibrium interest rate obtained by substituting the estimated coefficients into equation [10]

The empirical results further show that the monetary authorities cut interest rates by one percent when the output gap undershoots its long term trend by 0.72 percent. The results further show a statistically significant response to the financial conditions index. A one standard deviation increase in the index of financial conditions relative to its mean triggers an interest rate increase of 1.84 percent. The statistically significant coefficient on the index of financial conditions in the estimated optimal monetary policy rule implies that monetary authorities do consider financial conditions when determining monetary policy outcomes. The results further show monetary authorities react more to downward output deviations relative to their desired values. Thus by implication, monetary authorities tend to place a greater

weight on output contractions, a result which is not at odds with the developing economy like South Africa.

This is the first attempt to estimate the type of monetary policy rules that feature zone-like and asymmetric preferences on the part of monetary authorities for South Africa. As a result, there are no readily available studies to make direct comparison of the results, however, attempts have been made to compare the estimated results to those of Ortiz and Sturzenegger (2007). Using a dynamic stochastic general equilibrium for the period 1983 to 2002, they found almost similar results to the results in this study for a linear monetary policy rule. According to their results, the monetary authorities in South Africa increase the nominal interest rates by 1.11, 0.27 and 0.11 when inflation, output and the exchange rate increase by one percent, respectively. They further compare their results with the Generalised Method of Moments estimates by Lubik and Schorfheide (2007) for the United Kingdom and its former colonies. They conclude that the South African monetary authorities' reaction to inflation, output and exchange rate fluctuations are almost similar to those in these countries.

### **3.5 Conclusion**

In this chapter, an optimal monetary policy rule whose foundation relies on a representation of policymaker's preferences that allow for zone targeting and asymmetric behaviours with respect to its objectives was derived and estimated. This model was augmented with a comprehensive index of financial conditions comprising the stock prices, property prices, real exchange rates and measures of credit risk to address the current debate concerning targeting financial asset prices by central banks. The estimation was carried out using monthly data for South Africa spanning the period since the adoption of the inflation targeting framework. The empirical results point to the model with zone symmetric inflation, asymmetric output gap and linear financial conditions as the preferred specification. This model is superior in-sample to the alternative monetary policy rules including the traditional linear Taylor rule representation.

The preferred model shows a zone targeting response of the monetary authorities towards inflation. The monetary authorities shows negligible response to inflation when it lies in a zone of 4 to 5 percent. The Taylor principle is satisfied when inflation is outside the range 2.56 to 6.44 percent so that the inflation gap is about 1.94 percent. The monetary authorities increase desired interest rate by 0.47 percent above the equilibrium interest rate when inflation reaches the upper threshold of the inflation target. Furthermore, the results show that the monetary authorities cut interest rates by one percent when output gap undershoots its long term trend by 0.72 percent. Most importantly, the results reveal that that the monetary authorities pay close attention to the financial conditions index when setting interest rates. The monetary authorities' response to financial conditions is symmetric irrespective of the financial market upturns and downturns.

The significant response to financial conditions by the monetary authorities arguably has important policy implications as it sheds light on the reason why the current economic downturn is less severe in South Africa than it is in the other economies. The economic effects of the global downturn were relatively benign in the domestic economy despite the fact that the financial market occupies about 25 percent of the domestic economy's total output. Similar results were found in the context of the European Central Bank that acknowledges the importance of financial conditions in the conduct of monetary policy. This is contrary to the US and the United Kingdom where financial conditions do not feature in the Central Banks' reaction functions. Thus, the lack of attention to the financial conditions might have made the United Kingdom and the United States more vulnerable to the recent credit crunch than the Euro zone and other economies such as that of South Africa.

For future research, it would be interesting to investigate the robustness of our results by carrying out an out-of-sample forecasting experiment using the alternative specifications of monetary policy reaction function to establish the model that best predicts the South African Reserve Bank's interest rate setting behaviour.

## Chapter 4

### **Financial market conditions and the response of monetary policy to uncertainty with asymmetric and zone targeting preferences in South Africa**

#### **4.1 Introduction**

The economic environment in which central banks operate is ambiguous in that they have to contend with uncertainty that poses challenges and have implications for the design and conduct of monetary policy on an ongoing basis. The literature identifies limited knowledge about the structure and the current state of the economy as well as the unexpected future events as the main sources of uncertainty in monetary policy decision making. The limited knowledge about the structure of the economy or model uncertainty arises because the monetary authorities are not certain on the model that plausibly describes the economy because models are only rough approximations of reality. Model uncertainty may also be the result of parameter uncertainty where monetary authorities may be faced with limitations on the choice between various parameters that make up the economic models. The limited knowledge about the current state of the economy or data uncertainty arises because real time data are noisy estimates of the actual data. The macroeconomic data are sometimes revised because of the availability of new information, changes in sampling methods and seasonal adjustment factors. Additionally, some economic concepts such as expectations and potential output are not directly observable.

There is no consensus or generic rule that the monetary authorities should follow in designing and implementing monetary policy when faced with uncertainty. One strand of literature suggests that parameters of optimal monetary policy rules call for stronger responses to inflation and output than those estimated from historical data suggest (Rudebusch, 2001 and Tetlow and Von zur Muehlen, 2001). The empirical optimal monetary policy rules demonstrate a more restraint response of policy rates to inflation and output fluctuations than those that are recommended by the optimal monetary policy rules when the monetary authorities are faced with uncertainty concerning the true state of the economy. The view of less aggressive policy under



uncertainty was established by Brainard (1967) and has been supported by Estrella and Mishkin (2000), Svensson (1999), Swanson (2004), Cateau (2007), Martin and Milas (2009) among others. In particular, Rudebusch (2001) found that uncertainty about the data and the specification of the model substantially reduces the Taylor rule parameters while parameter uncertainty does not matter for the US. Contrary to the accepted wisdom, Soderstrom (2002) finds that uncertainty about structural parameters of the model does not dampen the monetary authorities' response but that it may amplify it more than when the monetary authorities are acting under certainty equivalence. This finding is supported by Giannoni (2000), Kimura and Kurozumi (2007), and more recent research by Tillmann (2008) as well as Flamini and Milas (2009).

The recent concern over the maintenance of financial stability has motivated some key policy makers to acknowledge the importance of asset price bubbles in monetary policy decision making. The president of the European Central Bank, Trichet (2005, 2009), and the former vice president, Papademos (2009), have acknowledged the importance and the impact of asset prices on economic stabilisation. On the contrary, the former chairman of the Federal Reserve, Alan Greenspan (2004, 2005, 2008) and the current chairman, Bernanke (2002), do not acknowledge the importance of the bubbles in asset prices in monetary policy decision making. The member of the Board of Governors of the Federal Reserve System, Mishkin (2008), has supported this view arguing that asset price bubbles are hard to identify and that the monetary policy that responds solely to the inflation and aggregate demand will still lead to better outcomes even when bubbles might arise. Empirical evidence in this subject is also mixed. For instance, Bernanke and Gertler (2000, 2001) have shown that there is not much benefit to be gained by targeting financial asset prices. However, Siklos and Bohl (2007) as well as Castro (2008) have shown that the European Central Bank policymakers pay close attention to financial conditions when setting the Euro zone interest rates.

This chapter analyses the impact of uncertainty about the true state of the economy on monetary policy in South Africa based on a framework that allows asymmetric and zone targeting monetary authorities' preferences. The empirical model is an extended version of Svensson's (1999), Yun (1996) and Woodford (2003) models of

inflation targeting. It combines elements from Orphanides and Wieland (2000) and Boinet and Martin (2008) to accommodate 'zone-like' and asymmetric behaviours in the policy reaction function. This modelling framework is coupled with models that are drawn from the theoretical literature on optimal monetary policy when there is uncertainty about the true state of the economy, most prominently Svensson and Woodford (2003, 2004) and Swanson (2004). It differs from the empirical model of Martin and Milas (2009) in that it uses a forward looking framework and incorporates more flexible preferences for the monetary policy maker. The chapter also innovates by augmenting the monetary policy reaction function with a comprehensive index comprising various financial asset variables describing the conditions in the financial market to address the current debate on the importance of financial assets prices in monetary policy decision making.

South Africa implemented inflation targeting as a preferred framework for monetary policy in 2000 where the inflation target range of 3 to 6 percent was adopted. The inflation target band practice suggests that policymakers may exhibit 'zone-like' behaviour by responding more to inflation when inflation is some way from the target band but by responding more passively when inflation is inside the target band. The literature also suggests asymmetries in which case the response of interest rates is different for positive and negative deviations of inflation, output and financial conditions from their desired levels. Therefore, low inflation that is below the target, desired inflation that is hitting the target and high inflation that is above the target have different impact on the economy and the monetary policy instance. Likewise, the economic recessions and expansions have different impact on future economic performance and the state of the economy. This chapter is important in that it will objectively reveal how the monetary authorities design and conduct monetary policy under uncertainty about the limited knowledge about the current true state of the economy using a framework that capture the stylised monetary policy practice at central banks.

The next section is the description of the theoretical model, which is an intertemporal optimisation problem that incorporates uncertainty. Section 3 provides the data description. Section 4 discusses the empirical results with emphasis on the impact of uncertainty on monetary policy. Section 5 concludes.

