University of Pretoria
Department of Economics Working Paper Series

Financial Markets and the Response of Monetary policy to Uncertainty in South Africa

Ruthira Naraidoo
University of Pretoria
Leroi Raputsoane
South African Reserve Bank
Working Paper: 2013-10
February 2013

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

Financial markets and the response of monetary policy to uncertainty in South Africa

Ruthira Naraidoo* and Leroi Raputsoane**

Abstract

This paper assesses the impact of uncertainty about the true state of the economy on monetary policy in South Africa since the adoption of inflation targeting. The paper also analyses the impact of uncertainty about the conditions in financial markets on the interest rate setting behavior that describes the South African Reserve Bank's monetary policy decisions over and above using inflation and output as indicator variables. The results indicate that the effect of uncertainty on the interest rates has led to a more cautious monetary policy stance by the monetary authorities consistent with a large body of literature that recognizes that an excessively activist policy can increase economic instability. The results further show that uncertainty about the state of the economy clusters around the financial crisis periods in 2003 and from 2007 to 2009. The uncertainty about inflation was important to the interest rate setting behavior in 2003, while the uncertainty about the conditions in financial markets was important to the interest rate setting behavior between 2007 and 2009.

JEL Classification: C51, E43, E44, E58

Key Words: Monetary policy, Uncertainty, Financial market conditions

*Department of Economics, University of Pretoria

**South African Reserve Bank.

1. Introduction

The majority of empirical models of monetary policy follow the Taylor (1993) rule due to its simplicity in approximating monetary policy decisions. According to Rotemberg and Woodford (1999) and Rudebusch and Svensson (1999), simple feedback rules achieve good results in simulated small macroeconomic models. Clarida et al. (2000) provide international evidence of empirical studies that have shown that the Taylor type policy specifications are consistent with the historical behavior of monetary policy setting at many central banks. This paper conjectures that the monetary policy decisions in South Africa can be described within the general form of Taylor type monetary policy reaction functions in that the South African Reserve Bank has a mandate to achieve and maintain price stability in the interest of balanced and sustainable economic growth. The South African Reserve Bank moved from a constant money supply growth rate rule that prevailed since 1986 to monetary policy that was based on the official repurchase rate since 1998. These policies were followed by central bank independence and the introduction of inflation targeting in 2000 where the inflation target was set at 3 to 6 percent.

Uncertainty is generally accepted to be a fundamental and an integral part of monetary policy decision making. The concept of uncertainty in monetary policy practice was coined by Brainard (1967) and hence the Brainard's attenuation principle. This principle hypothesizes that uncertainty dampens the monetary authorities' response to the target variables of monetary policy compared to when monetary policy decisions are made under complete certainty or certainty equivalence. The former Federal Reserve Chairman, Greenspan (2003), contends that "Uncertainty is not just an important feature of the monetary policy landscape, it is the defining characteristic of that landscape" and the former European Central Bank, President, Trichet (2011), further adds that "Operating in an uncertain environment is common business for central banks." Thus empirical and theoretical formulations of monetary policy must take into account the quantitative relevance of uncertainty because it is a constant feature of monetary policy practice.

There is a large body of literature on the quantitative significance of imperfect knowledge of the state of the economy and forward looking indicators, noisy and uncertain data and the measurement issues for monetary policy. These include Svensson (1999), Peersman and Smets (1999), Estrella and Mishkin (2000), Orphanides et al. (2000), Rudebusch (2001), Ehrmann and Smets (2003) and Martin and Milas (2009) who present evidence in support of the seminal Brainard (1967) attenuation principle. On the contrary, Giannoni (2002) and Sonderstrom (2002), among others, have presented evidence that supports an aggressive reaction of monetary policy under uncertainty. The theoretical underpinning of the monetary policy rules that address these issues can also be found in Svensson and Woodford (2003, 2004) and in a special issue of the Journal of Monetary Economics in 2003 following the conference on "Monetary Policy under Incomplete Information" in October 2000.

The first contribution of this paper is to appraise the impact of uncertainty about the state of the economy on monetary policy in South Africa. This is achieved following Svensson and Woodford (2003, 2004) and Swanson (2004) on the optimal weights on indicators in models of monetary policy with partial information about the state of the economy. The theoretical framework is borrowed from Svensson's (1997) model of expected inflation targeting and Swanson's (2004) model of monetary policy with signal extraction about the unobservable state of the economy. This framework posits that indicator variables such as inflation and output are used to make inference about the unobservable state of the economy for monetary policy purposes. The optimal weights on the indicators variables of the model are related to the volatilities surrounding these indicator variables as usual in a signal extraction problem. As such, when monetary policy affects the state of the economy, the optimal response to the imperfect observation of the state of the economy depends on the volatilities surrounding the indicator variables leading to non-certainty equivalence. This is contrary to the Taylor type monetary policy rules that exhibit certainty equivalence in that monetary policy is independent of all higher moments of the target variables given the expected values of the state variables of the economy.

The second contribution of this paper is to augment the monetary policy reaction function with the index of financial market conditions similar to one proposed by Montagnoli and Napolitano (2005) and Castro (2011) as one of the indicator variables of the unobservable true state of the economy. This is important because one of the primary goals of the South African Reserve Bank is to protect the value of the currency and to achieve and maintain financial stability as defined in the Constitution. The recent financial crisis has also heightened the concern by central banks over the maintenance of financial stability and has aroused their interest in the behavior of certain asset prices and measures of credit risk. Cecchetti et al. (2000) propose that monetary policy rules should be augmented with some measure of the misalignments in asset prices, whereas Bernanke and Gertler (2001) argue against this, citing the difficulties present in the estimation of such misalignments. Rudebusch (2002) also 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. English et al. (2003) and Gerlach-Kirsten (2004) find that inclusion of a financial spread reduces the empirical importance of interest rate smoothing, while Estrella and Mishkin (1997), among others, analyse the influence of the term structure variable in policy rules.

The next section outlines the model. Section 3 is the data description. The empirical results are discussed in section 4. Section 5 is the conclusion.

2. Model specification

The central bank's monetary policy design problem is a targeting rule where the monetary authorities minimize a loss function subject to the constraints given by the structure of the economy. The empirical model combines the elements of Svensson's (1997) model of inflation forecast targeting with the 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). The model is augmented with asset prices to account for the conditions in financial markets following Cecchetti et al. (2000) who presented the view that monetary policy reaction functions should be augmented with financial variables to account for the misalignments in asset prices. Such extensions to the monetary policy reaction function have also been considered by Bernanke and Gertler (2000, 2001), Alexandre and Baçao (2005) as well as Castro (2011), among others.

2.1. Structure of the economy with financial markets

The aggregate demand equation is given by

$$y_{t+1} = \beta_y y_t + \beta_X X_{t+1} + \varepsilon_{y,t+1} \quad , \qquad \varepsilon_{y,t} \sim N\left(0, \sigma^2_{\varepsilon_{y,t}}\right) \tag{1}$$

where y is the output gap and X is the state of the economy. The output gap is a function of lagged output following Svensson (1997) and the contemporaneous state of the economy. According to Svensson and Woodford (2003, 2004), the state of the economy represents a measure of overall excess demand. ε_y is the demand shock and its implied variance measures the uncertainty about the output gap. Alexandre and Baçao (2005) add an ad hoc term with financial markets to the aggregate demand equation to incorporate the wealth effects. This is a shortcut as shown by Cecchetti et al. (2000). This paper argues that the state of the economy variable is able to capture the wealth effects and the conditions in financial markets.