## 4.2 Theoretical model

The central bank's monetary policy design problem is a modified targeting rule following Svensson (1999). It is modified to accommodate advances in Orphanides and Wieland (2000) and Boinet and Martin (2008), Swanson (2004) and Martin and Milas (2009). We leave the model as a closed economy one given that modelling a fully fledged open economy set up is beyond the scope of the present chapter.

### 4.2.1 Structure of the economy

The framework of the evolution of monetary policy is the New-Keynesian forward looking model of the business cycle derived in Yun (1996) and Woodford (2003). The aggregate demand is a log linearised version of the Euler equation for consumption described by the following equation in which the output gap in the current period is affected by its future expectations and the state of the economy given by

$$y_t = \eta_y E_t y_{t+1} + \psi_y x_t + \varepsilon_t^y \quad [1]$$

where  $y_t$  is the output gap and  $x_t$  is the state of the economy.  $\eta_y > 0$  and  $\psi_y > 0$  are coefficients and  $\varepsilon_t^y \sim N(0, \sigma_{y_t}^2)$  is the demand shock.  $\sigma_{y_t}^2$  measures the uncertainty about the output gap and its volatility is assumed to evolve as a general autoregressive conditional heteroscedasticity (1,1) process.

The aggregate supply (Phillips curve) captures, in a log-linearised manner, the staggered feature of the Calvo type world in which inflation in the current period is affected its future expectations, the output gap and the state of the economy given by

$$\pi_t = \eta_\pi E_t \pi_{t+1} + \psi_\pi x_t + k y_t + \varepsilon_t^\pi \quad [2]$$

where  $\pi_t$  is the inflation rate,  $\eta_\pi > 0$ ,  $\psi_\pi > 0$  and  $k > 0$  are the coefficients, while  $\varepsilon_t^\pi \sim N(0, \sigma_{\pi t}^2)$  is the supply shock.  $\sigma_{\pi t}^2$  measures the uncertainty about the inflation and its volatility is assumed to evolve as a general autoregressive conditional heteroscedasticity (1,1) process.

The structure of the economy also comprises two additional equations describing financial conditions and the state of the economy as in Martin and Milas (2009) over and above the aggregate demand and supply curves in the usual New-Keynesian forward looking model. The equation describing the evolution of financial conditions is specified as follows

$$z_t = \eta_z E_t z_{t+1} + \psi_z x_t + \varepsilon_t^z \quad [3]$$

where  $z_t$  measures the financial conditions,  $\eta_z > 0$ ,  $\psi_z > 0$  is the coefficient, while  $\varepsilon_t^z \sim N(0, \sigma_{z t}^2)$  is the shock to financial conditions.  $\sigma_{z t}^2$  measures the uncertainty about the financial conditions and its volatility is assumed to evolve as a general autoregressive conditional heteroscedasticity (1,1) process. Financial stability can be increased by reducing nominal interest rates which allows the financial institutions to re-capitalise itself at a lower cost following Martin and Milas (2010c).

The equation describing the state of the economy is specified as follows

$$x_t = \eta_x E_t x_{t+1} - \psi_x (i_{t-1} - E_{t-1} \pi_t) + \varepsilon_t^x \quad [4]$$

where  $i_t$  is the nominal interest rate,  $\eta_x > 0$ ,  $\phi > 0$  is the coefficient, while  $\varepsilon_t^x \sim N(0, \sigma_{x t}^2)$  is the shock to the state of the economy. The state of the economy is included in equations [1], [2] and [3] so that monetary policy then affects the state of the economy as in Swanson (2004) and Martin and Milas (2009). The state of the economy may have more elements than one specified above. A detailed discussion on the forms of the state of the economy can be found in Swanson (2004).

The existing models of monetary policy under certainty assume that monetary policy affects inflation and the output gap directly. As a result, it is optimal for policymakers to use these variables in monetary policy decision making. This is the basis for the Taylor (1993) rule and its subsequent refinements by Woodford (2003). In Woodford (2003), Swanson (2004) and Martin and Milas (2009), the specified monetary policy reaction function assumes that monetary policy affects the state of the economy, which in turn affects inflation, the output gap and financial market conditions.

#### 4.2.2 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  $t - 1$

$$\text{Min}_{\{i_t\}} E_{t-1} \sum_{\tau=0}^{\infty} \delta^{\tau} L_{t+\tau} \quad [5]$$

where  $\delta$  and  $L$  is the discount factor and the period loss function, respectively.

The period loss function is a linear specification first introduced in the monetary policy literature by Nobay and Peel (2003) and extended to accommodate zone targeting preferences following Orphanides and Wieland (2000). The period loss function is a function of the variables describing the structure of the economy so that the monetary authorities are assumed to observe the state of the economy initially and later to be relaxed. Therefore, the period loss function is specified as follows

$$L_t = \frac{e^{\alpha_{\pi}(\pi_t - \pi^*)^{\beta_{\pi}}} - \alpha_{\pi}(\pi_t - \pi^*)^{\beta_{\pi}} - 1}{\beta_{\pi} \alpha_{\pi}^2} + \lambda_y \left( \frac{e^{\alpha_y (y_t)^{\beta_y}} - \alpha_y (y_t)^{\beta_y} - 1}{\beta_y \alpha_y^2} \right) \quad [6]$$

$$+ \lambda_z \left( \frac{e^{\alpha_z (z_t)^{\beta_z}} - \alpha_z (z_t)^{\beta_z} - 1}{\beta_z \alpha_z^2} \right) + \lambda_x \left( \frac{e^{\alpha_x (x_t)^{\beta_x}} - \alpha_x (x_t)^{\beta_x} - 1}{\beta_x \alpha_x^2} \right) + \frac{\lambda_i}{2} (i_t - i^*)^2$$

where  $\alpha_\pi$  captures the asymmetries, while  $\beta_\pi$  captures the zone-like properties in the central bank's preferences.  $i^*$  is the desired level of interest rate, while  $\pi^*$  is the inflation target.  $\lambda_{y,z,x} > 0$  are weights in output gap, financial conditions and the state of the economy. They measure the central bank's aversion to the fluctuations of these variables relative to their desired levels, while  $\lambda_i > 0$  measures the central bank's aversion to the fluctuations of the interest rate around the target level. The policy maker's preference towards inflation stability is normalised to one so that  $\lambda_{y,z,x} > 0$  and  $\lambda_i > 0$  are expressed in relative terms.

The loss function embodies numerous attractive characteristics of linearities, asymmetries and zone-like central bank's preferences depending on the values of  $\alpha_{\pi,y,z,x}$  and  $\beta_{\pi,y,z,x}$ . As special cases, whenever  $\beta_{\pi,y,z,x}$  approach one, the period loss function generalises to a linex function, while applying L'Hopital's rule on the loss function when whenever  $\alpha_{\pi,y,z,x}$  approach zero and  $\beta_{\pi,y,z,x}$  approach one simultaneously achieves a quadratic loss function. For a detailed discussion on all the possible configurations of the loss function, see Boinet and Martin (2008).

#### 4.2.3 Optimal monetary policy under observable state of the economy

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

$$\begin{aligned}
 & E_{t-1} \left( \frac{e^{\alpha_\pi(\pi_t - \pi^*)^{\beta_\pi}} - \alpha_\pi(\pi_t - \pi^*)^{\beta_\pi} - 1}{\beta_\pi \alpha_\pi^2} \right) + \lambda_y E_{t-1} \left( \frac{e^{\alpha_y(y_t)^{\beta_y}} - \alpha_y(y_t)^{\beta_y} - 1}{\beta_y \alpha_y^2} \right) \\
 & + \lambda_z E_{t-1} \left( \frac{e^{\alpha_z(z_t)^{\beta_z}} - \alpha_z(z_t)^{\beta_z} - 1}{\beta_z \alpha_z^2} \right) + \lambda_x E_{t-1} \left( \frac{e^{\alpha_x(x_t)^{\beta_x}} - \alpha_x(x_t)^{\beta_x} - 1}{\beta_x \alpha_x^2} \right) + \frac{\lambda_i}{2} (i_t - i^*)^2 + F_t
 \end{aligned} \tag{7}$$

Subject to the structure of the economy where  $F_t \equiv E_{t-1} \sum_{\tau=1}^{\infty} \delta^\tau L_{t+\tau}$ . The model is solved assuming that the central bank takes expectations as given. This is because the monetary authorities cannot directly manipulate the economic agents' expectations.

#### 4.2.4 Central bank's reaction function

The following first order condition describes the central bank's optimal monetary policy rule

$$\begin{aligned} \delta E_{t-1} f'(\pi_{t+1} - \pi^*) \frac{\partial \pi_{t+1}}{\partial y_{t+1}} \frac{\partial y_{t+1}}{\partial x_{t+1}} \frac{\partial x_{t+1}}{\partial i_t} + \delta \lambda_y E_{t-1} f'(y_{t+1}) \frac{\partial y_{t+1}}{\partial x_{t+1}} \frac{\partial x_{t+1}}{\partial i_t} + \\ \delta \lambda_z E_{t-1} f'(z_{t+1}) \frac{\partial z_{t+1}}{\partial x_{t+1}} \frac{\partial x_{t+1}}{\partial i_t} + \delta \lambda_x E_{t-1} f'(x_{t+1}) \frac{\partial x_{t+1}}{\partial i_t} + \lambda_i (i_t - i^*) = 0 \end{aligned} \quad [8]$$

where  $f(a_i; \alpha, \beta) = \left( \frac{e^{\alpha a_i^\beta} - \alpha a_i^\beta - 1}{\beta \alpha^2} \right)$  and  $f'(\cdot)$  is the first derivative of this function.

The parameter  $\alpha$  and the exponential function determine the asymmetric response of monetary policy rates to the departure of target variables from their reference values, while  $\beta$  captures the zone-like properties as above.

Solving equation [8] achieves the reduced form central bank's reaction function

$$\begin{aligned} \hat{i}_t = i^* + \omega_\pi E_{t-1} f'(\pi_{t+1} - \pi^*) (\pi_{t+1} - \pi^*) + \omega_y E_{t-1} f'(y_{t+1}) (y_{t+1}) \\ + \omega_z E_{t-1} f'(z_{t+1}) (z_{t+1}) + \omega_x E_{t-1} f'(x_{t+1}) (x_{t+1}) \end{aligned} \quad [9]$$

where  $\hat{i}_t$  is the optimal interest rate,  $\omega_\pi = -\left( \frac{k \psi_y \psi_x \delta}{\lambda_i} \right)$ ,  $\omega_y = -\left( \frac{\psi_y \psi_x \lambda_y \delta}{\lambda_i} \right)$ ,

$\omega_z = -\left( \frac{\psi_z \psi_x \lambda_z \delta}{\lambda_i} \right)$ , and  $\omega_x = -\left( \frac{\psi_x \lambda_x \delta}{\lambda_i} \right)$  are convolutions of parameters representing

the central bank's preferences and the structure of the economy and

$f'(a_t; \alpha, \beta) = a_t^{\beta-1} \left( \frac{e^{\alpha a_t^\beta} - 1}{\alpha} \right)$ . The weight in inflation is given by  $\omega E_{t-1} f'(\cdot)$  and the

weight on stabilization of the state of the economy is  $\omega_x$ . Equation (9) therefore shows optimal monetary policy under observable state of the economy.

As with the loss function in equation (7), whenever  $\beta_\pi$  equals one, the monetary authorities have linear preferences. The monetary policy reaction function generalises to a linear Taylor rule whenever  $\alpha_\pi$  approaches zero. The monetary policy reaction function reveals asymmetries to inflation and output whenever  $\alpha_\pi$  is not equal to zero. Whenever  $\beta_\pi$  is even, the monetary policy reaction function exhibits zone-like preferences similar to that proposed by Orphanides and Wieland (2000). A detailed discussion on all the possible configurations of the monetary policy reaction function is in Boinet and Martin (2008).

#### 4.2.5 Optimal monetary policy under unobservable state of the economy

Assuming that the state of the economy is not fully observed by the monetary authorities, then the monetary policy rule does not satisfy certainty equivalence. Therefore, the state of the economy, which is a measure of excess demand, must be inferred from observed inflation, output gap and financial market conditions. Signal extraction is used to derive the optimal predictor of the unobservable state of the economy. The optimal predictor of the true state of the economy is a nonlinear function of the equations describing the structure of the economy whose parameters are functions of the variances of the observed variables that are assumed to be time varying. Therefore, the expected value of the state of the economy is now specified in terms of the observables as follows

$$E_{t-1} f'(x_{t+1})(x_{t+1}) = \theta_{\pi t} E_{t-1} f'(\pi_{t+1} - \pi^*)(\pi_{t+1} - \pi^*) + \theta_{y t} E_{t-1} f'(y_{t+1})(y_{t+1}) + \theta_{z t} E_{t-1} f'(z_{t+1})(z_{t+1}) \quad [10]$$



where equation [10] is the optimal predictor of the state of the economy given the information set available to the monetary authorities at time  $t-1$ . The state of the economy depends on whether inflation moves out of the target range or if output overshoots or undershoots its target and likewise for financial market conditions. It is important to note that the non-quadratic preferences for inflation, output gap and financial conditions already imply non-certainty equivalence.

The changes in volatility of the state of the economy affect the coefficients of the state of the economy  $\theta_{\pi t}$ ,  $\theta_{y t}$  and  $\theta_{z t}$ . Therefore, the coefficients of the state of the economy vary overtime so that they are functions of the volatilities of the shocks to inflation, output gap and the index of financial conditions. The nonlinear functional form differs from Swanson (2004) and Martin and Milas (2009) who assume that the state of the economy is a linear function of its predictors. It follows from the zone targeting and asymmetric monetary policy preferences where the monetary authorities react differently to the deviation of the target variables from their desired values so that recessions and expansions have different impact on future economic performance and the state of the economy.

Using equation [10], the optimal monetary policy rule given by equation [9] is now rewritten in terms of the observables as

$$\hat{i}_t = i^* + \rho_{\pi t} E_{t-1} f'(\pi_{t+1} - \pi^*)(\pi_{t+1} - \pi^*) + \rho_{y t} E_{t-1} f'(y_{t+1})(y_{t+1}) + \rho_{z t} E_{t-1} f'(z_{t+1})(z_{t+1}) \quad [11]$$

where  $\rho_{\pi t} = \omega_{\pi} + \omega_x \theta_{\pi t}$ ,  $\rho_{y t} = \omega_x \theta_{y t}$  and  $\rho_{z t} = \omega_x \theta_{z t}$ . The monetary policy reaction function in [11] does not satisfy certainty equivalence because the expected value of the state of the economy is derived from the observable indicator variables of monetary policy. As above, the coefficients  $\rho_{\pi t}$ ,  $\rho_{y t}$  and  $\rho_{z t}$  are functions of the volatilities of inflation, output gap and the index of financial conditions and they vary overtime. As we noted earlier, non-certainty equivalence already follows from assuming non-quadratic preferences.

#### 4.2.6 Empirical model

The central bank's reaction function is linearised to eliminate the exponential terms by approximating equation [11] using a first order Taylor series expansion when  $\alpha_\pi$ ,  $\alpha_y$  and  $\alpha_z$  tend to zero. This is because estimating the central bank's reaction function in equation [11] to test the statistical significance of the parameters amounts to testing linearity against a non-linear model. Replacing the expectations with realised values and the parameters of the model with identifiable coefficients, the reduced form central bank's reaction function now becomes:

$$\begin{aligned} \hat{i}_t = & i^* + \rho_{\pi t} (\pi_{t+1} - \pi^*)^{2\beta_\pi - 1} \left( 1 + \frac{\alpha_{\pi t}}{2} (\pi_{t+1} - \pi^*)^{\beta_\pi} \right) \\ & + \rho_{y t} (y_{t+1})^{2\beta_y - 1} \left( 1 + \frac{\alpha_{y t}}{2} (y_{t+1})^{\beta_y} \right) + \rho_{z t} (z_{t+1})^{2\beta_z - 1} \left( 1 + \frac{\alpha_{z t}}{2} (z_{t+1})^{\beta_z} \right) \end{aligned} \quad [12]$$

where the parameters of the optimal policy rule are given by

$$\begin{aligned} \rho_{\pi t} &= \rho_\pi + \rho_\pi^\pi \sigma_{\pi t}^2 + \rho_\pi^y \sigma_{y t}^2 + \rho_\pi^z \sigma_{z t}^2, \\ \rho_{y t} &= \rho_y + \rho_y^\pi \sigma_{\pi t}^2 + \rho_y^y \sigma_{y t}^2 + \rho_y^z \sigma_{z t}^2, \\ \rho_{z t} &= \rho_z + \rho_z^\pi \sigma_{\pi t}^2 + \rho_z^y \sigma_{y t}^2 + \rho_z^z \sigma_{z t}^2, \\ \alpha_{\pi t} &= \alpha_\pi + \alpha_\pi^\pi \sigma_{\pi t}^2 + \alpha_\pi^y \sigma_{y t}^2 + \alpha_\pi^z \sigma_{z t}^2, \\ \alpha_{y t} &= \alpha_y + \alpha_y^\pi \sigma_{\pi t}^2 + \alpha_y^y \sigma_{y t}^2 + \alpha_y^z \sigma_{z t}^2 \text{ and} \\ \alpha_{z t} &= \alpha_z + \alpha_z^\pi \sigma_{\pi t}^2 + \alpha_z^y \sigma_{y t}^2 + \alpha_z^z \sigma_{z t}^2. \end{aligned}$$

All these parameters are identifiable and they depend on the volatilities of the disturbance terms to inflation, the output gap and financial conditions described in equation [1], [2] and [3].

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:

$$i_t = \rho(L)i_{t-1} + (1 - \rho(L)) \left( \begin{array}{l} \rho_0 + \rho_{\pi t} (\pi_{t+1} - \pi^*)^{2\beta_\pi - 1} \left( 1 + \frac{\alpha_{\pi t}}{2} (\pi_{t+1} - \pi^*)^{\beta_\pi} \right) \\ + \rho_y (y_{t+1})^{2\beta_y - 1} \left( 1 + \frac{\alpha_{yt}}{2} (y_{t+1})^{\beta_y} \right) \\ + \rho_z (z_{t+1})^{2\beta_z - 1} \left( 1 + \frac{\alpha_{zt}}{2} (z_{t+1})^{\beta_z} \right) \end{array} \right) + \varepsilon_t^i \quad [13]$$

where  $\varepsilon_t^i$  is the residual of the Taylor's series expansion.