The Phillips curve is given by

$$\pi_{t+1} = \pi_t + \alpha_X X_t + \varepsilon_{\pi,t+1} \quad , \quad \varepsilon_{\pi,t} \sim N\left(0, \sigma^2_{\varepsilon_{\pi,t}}\right) \quad (2)$$

where π is the inflation rate. The Inflation rate is affected by lagged inflation and the state of the economy in the previous period. ε_π is the supply shock and its implied variance measures the uncertainty about the inflation rate.

The equation for the financial markets is given by

$$z_{t+1} = \gamma_y z_t + \gamma_X X_{t+1} + \varepsilon_{z,t+1} \quad , \quad \varepsilon_{z,t} \sim N\left(0, \sigma^2_{\varepsilon_{z,t}}\right) \quad (3)$$

where z is an index of financial conditions. The index of financial conditions is a function of lagged financial market conditions and the contemporaneous state of the economy. It should be noted that equation (3) is usually obtained from a standard dividend model of asset pricing which gives asset prices as a function of the expected future dividends incorporated into the expected asset price and the real interest rate as in Alexandre and Baçao (2005). ε_z is the shock to the financial markets and its implied variance measures the uncertainty about the conditions in financial markets.

The state of the economy is given by

$$X_{t+1} = \phi_X X_t - \phi_r \left(i_t - E_t \pi_{t+1} \right) + \varepsilon_{X,t+1} \quad , \qquad \varepsilon_{X,t} \sim N\left(0, \sigma^2_{\varepsilon_X}\right) \tag{4}$$

where i is the nominal interest rate and E_t is the expectation operator assuming that the policy makers know all parameters of the model and the values of all variables up to the end of period t. The state of the economy at time t is affected by the state of the economy in the previous period and by the real interest rate at time $t-1$. ε_X is a shock to the state of the economy that is assumed to be normally distributed with constant variance.

The shocks ε_X, ε_y, ε_π, and ε_z are assumed to be serially and mutually uncorrelated. The conditional variances in equations (1), (2), (3) evolve according to the $GARCH(1,1)$ process so that $\sigma^2_{j,t} = k_{0j} + k_{1j}\varepsilon^{j2}_{t-1} + k_{2j}\sigma^{j2}_{t-1}$ where $j = y,\ \pi,\ z$, while k_{0j}, k_{1j} and k_{2j} are parameters. As discussed above, the structure of the economy is an extension of Svensson's (1997) model to include the state of the economy following Svensson and Woodford (2003, 2004) and Swanson (2004) together with developments in the financial markets following Cecchetti et al. (2000), among others. However, the expanded model leaves the proposition that the interest rate affects inflation with a two-period lag by Svensson (1997) intact. In this model, the interest rate affects the state of the economy with a one-period lag, while the state of the economy affects inflation with another one-period lag.

2.2. Optimal monetary policy under observable state of the economy

The optimal policy rule is solved following Svensson (1997) where the policy maker's problem is to minimise the loss function subject to the constraints given by the structure of the economy. The policy maker chooses the current and future interest rates assuming that the central bank has full information on the relevant data and full knowledge of all model parameters up to time t. The period loss function is given by

$$L_t = E_t \sum_{i=0}^{\infty} \delta^i \left\{ \frac{1}{2} (\pi_{t+i} - \pi^*)^2 \right\} \tag{5}$$

where δ is the discount factor. Equation (5) is the discounted sum of expected quadratic deviations of inflation from the inflation target π^*. Since the interest rate chosen at time t affects the inflation rate two periods ahead, the policymakers' problem is equivalent to minimising $L_t = E_t\delta^2 \frac{1}{2}(\pi_{t+2} - \pi^*)^2$ subject to the interest rate chosen at time t as follows

$$\underset{i_t}{\text{Min}}\, E_t\delta^2 \frac{1}{2}(\pi_{t+2} - \pi^*)^2 \tag{6}$$

Using equations (2) and (4) to substitute for $E_t\pi_{t+2}$ achieves the following optimal monetary policy reaction function under the assumption that the state of the economy X_t is perfectly observable:

$$\hat{i}_t = -\pi^* / \left(\phi_r \alpha_X\right) + \left(\phi_X / \phi_r\right) X_t + \left(1 + 1/\left(\phi_r \alpha_X\right)\right) E_t \pi_{t+1} \tag{7}$$

where $\hat{i}_t$ is the desired nominal interest rate.

2.3. Optimal monetary policy under unobservable state of the economy

In the event that the monetary authorities do not observe the state of the economy, the monetary authorities must infer the expectation of the state of the economy given available information. Swanson (2004) developed a model where the expectation of the unobservable state of the economy can be expressed as a function of the observable variables describing the structure of the economy, in this case X, π, y and z, since they are jointly normally distributed. Therefore, inflation, the output gap and financial market conditions are used in forming the optimal predictor of the unobservable state of the economy as follows

$$E_t X_t = \varphi_{\pi t} E_t\left(\pi_{t+1} - \pi^*\right) + \varphi_{yt} E_t y_{t+1} + \varphi_{zt} E_t z_{t+1} \tag{8}$$

Where the weight placed on each of the observable variable in forming an inference about the underlying state of the economy $\varphi_{\pi t}$, φ_{yt} and φ_{zt} are time varying parameters and are functions of the volatilities of the shocks to inflation, the output gap and financial market conditions. Swanson (2004) argues that the increase in uncertainty about a particular variable reduces the weight placed on that particular variable and increases the weight placed on other variables. For example, increased uncertainty about the output gap, that is, an increase in the volatility of the disturbance to the output gap equation ε_y will reduce φ_{yt} and increase $\varphi_{\pi t}$ and φ_{zt}. Likewise, an increase in the volatility of the shock to the inflation equation ε_π will reduce $\varphi_{\pi t}$ and increase φ_{yt} and φ_{zt}. Similarly, an increase in the volatility of the shock to the financial markets equation, ε_z will reduce φ_{zt} and increase $\varphi_{\pi t}$ and φ_{yt}.

Substituting (8) into (7) achieves the following optimal monetary policy rule in terms of the observables

$$\hat{i}_t = \partial_{0t} + \partial_{\pi t} E_t \pi_{t+1} + \partial_{yt} E_t y_{t+1} + \partial_{zt} E_t z_{t+1} \qquad (9)$$

Where $\partial_{0t} = -\pi^* \left(1+\varphi_{\pi t}\phi_X \alpha_X\right)/\left(\phi_r \alpha_X\right)$, $\partial_{\pi t} = 1+\left(1+\varphi_{\pi t}\phi_X \alpha_X\right)/\left(\phi_r \alpha_X\right)$, $\partial_{yt} = \phi_X \varphi_{yt}/\phi_r$ and $\partial_{zt} = \phi_X \varphi_{zt}/\phi_r$ are time varying parameters. This monetary policy rule does not satisfy certainty equivalence because the state of the economy is not observed this time around, hence inflation, the output gap and financial market conditions act as indicator variables of monetary policy.

2.4. Empirical model

The optimal monetary policy reaction function in equation (9) can be re-written as

$$\hat{i}_t = \rho_{0t} + \rho_{\pi t} E_t \pi_{t+1} + \rho_{yt} E_t y_{t+1} + \rho_{zt} E_t z_{t+1} \qquad (10)$$

where the identifiable parameters of the monetary policy rule are $\rho_{0t} = \rho_0 + \rho_0^\pi \sigma_{\pi t}^2 + \rho_0^y \sigma_{yt}^2 + \rho_0^z \sigma_{zt}^2$, $\rho_{\pi t} = \rho_\pi + \rho_\pi^\pi \sigma_{\pi t}^2 + \rho_\pi^y \sigma_{yt}^2 + \rho_\pi^z \sigma_{zt}^2$, $\rho_{yt} = \rho_y + \rho_y^\pi \sigma_{\pi t}^2 + \rho_y^y \sigma_{yt}^2 + \rho_y^z \sigma_{zt}^2$ and $\rho_{zt} = \rho_z + \rho_z^\pi \sigma_{\pi t}^2 + \rho_z^y \sigma_{yt}^2 + \rho_z^z \sigma_{zt}^2$. These parameters depend on the implied variances of the disturbance terms to inflation, the output gap and financial market conditions equations. Appendix A derives in details the signs of the coefficients in equation (10). For instance, from equation (8), given that we expect an inverse relationship between the volatility of the disturbance to the inflation equation and $\varphi_{\pi t}$, it implies that $\rho_{\pi}^{\pi} < 0$ in equation (10). Similarly, the inverse relationship between the volatility of the disturbance to the output gap equation and φ_{yt} implies that $\rho_{y}^{y} < 0$ and likewise the negative relationship between the volatility of the disturbance to the financial market conditions equation and φ_{zt} implies that $\rho_{z}^{z} < 0$. On the contrary, the positive relationship between the volatilities of the inflation equation disturbance and φ_{yt} and φ_{zt} implies that $\rho_{\pi}^{y} > 0$ and $\rho_{\pi}^{z} > 0$. Analogous, we expect $\rho_{y}^{\pi} > 0, \rho_{y}^{z} > 0, \rho_{z}^{\pi} > 0$ and $\rho_{z}^{y} > 0$.

Allowing for interest rate smoothing following Clarida et al. (2000) and Woodford (2003) by assuming that the actual nominal interest rate, i_t, gradually adjusts towards the desired rate $\hat{i}_t$ by adding the following partial adjustment mechanism $i_t = \rho_i(L)i_{t-1} + (1-\rho_i)\hat{i}_t$ achieves the following monetary policy reaction function

$$i_t = \rho_i(L)i_{t-1} + (1-\rho_i(L))\left(\rho_{0t} + \rho_{\pi t}E_t\pi_{t+1} + \rho_{yt}E_t y_{t+1} + \rho_{zt}E_t z_{t+1}\right) \quad (11)$$

where, $\rho_i(L) = \rho_{i1} + \rho_{i2}L + ... + \rho_{in}L^{n-1}$. The fitted value of equation (11) where $\sigma_{\pi t}^2$, σ_{yt}^2 and σ_{zt}^2 are equal to zero is given by the following counterfactual monetary policy reaction function

$$i_t^c = \hat{\rho}_i(L)i_{t-1} + (1-\hat{\rho}_i(L))\left(\hat{\rho}_0 + \hat{\rho}_{\pi}E_t\pi_{t+1} + \hat{\rho}_y E_t y_{t+1} + \hat{\rho}_z E_t z_{t+1}\right) \quad (12)$$

where $\hat{\rho}_0$, $\hat{\rho}_i$, $\hat{\rho}_{\pi}$, $\hat{\rho}_y$ and $\hat{\rho}_z$ are the coefficients of the estimated optimal monetary policy reaction function. The counterfactual monetary policy reaction function infers what the interest rate could have been in the absence of uncertainty.

2.5. Contribution of uncertainty to the interest rate

The gap between the estimated and the counterfactual monetary policy, $\hat{i}_t - i_t^c$, quantifies the effects of uncertainty on monetary policy so that a positive (negative) value of this gap indicates that the interest rates are higher (lower) under uncertainty. The contributions of the uncertainty about inflation, the output gap and financial conditions to the gap between the fitted and the counterfactual interest rates can be analysed using the following equation

$$\hat{i}_t - i_t^c = \left(1-\rho_i(L)\right)\begin{pmatrix} \hat{\rho}_{0t} + \left(\hat{\rho}_\pi^\pi E_t\pi_{t+1} + \hat{\rho}_y^\pi E_t y_{t+1} + \hat{\rho}_z^\pi E_t z_{t+1}\right)\sigma_{\pi t}^2 \\ +\left(\hat{\rho}_\pi^y E_t\pi_{t+1} + \hat{\rho}_y^y E_t y_{t+1} + \hat{\rho}_z^y E_t z_{t+1}\right)\sigma_{yt}^2 \\ +\left(\hat{\rho}_\pi^z E_t\pi_{t+1} + \hat{\rho}_y^z E_t y_{t+1} + \hat{\rho}_z^z E_t z_{t+1}\right)\sigma_{zt}^2 \end{pmatrix} \tag{13}$$

2.6. The reduced form structure of the economy

The relationships that describe the structure of the economy in equations (1), (2) and (3) depend on the unobservable state of the economy hence they need to be expressed in terms of observable variables. Therefore, substituting equation (4) into (1) achieves the following aggregate demand relationship

$$y_t = \theta_{y1} y_{t-1} - \theta_{y2} y_{t-2} - \theta_{yr}\left(i_{t-1} - \pi_t\right) + \xi_{yt} \quad , \quad \xi_{yt} \sim N\left(0, \sigma_{yt}^2\right) \tag{14}$$

where $\theta_{y1} = \phi_X + \beta_y$, $\theta_{y2} = \phi_X \beta_y$, $\theta_{yr} = \phi_r \beta_X$ and $\xi_{yt} = \varepsilon_{yt} - \phi_X \varepsilon_{yt-1} + \beta_X \varepsilon_{Xt}$. The variance of ξ_y is the demand shock and its implied variance measures the uncertainty about the output gap.

In the same manner, the aggregate supply depends on the unobserved state of the economy so that substituting (1) into (2) achieves

$$\pi_t = \pi_{t-1} + \theta_{\pi 1} y_{t-1} - \theta_{\pi 2} y_{t-2} + \xi_{\pi t} \quad , \quad \xi_{\pi t} \sim N\left(0, \sigma_{\pi t}^2\right) \tag{15}$$

where $\theta_{\pi 1} = \frac{\alpha_X}{\beta_X}$, $\theta_{\pi 2} = \frac{\alpha_X \beta_y}{\beta_X}$ and $\xi_{\pi t} = \varepsilon_{\pi t} - \frac{\alpha_X}{\beta_X}\varepsilon_{yt-1}$. The variance of ξ_π is the supply shock and its implied variance measures the uncertainty about inflation.