The estimates of the optimal monetary policy reaction function can be used to illustrate the effects of uncertainty on monetary policy. This illustration infers what the interest rates would be in absence of uncertainty. The following counterfactual monetary policy rule is used for this purpose

$$i_t^c = \hat{\rho}(L)i_{t-1} + (1 - \hat{\rho}(L)) \left( \begin{array}{l} \hat{\rho}_0 + \hat{\rho}_\pi (\pi_{t+1} - \pi^*)^{2\beta_\pi - 1} \left( 1 + \frac{\hat{\alpha}_\pi}{2} (\pi_{t+1} - \pi^*)^{\beta_\pi} \right) \\ + \hat{\rho}_y (y_{t+1})^{2\beta_y - 1} \left( 1 + \frac{\hat{\alpha}_y}{2} (y_{t+1})^{\beta_y} \right) \\ + \hat{\rho}_z (z_{t+1})^{2\beta_z - 1} \left( 1 + \frac{\hat{\alpha}_z}{2} (z_{t+1})^{\beta_z} \right) \end{array} \right) + \varepsilon_t^i \quad [14]$$

where  $\hat{\rho}$ ,  $\hat{\rho}_0$ ,  $\hat{\rho}_\pi$ ,  $\hat{\rho}_y$ ,  $\hat{\rho}_z$ ,  $\hat{\alpha}_\pi$ ,  $\hat{\alpha}_y$  and  $\hat{\alpha}_z$  are estimates of the parameters in the empirical monetary policy reaction function in equation [13]. The counterfactual monetary policy rule [14] is the fitted value of the empirical monetary policy reaction function where  $\sigma_{\pi t}^2$ ,  $\sigma_{yt}^2$  and  $\sigma_{zt}^2$  are equal to zero. Thus, the effects of uncertainty on monetary policy can be quantified by the difference between the estimated monetary policy reaction function and the counterfactual monetary policy reaction function. A positive gap between these monetary policy reaction function means that the interest rates were higher because of uncertainty. The next step is to assess the contributions of the uncertainties to the gap between the fitted and the counterfactual interest rates. This involves calculating the relative contributions of uncertainties about inflation, output gap and financial conditions gap to the gap between the fitted and the counterfactual interest rates as follows

$$\hat{i}_t - i_t^c \quad [15]$$

#### 4.2.7 Structure of the economy under unobservable state of the economy

The equations describing the structure of the economy depend on the unobserved state of the economy. Since the state of the economy is unobserved, then it is replaced from the equations describing the structure of the economy by expressing them in terms of the observable variables. Using [4] in [1] achieves the following equation for aggregate demand

$$y_t = \mu_{y1} E_t y_{t+1} - \mu_{y2} E_t y_{t+2} - \mu_r (i_{t-1} - E_{t-1} \pi_t) + \xi_t^y \quad [16]$$

where  $\mu_{y1} = \eta_y + \eta_x$ ,  $\mu_{y2} = \eta_x \eta_y$ ,  $\mu_r = \rho_y \phi$ , and  $\xi_t^y = \rho_y \varepsilon_t^x - \eta_x E_t \varepsilon_{t+1}^y + \varepsilon_t^y$ .  $\xi_t^y \sim N(0, \sigma_{yt}^2)$  is the demand shock. The implied variance of the demand shock, given by  $\sigma_{yt}^2 = a_{y0} + a_{y1} \xi_{yt-1}^2 + a_{y2} \sigma_{yt-1}^2$ , measures the uncertainty about the output gap. It is assumed to evolve as a general autoregressive conditional heteroscedasticity (1,1) process where  $a_{y0}$ ,  $a_{y1}$  and  $a_{y2}$  are parameters.

Substituting equation [1] into equation [2] achieves the following aggregate supply equation

$$\pi_t = \varsigma_\pi E_t \pi_{t+1} + \varsigma_{y1} y_t - \varsigma_{y2} E_t y_{t+1} + \xi_t^\pi \quad [17]$$

where  $\varsigma_\pi = \eta_\pi$ ,  $\varsigma_{y1} = \frac{\rho_\pi}{\rho_y} + k$ ,  $\varsigma_{y2} = \frac{\rho_\pi \eta_y}{\rho_y}$ , and  $\xi_t^\pi = \varepsilon_t^\pi - \frac{\rho_\pi}{\rho_y} \varepsilon_t^y$ . The supply shock is given by  $\xi_t^\pi \sim N(0, \sigma_{\pi t}^2)$ . The implied variance of the supply shock, given by  $\sigma_{\pi t}^2 = a_{\pi 0} + a_{\pi 1} \xi_{\pi t-1}^2 + a_{\pi 2} \sigma_{\pi t-1}^2$ , measures the uncertainty about inflation. It is assumed to evolve as a general autoregressive conditional heteroscedasticity (1,1) process where  $a_{\pi 0}$ ,  $a_{\pi 1}$  and  $a_{\pi 2}$  are parameters.

Using equation [4] in equation [3] achieves the following equation for the index of financial conditions

$$z_t = \vartheta_{z_1} E_t z_{t+1} - \vartheta_{z_2} E_t z_{t+2} - \vartheta_r (i_{t-1} - E_{t-1} \pi_t) + \xi_t^z \quad [18]$$

where  $\vartheta_{z_1} = \eta_z + \eta_x$ ,  $\vartheta_{z_2} = \eta_x \eta_z$ ,  $\vartheta_r = \rho_z \phi$  and  $\xi_t^z = \varepsilon_t^z - \eta_x \varepsilon_t^z + \rho_z \varepsilon_t^x$ .  $\xi_z^y \sim N(0, \sigma_{z_t}^2)$  is the shock to financial conditions.  $\sigma_{z_t}^2 = a_{z_0} + a_{z_1} \xi_{z_{t-1}}^2 + a_{z_2} \sigma_{z_{t-1}}^2$  is the implied variance of the shock to financial conditions that measures the uncertainty about the conditions in the financial market. It is assumed to evolve as a general autoregressive conditional heteroscedasticity (1,1) process where  $a_{z_0}$ ,  $a_{z_1}$  and  $a_{z_2}$  are parameters.

### 4.3 Data description

Monthly data for South Africa spanning January 2000 to December 2008 is used in the analysis commensurate with the inflation targeting period. All the data is sourced from the South African reserve Bank database. The three month treasury bill rate measures the rate of interest. This follows Boinet and Martin (2008) and Nelson (2003) for the United Kingdom monetary policy where the official policy rate is the repurchase rate, same as in South Africa. The three month treasury bill rate is also preferred to the key policy rate, the repurchase rate, given that it contains more variation. The repurchase rate and treasury bill rate have a sufficiently high correlation of about 98 percent during the sample period, which drops to about 96 percent after 2007 as a result of the disruption of the close relationship between policy rates and money market interest rates during the recent financial crisis. The inflation rate is measured by the annual change in consumer price index, while the inflation gap in the monetary policy rule is the difference between the inflation rate and the 4.5 percent midpoint of the inflation target range.

Output gap is measured by the difference in logarithms between coincident business cycle indicator and its Hodrick and Prescott (1997) trend. The coincident business cycle indicator is the composite index comprising five equally weighted components

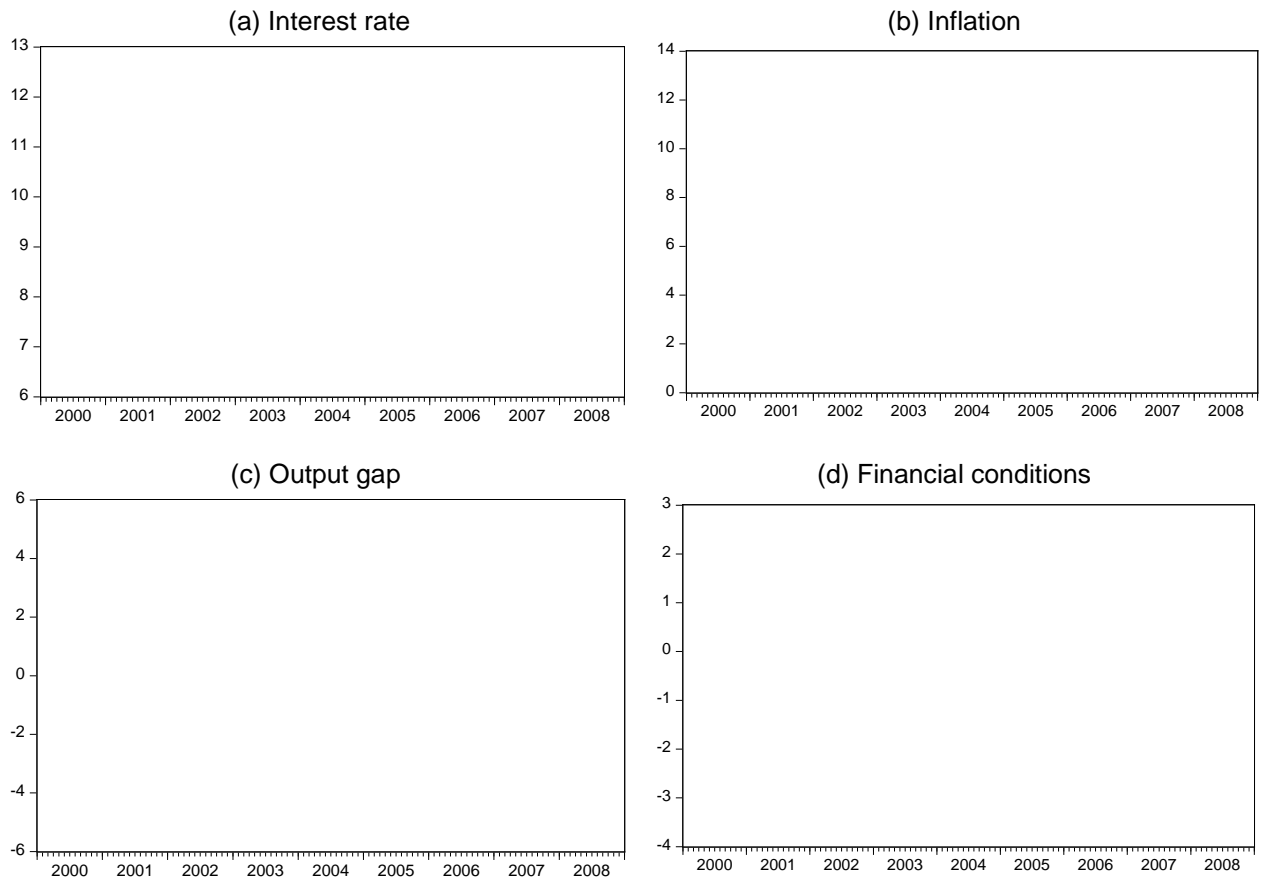
including Gross value added and Industrial production index making a broader measure of economic activity. Industrial production is often used as the measure of the output gap at the monthly frequency. However, although industrial production is obtainable from the South African Reserve Bank, it is not official data in South Africa. Moreover, the coincident business cycle indicator has a higher correlation with output that is interpolated to monthly frequency making it a better proxy for output both in levels and in deviation from trend. The autoregressive ( $n$ ) model was applied to the output measure in calculating the Hodrick Prescott trend to tackle the end-point problem following Mise et al, (2005a,b) where  $n$  is set to 4 to eliminate serial correlation and heteroscedasticity. The Hodrick Prescott filter is preferred over the other methods such the Blanchard-Quah decompositions, the Kalman filters, or the production function in computing the output gap because is the most commonly used approach in the literature, particularly in similar studies such as in Surico (2007a, b), Boinet and Martin (2008).