The conditions in the financial markets also depend on the unobserved state of the economy so that substituting (4) into (3) achieves

$$z_t = \theta_{z1} z_{t-1} - \theta_{z2} z_{t-2} - \theta_{zr}\left(i_{t-1} - \pi_t\right) + \xi_{zt} \quad , \quad \xi_{zt} \sim N\left(0, \sigma_{zt}^2\right) \tag{16}$$

where $\theta_{z1} = \phi_X + \gamma_z$, $\theta_{z2} = \phi_X \gamma_z$, $\theta_{zr} = \phi_r \gamma_Z$ and $\xi_{zt} = \varepsilon_{zt} - \phi_X \varepsilon_{zt-1} + \gamma_z \varepsilon_{Xt}$. The variance of ξ_z is the financial conditions shock and its implied variance measures uncertainty about the financial markets. The variances in equations (14), (15) and (16) evolve according to the $GARCH(1,1)$ process so that $\sigma_{jt}^2 = \mu_{0j} + \mu_{1j}\varepsilon_{jt-1}^2 + \mu_{2j}\sigma_{jt-1}^2$ where $j = y,\ \pi$ and z, while μ_{0j}, μ_{1j} and μ_{2j} are parameters.

3. Data description

Monthly data ranging from January 2000 to December 2011 is used in the analysis and it is sourced from the South African Reserve Bank. The 91-day Treasury bill rate measures the nominal interest rate. The Treasury bill rate is preferred over the official policy rate, the repurchase rate, because of its reasonable variation over time. The Treasury bill rate is also commonly used as a proxy for the official policy rate, for example, in Nelson (2003) and Boinet and Martin (2008) for the United Kingdom, among others. The correlation between the Treasury bill rate and the repo rate is sufficiently high at about 98 percent for South Africa over this sample period. Inflation is approximated by the annual change in the consumer price index. The output gap is constructed as the deviation of coincident business cycle indicator from its Hodrick and Prescott (1997) trend. Additional 12 months are forecasted using the autoregressive model with a lag order of 4 and added to the output measure to tackle the end-point problem when using the Hodrick and Prescott (1997) filter following Mise et al. (2005). Industrial production is often used as the proxy for the output gap. However, industrial production is not official data in South Africa and is a proxy for output in South Africa. It has a lower correlation of 0.65 with monthly interpolated gross domestic product (GDP) compared to the coincident business cycle indicator's correlation of 0.89. The coincident business cycle indicator is constructed at the monthly frequency by integrating various indicators of economic activity into a single indicator to the turning points in the business cycle.

Castro (2011) argues that rather than attempting to target different asset prices, central banks could monitor them in the form of a composite financial index. Therefore, the financial conditions index is constructed as an equally weighted average of the following variables. The real house price index, which is the average price of all houses compiled by the ABSA bank, deflated by the consumer price index. The real stock price, which is measured by the Johannesburg Stock Exchange All Share index, deflated by the consumer price index. The real effective exchange rate is the value of the South African rand relative to the trade weighted basket of South Africa's major trading partners' currencies adjusted for the effects of inflation, where the appreciation of the domestic currency increases the index. The credit spread, which is the spread between the yield on the 10-year government bonds and the yield on the A rated corporate bonds. Last is the future spread, which is the change of spread between the 3-month interest rate on futures contracts and the current short-term interest rate. According to Castro (2011), these variables contain valuable information from the monetary authorities' point of view in that they provide an indication of the stability in financial markets and the expectations about monetary policy stance. The financial conditions index also recognizes the importance of the transmission of monetary policy through the asset price channel and the credit channel over and above the interest rate channel.

The real stock price, real effective exchange rate and the real house price variables are detrended using the Hodrick Prescott (1997) filter. As above, additional 12 months are forecasted using the autoregressive model with a lag order of 4 and then added to each of the series before applying the HP filter to tackle the end-point problem same as with the output measure. All the variables in the index of financial conditions are seasonally adjusted and expressed in standardized form relative to their mean value in 2000 such that the vertical scale measures the variables' standard deviations. This is similar to the United Kingdom's index of financial conditions described in the Bank of England's Financial Stability Report of April 2007. Therefore, a value of 1 represents a 1 standard deviation difference from the mean value in 2000. Castro (2011) uses time-varying weights based on the extended model of Rudebusch and Svensson (1999). However, the standardization is preferred because the index is consistent with the movements in the financial markets in South Africa.

The evolution of main variables is presented in Figure 1 and the variables' descriptive statistics in Table 1. The movements in inflation are closely mirrored by the interest rate, increasing significantly from late 2001 and peaking in 2002 before falling dramatically, reaching an all time low at the end of 2003. Inflation subsequently increased steadily since the beginning of 2004 to the middle of 2008 before falling steadily towards the end of the sample period. The output gap was largely range bound between 2000 and 2004 but increased notably from 2005 before falling significantly towards the end of 2008 and subsequently increasing from the middle of 2009. The turning points of the financial conditions index, particularly the downturns, are consistent with the milestones in global financial markets and the resulting contagion to the domestic economy. These include the sustained fall from late 2001 to early 2003 consistent with the weak investor confidence following the bust of the tech bubble, the corporate scandals involving Enron, the September 11 attacks and the rapid depreciation of the South African currency in 2001. These events were followed by the turmoil in global stock markets in 2002 and the war on terror and the Iraq war in 2003. Subsequently, the subprime crisis took hold in September 2007, the financial crisis in 2008 and the recession that followed in 2009. All these factors resulted in stock markets reaching lows not experienced since the 1998 Asian.

4. Empirical results

Generalised method of moments (GMM) is used in the estimation of the central bank's reaction functions where inflation, the output gap and the financial conditions index are treated as endogenous. The set of instruments include lagged values of the explanatory variables, which is normal practice in GMM estimation. Additional instruments include the annual rate of change in the producer price index, the repurchase rate, M3 growth, and the yield on the 10-year government bond. Preliminary analysis suggests that the inflation rate series follow a nonstationary process. The Augmented Dickey Fuller and the Phillips Perron unit root tests do not reject the null, with p-values of around 0.13. However, inflation is treated as stationary in line with common practice in the estimation of monetary policy reaction functions.

The first step involves estimating the counterfactual monetary policy reaction function described in equation (12). This monetary policy reaction function serves as the benchmark and the results are presented in column (i) of Table 2. The counterfactual monetary policy reaction function is certainty equivalent because the interest rate is independent of all higher moments of inflation, the output gap and financial conditions. The preferred specification allows for a lead of 4 months on inflation and 2 months on the output gap and financial conditions, respectively. The model with the repurchase rate as a measure of the interest rate was estimated.[1]

[1]However, the results are not satisfying, perhaps due to the lack of variability of this variable. The Akaike Information Criterion (AIC) for the model with the repurchase rate reported a value of 0.82 compared to 0.56 for the model with the 3 month Treasury bill rate as a measure of the interest rate, which is what we report in the paper.