Financial variables form another group of variables that have recently been considered in monetary policy reaction functions to analyse the behaviour of central banks. The index of financial conditions pools together relevant information provided by a weighted average of financial as well as asset price variables following Castro (2008). This index is expressed in standardised form, relative to the mean value of 2000 so that the vertical scale measures deviations from the mean. Therefore, a value of one represents a 1-standard deviation difference from the mean. Contrary to the use of time-varying weights in Castro (2008), we use equal weights in the computation of the index of financial conditions. The potential financial variables to include in the index of financial conditions is vast due to the overabundance of financial measures that influence the supply and demand of financial instruments relevant for economic activity. Gerlach-Kristen (2004) and English et al. (2003) found that the inclusion of a financial spread reduces the empirical importance of interest rate smoothing following an appraisal of omitted variables problem by Rudebusch (2002). Estrella and Mishkin (1997) analysed the influence of a term structure variable in policy rules, while (Woglom, 2003) as well as Ortiz and Sturzenegger (2007) have studied the real exchange rate for the South African monetary policy.

The index of financial conditions is constructed as a weighted average of the variables that contain valuable information from the monetary authorities' point of view in that they provide an indication of financial markets stability. These include the real house price index, which is a deflated average price of all houses compiled by the ABSA bank. Second is the real stock price, which is measured by the Johannesburg Stock Exchange All Share index, also deflated by the consumer price index. Third is the real effective exchange rate with the foreign exchange rate in the denominator. Fourth is the credit spread, which is the spread between the yield on the 10-year government bond and the yield on A rated corporate bonds. The credit spread is a good proxy for the business cycle and financial stress. The future spread, which is the change of spread between the 3-month interest rate futures contracts in the previous quarter and the current short-term interest rate. The future interest rates spread is a good indicator of expected interest rates by the economic agents.

The stock price, real effective exchange rate and house price variables are detrended using the Hodrick Prescott filter bearing in mind the end point problem discussed above. The index of financial conditions recognises the importance of the transmission of monetary policy through the asset prices channel and the credit channel over and above the interest rate channel (Mishkin, 1996 and Bernanke and Gertler, 2000). More details on the construction of this index are in Naraidoo and Raputsoane (2010). The evolution of the main variables is shown in Figure 4.1. Inflation has had a sustained fall in 2003 and at the end of the sample period and is showing a persistent increase from 2004 to 2007 together with the accompanying increase in interest rate. The output gap was largely range bound but increased notably from 2005 before the severe downturn by the end of 2008. The movements in financial conditions index show significant volatility in 2001, 2003 and 2007, consistent with the financial markets uncertainty concerning the 9/11 attacks, the rapid depreciation of the domestic currency, the rapid capital withdrawal from emerging economies due to the United States invasion of Iraq and the onset of the sub-prime crisis.

**Figure 4.1 Evolution of the main variables**



Note: Own calculations with data sourced from the South African Reserve bank

#### 4.4 Empirical Results

The orthogonality conditions in the central bank's reaction function allow the use of Generalised Method of Moments in estimation. The set of instruments includes a constant, 1-6, 9 and 12 months lagged values of inflation, the output gap, the 10-year government bond, M3 growth, and the index of financial conditions. Naraidoo and Raputsoane (2010,2011) have shown that the monetary authorities' preferences in South Africa are such that they are zone symmetric to inflation, asymmetric to output and linear to financial conditions. As a result, the monetary policy reaction function where the choice variables are functions of their volatilities is estimated using the same assumption. The benchmark monetary policy reaction function is also estimated assuming certainty equivalence and serves as a reference point to the specification.



The first step involves generating the conditional variances for inflation, output gap and financial conditions. This step is a preparation to estimate the monetary policy reaction function given by equation [13] where inflation, output gap and financial conditions gap are functions of their implied volatilities. It involves Generalised Method of Moments estimation of equations [16], [17] and [18] that describe the structure of the economy. The estimation results for these equations are presented in Table 4.1. These results are generally consistent with expectations. The signs of the coefficients on the aggregate demand and the Phillip's curve are correct and mostly statistically significant except coefficient on the real interest rate. The measure of the goodness of fit is also sufficiently high for both equations. The estimation results for the equation describing the conditions in the financial market are consistent with expectations given that this index incorporates the exchange rate and the stock market index which theory has shown that they follow an autoregressive (1) process (Stock and Watson, 1998). The measure of goodness of fit is low and the real interest rate coefficient is statistically.

**Table 4.1 Estimates of the equations describing the state of the economy**

	Output gap		Inflation		Financial conditions	
	Coefficient	Std. Error	Coefficient	Std. Error	Coefficient	Std. Error
$\mu_{y1}$	1.439972*	0.081184				
$\mu_{y2}$	0.516673*	0.079053				
$\mu_r$	0.013769*	0.013479				
$\zeta_\pi$			1.007326*	0.010821		
$\zeta_{y1}$			0.303457*	0.099780		
$\zeta_{y2}$			0.447286	0.095380		
$g_{z1}$					0.617099*	0.097679
$g_{z2}$					0.007781	0.092612
$g_r$					0.000411	0.017798
$\bar{R}^2$	0.929224		0.964672		0.382040	
<i>Std error</i>	0.542296		0.639072		0.734931	

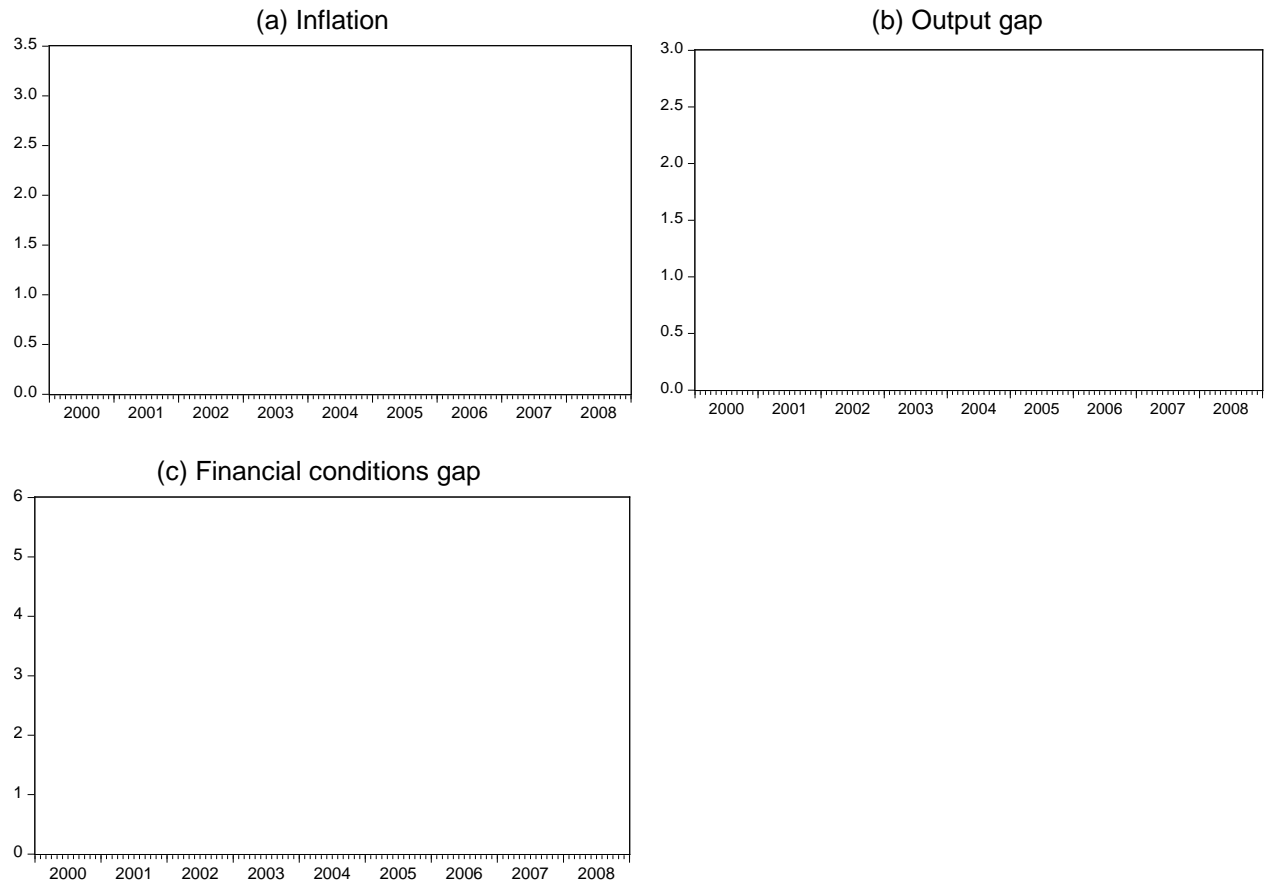
Note: \* denotes statistical insignificance at 5 percent level.