According to the results, the weight on financial markets conditions suggests that the monetary authorities take into account the changes in the financial markets when setting the interest rate since the null hypothesis $H_0 : \rho_z = 0$ is rejected at 1.00 percent level of significance, which is consistent with the recent findings in the South African literature in Naraidoo and Paya (2012) and Kasaï and Naraidoo (2013). The results also show that the monetary authorities increase interest rates by about 1.04 percent and 0.58 percent for a 1.00 percent increase in inflation and the output gap, respectively. The results are consistent with the Taylor requirement that the monetary authorities should adjust the interest rates by more than the change in inflation and by less than the change in the output gap. However, the monetary authorities' response to inflation is relatively weak compared to the 1.5 percent, which is recommended by the Taylor principle. The benchmark model satisfies the Hansen's J test in terms of the validity of instruments. An in-sample analysis of the model does not suggest the superiority of the model with separate variables relative to the model with the composite financial index in terms of the Akaike Information Criterion. Therefore, the composite index was used in quest to be parsimonious. The empirical models that exclude the financial index variable performed poorly compared to the reported model in terms of the Akaike Information Criterion and the lagged interest rate effect turned out to be slightly higher than the one reported here, therefore providing some support for an omitted variables problem.[2]

The next step involves estimating the system of equations describing the structure of the economy that comprise equations (14), (15) and (16) together with the policy rule in Equation (11) in column (ii) of Table 2 and the results for Equations (14) through (16) are presented in Table 3. The inflation equation failed the serial correlation test and was corrected using an autoregressive scheme with a lag of 2. The signs of the coefficients on the output gap, inflation and financial conditions equations are consistent. The coefficients of the real interest rate variable show wrong signs for the aggregate demand and the financial conditions equations (equations (14) and (16) respectively), showing a positive response of the output gap and financial conditions to an increase in real interest rate. Equations (14) and (16) were re-estimated using the sample up to 2006 and the correct negative coefficients on the real interest rate were obtained. However, this sign changes to positive when the sample is extended beyond 2007. The possible change in the signs of the coefficients post 2007 may be that

[2]Detailed results are not reported in the paper but are available from the authors upon request.

monetary policy has not been effective since the onset of the financial crisis, since the interest rate has dropped to very low level.

Next, the measures of uncertainty about inflation, the output gap and financial market conditions are generated from the residuals of equations (14), (15) and (16). According to Pagan (1984) and Pagan and Ullah (1988), the conditional variance for inflation, output and financial markets conditions are generated regressors and, as such, the estimated variances from equations (14), (15) and (16) may be biased and inconsistent measures of the true level of uncertainty if these equations are misspecified. To check this, we follow Pagan and Ullah (1988) in testing the squared residuals of the estimated GARCH models for neglected serial correlation of up to order 4. The results in Table 3 do not indicate misspecification suggesting adequate measures of the conditional heteroscedasticity. The evolution of these variables is illustrated in Figure 2. The uncertainty about inflation is high in 2001 and 2003 as well as between 2007 and 2009. The uncertainty about the output gap is high in 2002 and 2003 as well as from 2007 to early 2009. The uncertainty about the financial conditions is high in 2008 and 2009. The heightened volatility in the measures of uncertainty is generally clustered between 2001 and 2003 and between 2007 and 2009. These periods coincide with the financial markets turbulences that adversely impacted on the real economy and inflation. The simmering asset bubbles just before these periods artificially inflated domestic demand conditions and consumer prices as the economies overheated resulting in a massive correction after the bubbles busted resulting in adverse costs to the economy in the form of falling real output and inflation.

The non certainty equivalent monetary policy reaction function described in equation (11) is estimated and the results are presented in Table 2. The lead structure and the set of instruments in the counterfactual monetary policy reaction function above are maintained to keep consistency. After removing ρ_0^{π}, ρ_0^{y} and ρ_0^{z} which were not statistically significant, the remaining estimated coefficients are all statistically significant and the model satisfies the Hansen's J test for the validity of instruments. The AIC measure shows the benchmark monetary policy reaction function as the preferred specification though the non-certainty monetary policy reaction function has lower standard error. While the Eitrheim and Terasvirta (1996) parameter stability test suggests parameter stability in both the benchmark monetary policy reaction and the non-certainty equivalent monetary policy reaction function. The coefficients corresponding to the weights on inflation and the output gap show that the monetary authorities increase the interest rates by 1.02 percent and 0.34 percent for a 1.00 percent increase in inflation and the output gap, respectively. The monetary authorities increase interest rates by 0.86 percent for a 1.00 standard deviation increase in financial conditions. The results of non-certainty equivalent monetary policy reaction function are largely consistent with those of the benchmark counterfactual monetary policy reaction function for the coefficients corresponding to the weights on inflation and the output gap.

The coefficients corresponding to the volatility of the indicator variables are all statistically significant. The uncertainty about the output gap decreases the monetary authorities' reaction to output ($\rho_y^y < 0$), while it increases their reaction to inflation and financial conditions ($\rho_y^\pi > 0$ and $\rho_y^z > 0$). We find similar results for $\rho_\pi^\pi < 0$ and $\rho_z^z < 0$, which are largely consistent with the Brainard's (1967) attenuation principle and the proposition of cautious policy under uncertainty by Blinder (1999), suggesting that monetary policy becomes less aggressive to a particular variable when it becomes more uncertain. The uncertainty about inflation and financial conditions decreases the monetary authorities' reaction to inflation and financial conditions, while it increases their reaction to the output gap. On the contrary, the uncertainty about any particular variable, calls for a more aggressive reaction to the other variables as shown by $\rho_\pi^y > 0$, $\rho_y^\pi > 0$, $\rho_y^z > 0$, and $\rho_z^y > 0$. However, the response by the monetary authorities to the uncertainty about inflation calls for less aggressive responses to financial conditions ($\rho_\pi^z < 0$) and the uncertainty about financial conditions calls for less aggressive responses to inflation ($\rho_z^\pi < 0$). These results suggest that the monetary authorities perceive changes in the financial markets conditions as a good indicator of inflationary pressures and therefore their subdued reaction to inflation when the financial markets become more uncertain reflects the attenuation principle. This view that asset prices help to predict inflation is supported by Goodhart and Hofmann (2000), Cecchetti et al, (2003), and Surico (2009), among others. Stock and Watson (2003) also survey the literature that assesses the relationship between inflation and output and conclude that, although this literature supports the usefulness of asset prices in determining inflation and output, such results are plagued by instability and low predictive ability, particularly in the case of output growth and hence they suggest that the use of a group of asset prices, rather than individual asset price variables, may be more suitable.

The gap between the estimated and the counterfactual monetary policy described in equation (13) is estimated to quantify the effects of uncertainty on monetary policy and the results are illustrated in Figure 3. The overall impact of uncertainty about the output gap, inflation and financial market conditions is provided in quadrant (a) and is significant in 2003 and between 2007 and 2009. In particular, the overall uncertainty led to the decrease in interest rates by about 53 basis points in 2003 and this was mostly accounted for by the uncertainty about inflation as illustrated in quadrant (b) of Figure 3. The overall impact of uncertainty about the output gap, inflation and financial market conditions shown by the gap between the fitted and the counterfactual interest rate increased again from 2007 and led to an increase in interest rates by 53 basis points by the middle of 2008. In this period, the monetary authorities were faced with high uncertainty over and above the risk that was posed by the onset of the global recession that preceded a long period of booming economic conditions.

Subsequent to the onset of the global recession, uncertainty led to the decrease in interest rates by about 100 basis points by early 2009. This was largely accounted for by the uncertainty about the financial conditions as illustrated in quadrant (d) of Figure 3. Uncertainty about the output gap was relatively muted during the sample period and led to a mild decrease in interest rates in 2004 and 2008. Overall, the contribution of uncertainty to interest rates is dominated by the uncertainty about inflation in 2003 and by the uncertainty about the financial conditions between 2007 and 2009. The results generally suggest that uncertainty about inflation was important at the beginning of the sample, while the uncertainty about financial conditions was important during the financial crisis period. This suggests that the domestic price developments and the movements in financial markets largely drove the uncertainty to domestic interest rates compared to uncertainty about the output gap.

5. Conclusion

This paper has analysed the impact of uncertainty about the true state of the economy on monetary policy in South Africa. The empirical framework uses the structure of the economy that is described by four equations, one of which features the conditions in financial markets. The set of estimated equations consists of an optimal monetary policy reaction function where the monetary authorities react to expected changes in indicator variables and to uncertainties about these indicators. The empirical results reveal that the impact of uncertainty about inflation, the output gap and the financial conditions are statistically significant to domestic interest rates during the sample period. The effect of uncertainty on the interest rates has resulted in a more cautious monetary policy stance by the monetary authorities consistent with a large body of literature that recognizes that excessively activist policy can increase economic instability. The results further show that the uncertainty about the state of the economy clusters around the financial crises periods in 2003 and from 2007 to 2009. The uncertainty about inflation was important to the interest rate setting behavior in 2003, while the uncertainty about the conditions in financial markets was important to the interest rate setting behavior between 2007 and 2009.

In conclusion, monetary policy in South Africa is consistent with the Brainard's (1967) attenuation principle and the uncertainty about inflation, the output gap and the conditions in financial markets are important to domestic interest rates. Although the results suggest milder responses by the monetary authorities when faced with uncertainty, there is no consensus or a generic rule that the monetary authorities should follow in designing and implementing monetary policy when faced with uncertainty. One strand of literature, such as the Brainard's (1967) attenuation principle, suggests mild responses by the monetary authorities to the deviations of target variables when faced with uncertainty. The other strand suggests aggressive responses when faced with uncertainty following the finding by Giannoni (2002) and Sonderstrom (2002). There is also a strand of literature that suggests a discretionary and case by case stance, such as Conway (2000) and Greenspan (2003). Conway (2000) also suggests a high degree of transparency because when the central bank is transparent about its operational framework, the reaction of the economic agents is likely to be consistent with the central bank's objectives.

Future research could extend the analysis to study the other forms of uncertainty, such as model or parameter uncertainty and the uncertainty about the unexpected future events, and to the use of real time data where available.

References

Alexandre, F. and Baçao, P. (2005). "Monetary Policy, Asset Prices, and Uncertainty," Economics Letters, Vol. 86, No. 1, pp. 37-42, January

Andrews, D. W. K. and Fair, R. C. (1988). "Inference in Nonlinear Econometric Models with Structural Change," Review of Economic Studies, Vol. 55, No. 4, pp. 615-639, October

Bernanke, B. and Mark Gertler, M. (2000). "Monetary Policy and Asset Price Volatility," NBER Working Papers 7559, Massachusetts: National Bureau of Economic Research, February

Bernanke, B. S. and Gertler, M. (2001). "Should Central Banks Respond to Movements in Asset Prices?" American Economic Review, Vol. 91, No 2, pp. 253-257, May

Blinder, I. S. (1999). "Central Banking in Theory and Practice," The MIT Press, 1st Edition, Cambridge, Mass

Boinet, V. and Martin, C. (2008). "Targets, Zones and Asymmetries: A Flexible Nonlinear Model of Recent UK Monetary Policy," Oxford Economic Papers, Vol. 60, No. 3, pp. 423-439, July

Brainard, W. (1967). "Uncertainty and the Effectiveness of Policy," American Economic Review, Vol. 58, No. 2, pp. 411-425, May

Castro, V., (2011). "Can Central Banks' Monetary Policy Be Described by a Linear (Augmented) Taylor Rule or by a Nonlinear Rule?" Journal of Financial Stability, Vol. 7, pp. 228-246, No. 4

Clarida, R., Gali, J. and Gertler, M. (2000). "Monetary Policy Rules and Macroeconomic Stability: Evidence and Some Theory," Quarterly Journal of Economics, Vol. 115, No. 1, pp. 147-180, February

Cecchetti, S. G., Genberg, H., Lipsky J. and Wadhwani, S. (2000). "Asset Prices and Central Bank Policy," The Geneva Report on the World Economy, No. 2, Geneva: International Centre for Monetary and Banking Studies, May

Cecchetti, S. G. and Wynne, M. A. (2003). "Inflation Measurement and The ECB's Pursuit of Price Stability: A First Assessment," Economic Policy, CEPR, CES and MSH, Vol. 18, No. 37, pp. 395-434, October

Conway, P. (2000). "Monetary Policy in an Uncertain World," Bulletin, Vol. 63, No 3, Wellington: Reserve Bank of New Zealand, September

Ehrmann, M. and Smets, F. 2003. "Uncertain Potential Output: Implications for Monetary Policy," Journal of Economic Dynamics and Control, Vol. 27, No. 9, pp. 1611-1638, July

Engle, R. F. (1982). "Autoregressive Conditional Heteroscedasticity with Estimates of the Variance of United Kingdom Inflation," Econometrica, Vol. 50, No. 4, pp. 987-1007, July

English, W. B., Nelson, W. R. and Sack, B. P. (2003). “Interpreting the Significance of the Lagged Interest Rate in Estimated Monetary Policy Rules,” The B.E. Journal of Macroeconomics, Vol. 3, pp. 5, No. 1

Estrella, A and Mishkin, F. S. (1997). “Is there a Role For Monetary Aggregates in the Conduct of Monetary Policy?,” Journal of Monetary Economics, Vol. 40, No. 2, pp. 279-304, October.

Estrella, A and Mishkin, F. S. (2000). “Rethinking the Role of NAIRU in Monetary Policy: Implications of Model Formulation and Uncertainty,” Working Paper, No. 6518, pp. , Massachusetts: National Bureau of Economic Research

Gerlach-Kristen, P. (2004). “Interest-Rate Smoothing: Monetary Policy Inertia or Unobserved Variables?,” The B.E. Journal of Macroeconomics, Vol. 3, pp. 3, No. 1

Giannoni, M. P. (2002). “Does Model Uncertainty Justify Caution? Robust Optimal Monetary Policy in a Forward Looking Model,” Macroeconomic Dynamics, Vol. 6, No. 6, pp. 111-144, February

Greenspan, A. (2003). “Opening Remarks,” Speech at the Symposium on Monetary Policy and Uncertainty: Adapting to a Changing Economy, Jackson Hole, Wyoming, August

Goodhart, C. and Hofmann, B. (2000). “Do Asset Prices Help to Predict Consumer Price Inflation?” Supplement, Vol. 68, No s1, pp. 122-140, Manchester: The Manchester School

Hodrick, R. J. and Prescott, E. C. (1997). “Postwar U.S. Business Cycles: An Empirical Investigation,” Journal of Money, Credit and Banking, Vol. 29, No. 1, pp. 1-16, February

Kasaï, N. and Naraidoo, R. (2013). “The Opportunistic Approach to Monetary Policy and Financial Market Conditions, ” Applied Economics, Vol. 45, No.18, pp. 2537-2545, June

Martin C. and Costas Milas, C. (2009). “Uncertainty and Monetary Policy Rules In The United States,” Economic Inquiry, Vol. 47, No. 2, pp. 206–215, April

Mise, E., Kimand, T. H. and Newbold, P. (2005). “On Suboptimality of the Hodrick-Prescott Filter At Time Series Endpoints,” Journal of Macroeconomics, Vol. 27, pp. 53-67, March

Montagnoli, A. and Napolitano, O. (2005) “Financial Condition Index and Interest Rate Settings: A Comparative Analysis,” Working Paper, No. 8, Università Degli Studi Di Napoli, December