Next, the measures of uncertainty about inflation, output gap and financial conditions gap are generated using the implied volatilities from the general autoregressive conditional heteroscedasticity (1,1) model based on the residuals from the equations

describing the structure of the economy. The evolutions of measures of uncertainty are presented in Figure 4.2. The uncertainty about inflation is high in 2000, from 2002 through 2004 and again in 2008. The uncertainty about the output gap is high in 2001, 2003 and 2004 as well as in 2007 and 2008. The uncertainty about financial conditions gap is high in 2003 and again in 2007 and 2008. Uncertainty is generally low in 2005 and in 2006 reflecting stability in inflation, output gap and financial conditions gap in these periods. The measures of uncertainty show significant volatility in 2001 consistent with the United States 9/11 attacks and the speculative attacks on the rand. There is also high volatility in 2003 and 2004 consistent with the United States' invasion of Iraq, the spike in oil prices and hence the accompanying high interest rates that discouraged fixed capital formation. These tight monetary conditions quickly reversed in 2004 as economic conditions improved. The high volatility in 2007 and 2008 is consistent with the onset of the sub-prime crisis and the subsequent collapse of the global economy.

The next step involves estimating the monetary policy reaction function under the assumption of zone symmetric, asymmetric, and linear monetary authorities' preferences towards inflation, output gap and financial conditions, respectively, is maintained. The results for the benchmark monetary policy reaction function assuming certainty equivalence are presented in Table 4.2. The model is satisfactory in terms of the goodness of fit and the Hansen's J- test accepts the null hypothesis that the over identifying restrictions are satisfied so that the set of instruments are valid. The standard errors and the measure of the goodness of fit are also within reasonable levels. The results show that the monetary authorities increase the interest rates by 0.45 percent when inflation hits the upper bound of the inflation target, while they increase the interest rates by 1.96 percent when inflation is one percent above the upper bound of the inflation target. The results also show that the monetary authorities increase the interest rates by 1.34 percent when the output gap undershoots its long term trend by one percent, while they increase the interest rates by 2.66 percent when financial conditions index increases by one percent above its long term trend. The results are generally consistent with the results in Naraidoo and Raputsoane (2010,2011) on the size and interpretability of coefficients.

**Figure 4.2 Implied variances of inflation, output gap and financial conditions**



Note: The implied variances of inflation, output gap and financial conditions gap are obtained from the general autoregressive conditional heteroscedasticity (1,1) models based on the residuals from the equations describing the structure of the economy. These results are available from the authors.

The generated measures on uncertainty are now used in estimating the non-certainty equivalent monetary policy reaction function described by equation [13] maintaining the assumption of the zone symmetric, asymmetric, and linear monetary authorities' preferences towards inflation, output gap and financial conditions, respectively. The estimated results for the estimation window spanning January 2000 to December 2006 are presented in table 4.2. The results show that this monetary policy reaction function is robust in terms of the Hansen J-test and the standard error. The estimated coefficients are all statistically significant meaning that uncertainty is well determined. The monetary policy reaction function that incorporates uncertainty provides a better representation of monetary policy in South Africa than the monetary policy reaction function that is estimated assuming certainty equivalence. The results show that the monetary authorities increase the interest

rates by 0.63 percent when inflation hits the upper bound of the inflation target, while they increase the interest rates by 2.77 percent when inflation is one percent above the upper bound of the inflation target. The results also show that the monetary authorities increase the interest rates by 0.41 percent when the output gap undershoots its long term trend by one percent, while they increase the interest rates by 0.70 percent when financial conditions index increases by one percent above its long term trend. The parameters of the monetary policy reaction function with the implied volatilities are consistent with those of the certainty equivalent benchmark specification and more so with the results in Naraidoo and Raputsoane (2010) albeit with a lower coefficient on the index of financial conditions.

The estimated results show negative signs on the coefficients  $\rho_{\pi}^{\pi}$ ,  $\rho_{\pi}^y$  and  $\rho_{\pi}^z$  that measure the impact of uncertainty about inflation, the output gap and financial conditions, respectively, on the width of the inflation target band, which is measured by  $\rho_{\pi}$ . This means that the monetary authorities increase their zone of tolerance to the deviations of inflation away from the inflation target midpoint when faced with uncertainty. The negative signs on the coefficients  $\alpha_{\pi}^{\pi}$  and  $\alpha_{\pi}^y$  that measure the impact of uncertainty about inflation and the output gap, respectively, with respect to the coefficient  $\alpha_{\pi}$  that measure the monetary authorities' aversion to deviations of inflation outside the target band, imply a passive reaction to deviations of inflation outside the inflation target zone. The positive sign on the coefficient  $\alpha_{\pi}^z$ , which measures uncertainty about financial conditions implies more aversion to the deviations of inflation outside the inflation target band when uncertainty to financial markets increases.

The results show positive signs on the coefficients  $\rho_y^{\pi}$  and  $\rho_y^y$  that measure the impact of uncertainty about inflation and the output gap, respectively, on the monetary authorities' response to output as measured by  $\rho_y$ . This imply a more aggressive reaction towards the deviations of the output gap from its long term level by the monetary authorities when faced with uncertainty, while the opposite holds for uncertainty about financial conditions  $\rho_y^z$ . The results also show increased

asymmetry to the deviations of output away from its desired level by the monetary authorities, measured by  $\alpha_y$ , when they are faced with uncertainty about inflation and the output gap measured by the coefficients  $\alpha_y^\pi$  and  $\alpha_y^y$ .

**Table 4.2 Estimates of the monetary policy reaction functions**

	Certainty equivalent monetary policy reaction function		Non- Certainty equivalent monetary policy reaction function	
	Coefficient	Std. Error	Coefficient	Std. Error
$\rho(L)$	0.963147*	0.005443	0.967250*	0.001616
$\rho_0$	8.593248*	0.371057	9.645674*	0.107349
$\rho_\pi$	0.137404*	0.018872	0.193906*	0.008011
$\rho_\pi^\pi$			-0.050434*	0.002280
$\rho_\pi^y$			-0.290828*	0.016597
$\rho_\pi^z$			-0.023213*	0.008349
$\alpha_\pi$	-0.027800*	0.000387	-0.027234*	0.002102
$\alpha_\pi^\pi$			-0.015037*	0.002278
$\alpha_\pi^y$			-0.024352*	0.006774
$\alpha_\pi^z$			0.005931*	0.001538
$\rho_y$	1.112692*	0.219817	0.997151*	0.066349
$\rho_y^\pi$			0.563856*	0.064347
$\rho_y^y$			1.443474*	0.080100
$\rho_y^z$			-0.285149*	0.017487
$\alpha_y$	-0.450278*	0.272218	-1.166151*	0.225619
$\alpha_y^\pi$			1.245232*	0.159936
$\alpha_y^y$			1.904995*	0.397570
$\alpha_y^z$			-1.738895*	0.119492
$\rho_z$	2.658979*	0.555675	0.695365*	0.181165
$\rho_z^\pi$			1.685434*	0.253805
$\rho_z^y$			-4.955705*	0.525914
$\rho_z^z$			1.549242*	0.207318
$\bar{R}^2$	0.977598		0.982786	
<i>Std error</i>	0.295664		0.260123	
<i>J – statistic</i>	0.124102		0.112345	

Note: \* denotes statistical insignificance at 5 percent level. *j*-statistic reports Hansen's test for over-identifying restrictions. The model is estimated assuming zone symmetric to inflation, asymmetric to output and linear to financial conditions following Naraidoo and Raputsoane (2010)