Naraidoo, R. and Paya, I. (2012). “Forecasting Monetary Policy Rules in South Africa,” International Journal of Forecasting,” Vol. 28, No. 2, April-June

Nelson, E. (2003). “UK Monetary Policy 1972–97: A Guide Using Taylor Rules,” in P. Mizen (ed.) Central Banking, Monetary Theory and Practice: Essays in Honor of Charles Goodhart, Vol. 1, Edward Elgar, Cheltenham

Orphanides, A., Porter, R. D., Reifschneider, D., Tetlow, R. and Finan, F. (2000). “Errors in the Measurement of the Output Gap and The Design of Monetary Policy,” Journal of Economics and Business, Vol. 52, No. 1-2, pp. 117-141, August

Pagan, A. (1984). “Econometric Issues in the Analysis of Regressions with Generated Regressors,” International Economic Review, Vol. 25, No. 1, pp. 221-247, February

Pagan, A. and Ullah, A. (1988). “The Econometric Analysis of Models with Risk Terms,” Journal of Applied Econometrics, Vol. 3, Vol. 2, pp. 87-105, April

Peersman , G. and Smets, F. (1999). “The Taylor Rule: A Useful Monetary Policy Benchmark for the Euro Area?” International Finance, Vol. 2, No. 1, pp. 85-116, April

Rotemberg, J. J. and Woodford, M. (1999). “Interest Rate Rules in an Estimated Sticky Price Model,” NBER Chapters, in: Monetary Policy Rules, Pages 57-126, Massachusetts: National Bureau of Economic Research

Rudebusch, G. D. and Svensson, L. E. O. (1999). “Policy Rules for Inflation Targeting,” NBER Chapters, in: Monetary Policy Rules, pp. 203-262, Massachusetts: National Bureau of Economic Research

Rudebusch, G. D. (2001). “Is the Fed too Timid? Monetary Policy in an Uncertain World,” Review of Economics and Statistics, Vol. 83, No. 2, pp. 203-217, May

Rudebusch, G. D. (2002). “Term Structure Evidence on Interest Rate Smoothing and Monetary Policy Inertia,” Journal of Monetary Economics, Vol. 49, No. 6, pp. 1161-1187, September

Sonderstrom, U. (2002). “Monetary Policy with Uncertain Parameters,” Scandinavian Journal of Economics, Vol. 104, No. 1, pp. 125-145, March

D'Agostino, A. and Surico, P. (2009). “Does Global Liquidity Help to Forecast U.S. Inflation?, ” Journal of Money, Credit and Banking, Vol. 41, No. 2-3, pages 479-489, March.

Svensson, L. E. O. (1997). “Inflation forecast targeting: Implementing and monitoring inflation targets,” European Economic Review, Vol. 41, No. 6, pp. 1111-1146, June

Svensson, L. E. O. (1999). “Inflation Targeting as a Monetary Policy Rule,” Journal of Monetary Economics, Vol. 43, No. 3, pp. 607-654, June

Svensson, L. E. O. and Woodford, M. (2003). “Indicator Variables for Optimal Policy,” Journal of Monetary Economics, Vol. 50, No. 3, pp. 691-720, April

Svensson, L. E. O. and Woodford, M. (2004). “Indicator Variables of Optimal Policy Under Asymmetric Information,” Journal of Economic Dynamics and Control, Vol. 28, No. 4, pp. 661-690, January

Swanson, E. (2004). “Signal Extraction and Non-certainty Equivalence in Optimal Monetary Policy Rules,” Macroeconomic Dynamics, Vol. 8, No. 1, pp. 27-50, February

Taylor, J. B. (1993). "Discretion versus Policy Rules in Practice," Carnegie-Rochester Conference Series on Public Policy, Vol. 39, No. 1, pp. 195-214, December

Trichet, J-C. (2011). “Monetary Policy in Uncertain Times,” Speech at Bank of Finland, Helsinki, May 5

Woodford, M. (2003). “Interest and Prices: Foundations of a Theory of Monetary Policy,” Princeton University Press, New Jersey

Table 1 Descriptive Statistics of the main variables

	Mean	Median	Maximum	Minimum	S. D.	Skewness	Kurtosis	J-Bera	Probability
Interest rate	8.57	8.27	12.75	5.45	2.03	0.24	1.99	7.42	0.02
Inflation	5.89	5.58	13.70	0.10	3.05	0.54	3.03	6.94	0.03
Output gap	0.04	0.25	6.22	-7.33	2.71	-0.51	3.59	8.31	0.02
Fin. Conditions	0.00	0.14	2.31	-3.73	1.00	-1.10	5.57	68.50	0.00
Credit spread	1.08	0.83	3.98	0.02	0.93	1.54	4.75	75.34	0.00
Future spread	3.71	3.55	6.52	2.02	0.76	1.42	5.72	92.67	0.00
REER	0.15	1.78	8.83	-22.81	6.48	-1.19	3.89	38.60	0.00
Real house price	7.71	8.10	33.93	-12.13	10.77	0.42	2.96	4.23	0.12
Real stock price	0.44	1.11	20.52	-29.30	10.92	-0.60	3.40	9.53	0.01

Note: Variables definitions are provided in the main text in Section 3 and the data is sourced from the South African Reserve bank.

Table 2 Estimates of the monetary policy reaction functions

Coefficients	(i) Certainty equivalent monetary policy reaction function		(ii) Non Certainty equivalent monetary policy reaction function	
$\rho(L)$	0.954549***	(0.002879)	0.961344***	(0.001525)
ρ_0	1.608165***	(0.381911)	1.455854***	(0.153287)
ρ_π	1.036624***	(0.054602)	1.021349***	(0.027279)
ρ_π^π			-0.197493***	(0.035794)
ρ_π^y			0.345348***	(0.019727)
ρ_π^z			-0.130668***	(0.062523)
ρ_y	0.577548***	(0.039714)	0.343238**	(0.024120)
ρ_y^π			1.254727***	(0.133294)
ρ_y^y			-1.213434***	(0.088090)
ρ_y^z			2.744557***	(0.321848)
ρ_z	0.985578***	(0.154210)	0.861339***	(0.186712)
ρ_z^π			-2.022911***	(0.252923)
ρ_z^y			1.189994***	(0.168262)
ρ_z^z			-1.079107***	(0.408407)
$\overline{R}^2$	0.975716		0.977008	
Std error	0.315818		0.312259	
Log likelihood	-35.78631		-28.32461	
AIC	0.566476		0.587842	
J Statistic	29.377366	(0.248449)	27.158329	(0.348021)
Parameter Stability	1.858000	(0.113800)	0.487500	(0.999900)

Note: Sample: Jan 2000 – Dec 2011. The certainty equivalent monetary policy reaction function is specified as $i_t^c = \hat{\rho}_i(L)i_{t-1} + (1-\hat{\rho}_i(L))(\hat{\rho}_0 + \hat{\rho}_\pi E_{t-1}\pi_{t+1} + \hat{\rho}_y E_{t-1}y_{t+1} + \hat{\rho}_z E_{t-1}z_{t+1})$, the non-certainty equivalent monetary policy reaction function is $i_t = \rho_i(L)i_{t-1} + (1-\rho_i(L))(\rho_{0t} + \rho_{\pi t}E_t\pi_{t+1} + \rho_{yt}E_t y_{t+1} + \rho_{zt}E_t z_{t+1})$ with the following identifiable parameters $\rho_{\pi t} = \rho_\pi + \rho_\pi^\pi\sigma_{\pi t}^2 + \rho_\pi^y\sigma_{yt}^2 + \rho_\pi^z\sigma_{zt}^2$, $\rho_{yt} = \rho_y + \rho_y^\pi\sigma_{\pi t}^2 + \rho_y^y\sigma_{yt}^2 + \rho_y^z\sigma_{zt}^2$ and $\rho_{zt} = \rho_z + \rho_z^\pi\sigma_{\pi t}^2 + \rho_z^y\sigma_{yt}^2 + \rho_z^z\sigma_{zt}^2$. *, **, *** denotes statistical insignificance at 10, 5 and 1 percent levels, respectively. The standard errors are in parentheses. *J Statistic* reports Hansen's test for over-identifying restrictions. Parameter stability is an F test of parameter stability (Eitrheim and Teräsvirta 1996).