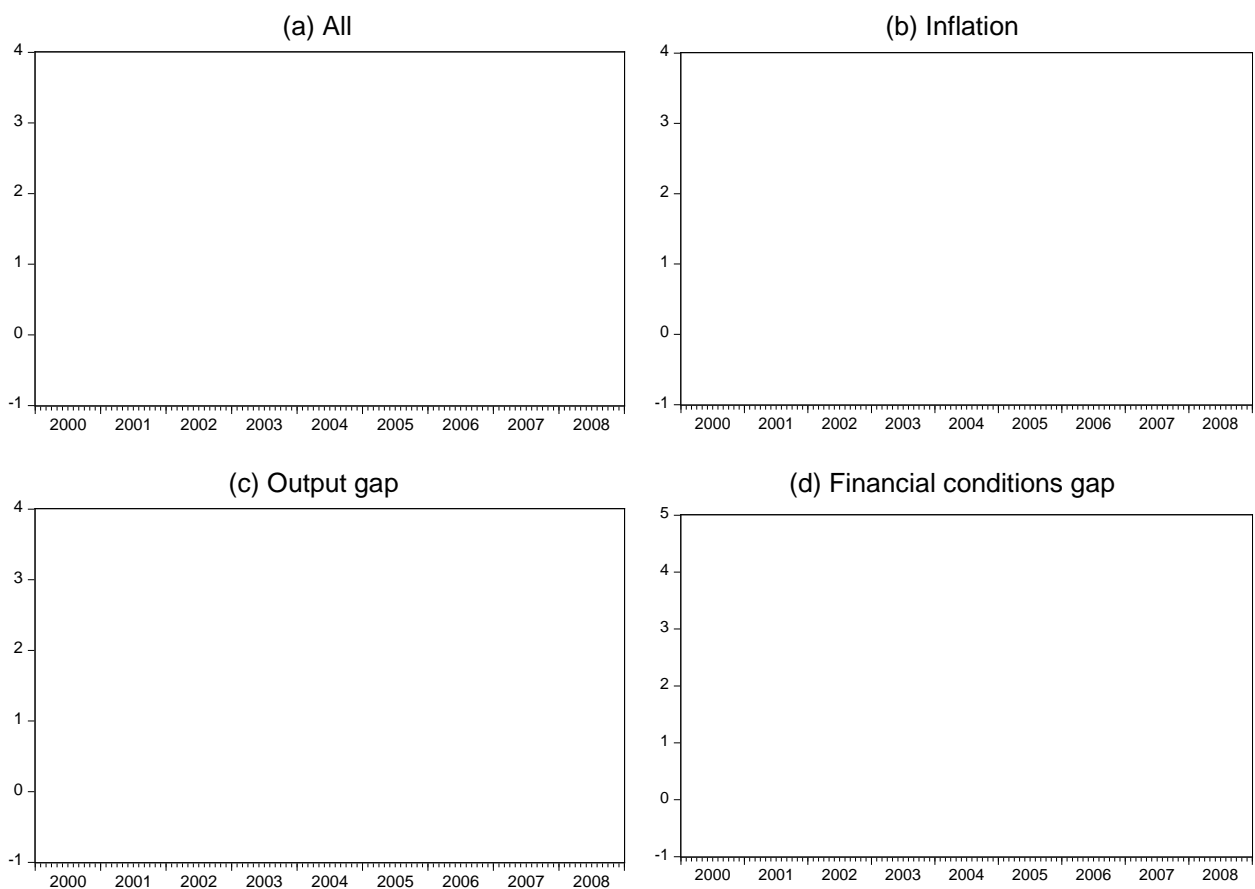
The uncertainty about financial conditions, measured by  $\rho_y^z$  and  $\alpha_y^z$ , implies a passive reaction as well as decreased asymmetry to the deviations of output away from its desired level. Finally, with reference to the response of monetary policy to financial conditions, the uncertainty about inflation, the output gap and financial conditions is analysed relative to the coefficient  $\rho_z$ . There are positive signs on the coefficients  $\rho_z^\pi$  and  $\rho_z^y$  that measure the impact of uncertainty about inflation and the output gap, respectively, with respect to the coefficient  $\rho_z$  that measures the monetary authorities' response to deviations of financial conditions gap from the desired level. These imply increased aggressiveness by the monetary authorities towards the deviations in financial conditions gap from the desired level, while the uncertainty about financial conditions increases their aggression as shown by the negative sign on the coefficient  $\rho_z^z$ .

To establish the impact of uncertainty on domestic interest rates, the gap between the fitted and the counterfactual interest rates is quantified by taking the difference between the estimated monetary policy reaction function and the counterfactual monetary policy reaction function as shown in equation [15]. The overall contribution of uncertainty to monetary policy and the relative contributions of uncertainty about inflation, output gap and financial conditions gap to overall uncertainty are depicted in Figure 4.3 when the model is estimated over the whole sample period 2000-2008. According to graph (a), the overall uncertainty was important for domestic interest rates in 2002 to 2003 and in 2008. Uncertainty was relatively unimportant between 2000 and 2001 as well as between 2004 and 2007. The uncertainty about inflation was prominent in 2002, 2003 and in 2008. The uncertainty about the output gap was somewhat important in 2003 and reached severity in 2008.

The uncertainty about financial conditions was important in 2002 and reached unprecedented levels in 2008. The heightened uncertainty can be attributed to a number of factors that were experienced since the beginning of the inflation targeting era. The most important factors include the consequences of rapid depreciation of the domestic currency in late 2001 that led to greater inflationary pressures in 2002.

Another important factor was the war in Iraq that broke out in early 2003 leading to a spike in oil prices. Finally, the most important factor was the onset of the global financial crisis that began in late 2007 and the manifested in 2008 resulting in disastrous consequences for the global economy.

**Figure 4.3 Contributions of inflation, output gap and financial conditions to the gap between the fitted and counterfactual interest rates**



Note: The dashed line is a replica of (a) that shows the overall contribution of uncertainty to the gap between the fitted and counterfactual interest rates

The onset of the global financial crisis towards the end of 2007 presents an interesting era in the monetary policy landscape as witnessed by the predominant impact of uncertainty on monetary policy experienced in 2008. To analyse the impact of uncertainty on domestic interest rates during the financial crisis, the monetary policy reaction function given by equation [13] is estimated recursively over expanding windows of data from January 2007 to December 2008. The first data

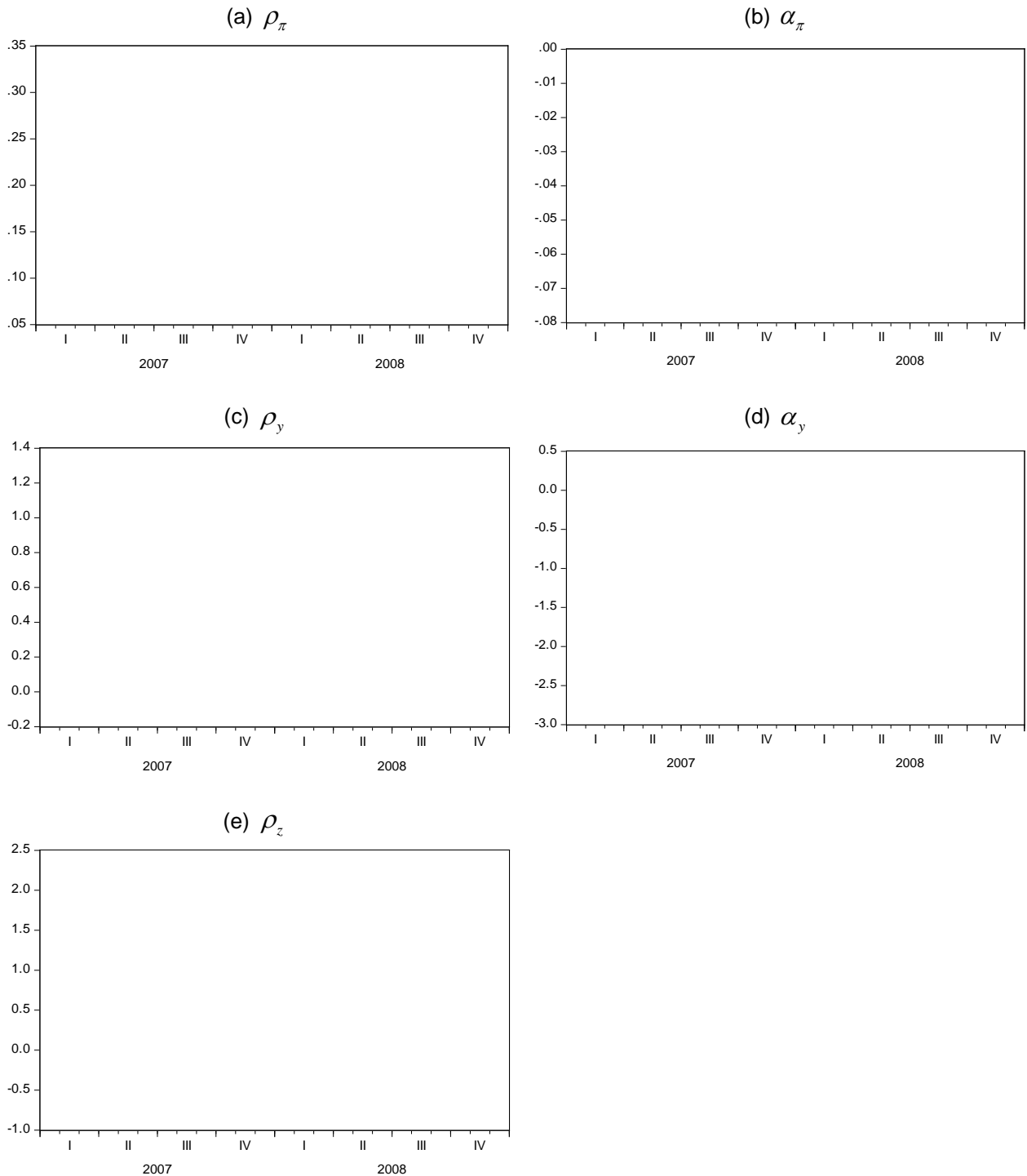
window runs from January 2000 to December 2006 and each successive data window is extended by one observation delivering 24 expanding windows. From a policy point of view, this allows us to identify the evolution of the estimated model parameters over time.

The recursive estimates of the monetary policy reaction function allow identification of the evolution of the estimated model parameters overtime and provide important information on the response the monetary policy to inflation, output and financial conditions during the height of the financial crisis. The recursive estimates plus/minus 2\*standard errors over expanding data windows are depicted in Figure 4.4 where only the plots of the main parameters of the model out of 22 estimated parameters as shown in table 4.2. The monetary authorities increasingly allowed a wider zone of tolerance or increased their acceptance of the deviations of inflation away from the inflation target midpoint from early 2007 to the end of 2008 as shown in graph (a). Graph (b) shows that the monetary authorities were increasingly aggressive to deviations of inflation around the inflation target zone until the onset of the financial crisis in the third quarter of 2007 and from the third quarter of 2008 onwards while the opposite is true for the period in between.

Graph (c) shows an increasing passive reaction by the monetary authorities to output deviation from its desired level from the beginning of 2007 to the end of 2008. Graph (d) shows stable asymmetry to the deviations of output until the onset of the financial crisis in the third quarter of 2007 where the monetary authorities decrease their asymmetry to the output deviations to a point where their asymmetry was virtually nonexistent from the last quarter of 2007 to the end of the sample. Graph (e) shows that the monetary authorities' response to financial conditions was strong at the beginning of 2007 but that they became increasingly passive until the third quarter of 2007. Their reaction increased significantly as the financial crisis took effect and remained strong until the end of 2008.



**Figure 4.4 Recursive coefficients of inflation, output gap and financial conditions**



Note: The graphs show the recursive estimates plus/minus 2\*std error for the coefficients on the zone symmetric to inflation, asymmetric to output and linear to financial conditions, while the recursive estimates for the coefficients of the implied variances are available from the authors.

The preceding discussion on the monetary authorities' response to deviations of inflation, output and financial conditions from their desired values when faced with

uncertainty has shown a complex and mixed response by the monetary authorities. The results do not support the hypothesis of reduced reaction of monetary policy to the target variables under uncertainty as proposed Brainard (1967), Swanson (2004) as well as Martin and Milas (2009). The results also do not support the hypothesis of increased reaction of monetary policy to the target variables when acting under uncertainty as propounded by Soderstrom (2002), Tillmann (2008) and the others. The results are consistent with the suggestions by Conway (2000) and Greenspan (2003) that the monetary authorities should deal with uncertainty on a case by case basis, judging the probabilities, costs, and the benefits of the various possible outcomes. The monetary authorities in South Africa do not seem to follow any hard and fast guidelines and there is no consistently preferred pattern in their response to the deviation of target variables from their desired values when faced with uncertainty.

#### **4.5 Conclusion**

This chapter analyses the impact of uncertainty about the true state of the economy on monetary policy in South Africa using a framework that allows asymmetric and zone targeting monetary authorities' preferences. The monetary policy reaction function is augmented with an index that collects and synthesises the information from the financial asset markets to assess the importance of financial asset prices in monetary policy decision making in the presence of uncertainty. The measures of uncertainty were generated from the conditional variances for inflation, output gap and financial conditions. The estimation was carried out using monthly data for South Africa spanning the period since the adoption of the inflation targeting framework. The overall impact of uncertainty on monetary policy and the relative contributions of inflation, output gap and financial conditions gap to uncertainty were established by taking the difference between the estimated monetary policy reaction function and the counterfactual monetary policy reaction function. The recursive estimates of the monetary policy reaction function were analysed to identify if the evolution of the estimated model parameters provide important information on the response the monetary policy to inflation, output and financial conditions during the financial crisis.

The empirical results reveal a significant impact of uncertainty on domestic interest rates during the inflation targeting period. The examination of the recursive estimates of the parameters of monetary policy reaction function overtime also provide important information on the response the monetary policy to inflation, output and financial conditions during the height of the financial crisis. The monetary authorities' response to deviations of inflation, output gap and financial conditions from their desired values when faced with uncertainty is complex and mixed. The monetary authorities' response to uncertainty neither support the hypothesis of reduced reaction as proposed Brainard (1967) nor does it support the notion of increased reaction as propounded by Soderstrom (2002). The results are consistent with the suggestions by Conway (2000) and Greenspan (2003) that the monetary authorities should deal with uncertainty on a case by case basis, reaching judgment about the probabilities, costs, and the benefits of the various possible outcomes. Therefore, the conclusion means that the monetary authorities exhibit discretionary behaviour when implementing monetary policy under uncertainty.

Future research could extend the analysis by investigating how uncertainty influences monetary policy using a structural model. It would also be worthwhile to carry out an out-of-sample forecasting experiment to ascertain the accuracy of the estimates from a non-certainty equivalent monetary policy reaction function. Most importantly, future research could extend the analysis to model and parameter uncertainty.

## Chapter 5

### Conclusion

The aim of the thesis is to address issues concerning modelling and evaluation of monetary policy by obtaining targeting rules from optimisation techniques using welfare loss functions that capture asymmetries and zone targeting monetary policy preferences. This is motivated by Orphanides and Wieland (2000) who argue that the quantitative evaluations of monetary policy that are based on linear models such as the Taylor (1993) rule and its extensions by Clarida et al. (2000) may not fully capture the actual practice of inflation targeting. Orphanides and Wilcox (2002) further argue that when endowed with inflation and output stabilisation, the monetary authorities may exhibit asymmetric behaviour by having an inflation bias when inflation overshoots the target and an output bias during output declines. The monetary authorities may also exhibit zone-like behaviour by penalising more when inflation or output move out of the target range and being passive when they are 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 actual practice of monetary policy by central banks.

First, the optimal response of the monetary authorities to deviations of inflation and output from their target values over the inflation targeting era was estimated for South Africa using an empirical framework that allows the central bank's policy preferences to be zone-like and asymmetric. The first major finding is that the monetary authorities' response towards inflation is zone symmetric. That is, they react in a passive manner when inflation is within the target band and become increasingly aggressive when it deviates from the target band. The monetary authorities also react with the same level of aggressiveness regardless of whether inflation overshoots or undershoots the inflation target band. The second major finding is that the monetary authorities' response to output fluctuations is asymmetric. That is, they react more aggressively to negative deviations of output

from the potential so that they weigh business cycle recessions more than expansions.

Second, a flexible monetary policy reaction function for South Africa based on a representation of the policymaker's preferences that capture asymmetries and zone targeting behaviours is estimated. The analysis is augmented with a comprehensive index that collects and synthesises information from the financial asset markets to address the current debate on the importance of financial assets prices in monetary policy decision making. The empirical results show that the conditions in the financial asset markets form an important information set for the monetary authorities and that they pay close attention to the conditions in these markets by placing an equal weight on financial asset markets booms and recessions. The significant response by the monetary authorities to financial conditions has important policy implications. It sheds light on the reason why the current economic downturn is less severe in South Africa than it is in the other economies.

Third, the impact of uncertainty about the true state of the economy on monetary policy in South Africa based on a framework that allows asymmetric and zone targeting monetary authorities' preferences is estimated. The monetary policy reaction function is augmented with a comprehensive index that collects and synthesises the information from the financial asset markets to assess the importance of financial variables in monetary policy decision making in the presence of uncertainty. The empirical results reveal a significant impact of uncertainty on domestic interest rates during the inflation targeting period and that the monetary authorities exhibited discretionary behaviour when implementing monetary policy under uncertainty. The recursive estimates also show that the monetary authorities allowed a wider zone of tolerance of the deviations of inflation away from the inflation target mid point after the onset of the financial crisis. Their reaction to the deviations of output from its desired level was increasingly passive, while their reaction to financial conditions increased significantly since the onset of the financial crisis.

The thesis contributes to the body of knowledge in the field of economics and enhances the understanding of monetary policy design and conduct in South Africa in ways that have not been done before. The thesis addresses important aspects of

monetary policy design and conduct in South Africa using a framework that captures the stylised features of monetary policy practice at central banks. The thesis analyses the recent macroeconomic fluctuations that have brought about a renewed focus on the formulation and practice of monetary policy using a comprehensive index that collects and synthesises information from the financial asset markets. The thesis addresses uncertainty, a fundamental and an integral part of monetary policy decision making that the monetary authorities have to contend with in the design and conduct of monetary policy on an ongoing basis. All these issues are important and are currently debated in the context of South Africa and other central banks around the world.

For future research, extending the analysis to model uncertainty and parameter uncertainty would be interesting. It would also be interesting to carry out an out-of-sample forecasting experiment using the alternative specifications of monetary policy reaction function to establish if the monetary policy reaction function with target zones and asymmetries best predicts the South African Reserve Bank's interest rate setting behaviour. Future research could also extend the analysis by investigating how uncertainty influences monetary policy using a structural model. Analysing the determinacy and learnability of the rational expectations equilibrium using a framework that allows asymmetric and zone targeting central bank's monetary policy preferences for South Africa is another important area for further research.