Table 3 Estimates of the models describing the structure of the economy

Coefficients	Output gap		Inflation		Financial conditions	
θ_{y1}	1.496932***	(0.007310)				
θ_{y2}	0.546365***	(0.007221)				
θ_{yr}	-0.005330***	(0.001806)				
$\theta_{\pi y1}$			1.377842***	(0.008016)		
$\theta_{\pi y2}$			0.383952***	(0.007687)		
$\theta_{\pi 1}$			0.191383***	(0.007737)		
$\theta_{\pi 2}$			0.230724***	(0.008017)		
θ_{z1}					1.117021***	(0.005475)
θ_{z2}					0.245365***	(0.005993)
θ_{zr}					-0.004669***	(0.000882)
$\overline{R}^2$	0.953877		0.965841		0.825008	
Std error	0.582730		0.563739		0.418261	
J Statistic	29.424915	(0.2465450)	29.365167	(0.248940)	29.194011	(0.255887)
ARCH test	1.939532	(0.207430)	3.253091	(0.139135)	3.047147	(0.192703)
AF Statistic	1997.139	(0.000000)	19591.27	(0.000000)	1891.938	(0.000000)

Note: Sample: Jan 2000 – Dec 2011. The output gap equation is specified as $y_t = \theta_{y1} y_{t-1} - \theta_{y2} y_{t-2} - \theta_{yr} (i_{t-1} - \pi_t) + \xi_{yt}$, the inflation equation is $\pi_t = \theta_{\pi y1}\pi_{t-1} + \theta_{\pi y2}\pi_{t-2} + \theta_{\pi 1} y_{t-1} - \theta_{\pi 2} y_{t-2} + \xi_{\pi t}$ (inflation equation (15) in the main text has been amended to account for serial correlation) and the financial conditions equation is $z_t = \theta_{z1} z_{t-1} - \theta_{z2} z_{t-2} - \theta_{zr} (i_{t-1} - \pi_t) + \xi_{zt}$. *, **, *** denotes statistical insignificance at 10, 5 and 1 percent levels, respectively. The standard errors are in parentheses. *J Statistic* reports the Hansen's test for over identifying restrictions with $p-value$ in parentheses. The *ARCH test* is the Engle (1982) ARCH Lagrange multiplier test to test the null hypothesis of no ARCH up to order q in residuals. The *AF Statistic* is the Andrews-Fair (1998) Wald statistic to test the null hypothesis of no structural breaks in the equation parameters.

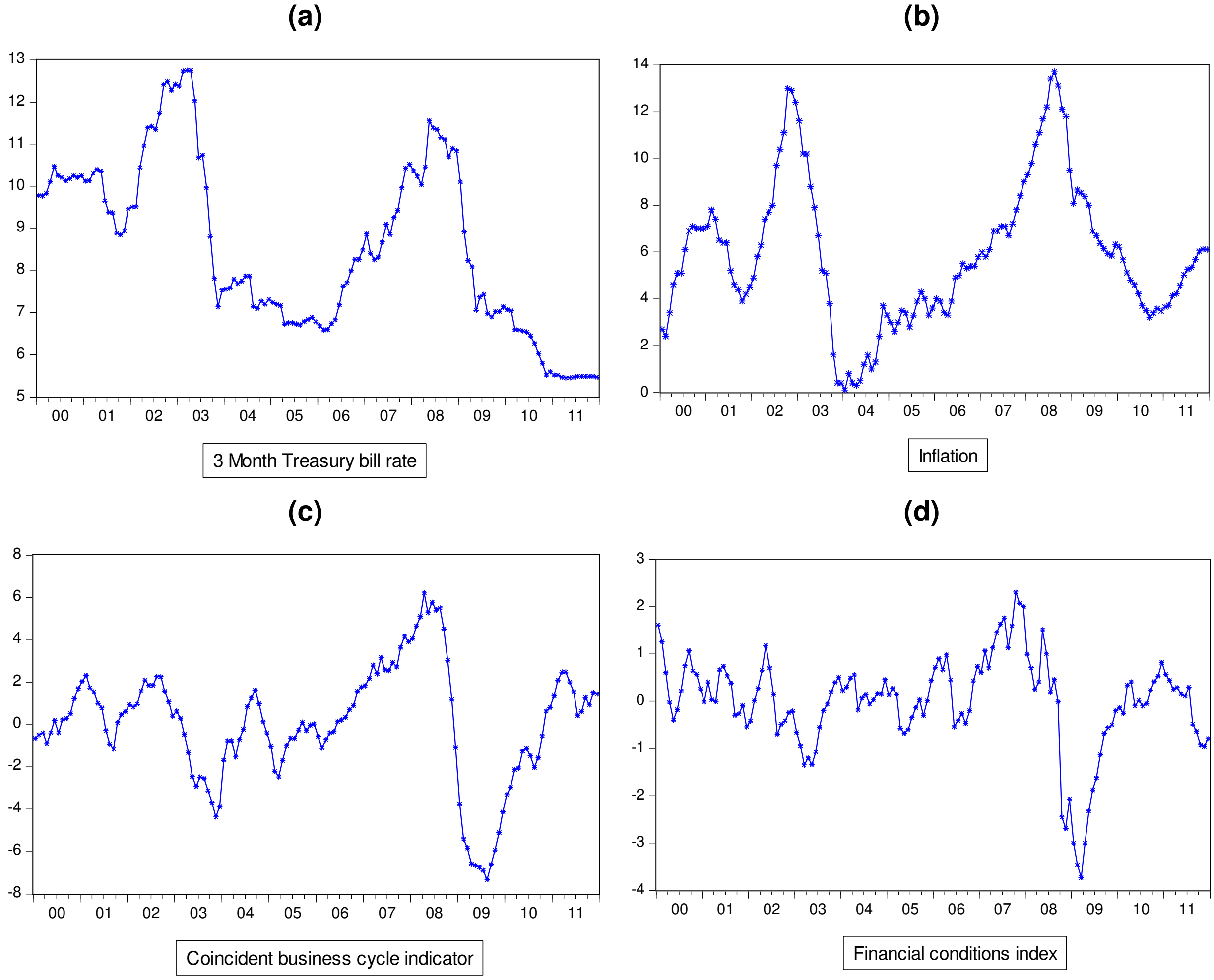

Fig. 1 Evolution of the main variables. Own calculations with data sourced from the South African Reserve bank

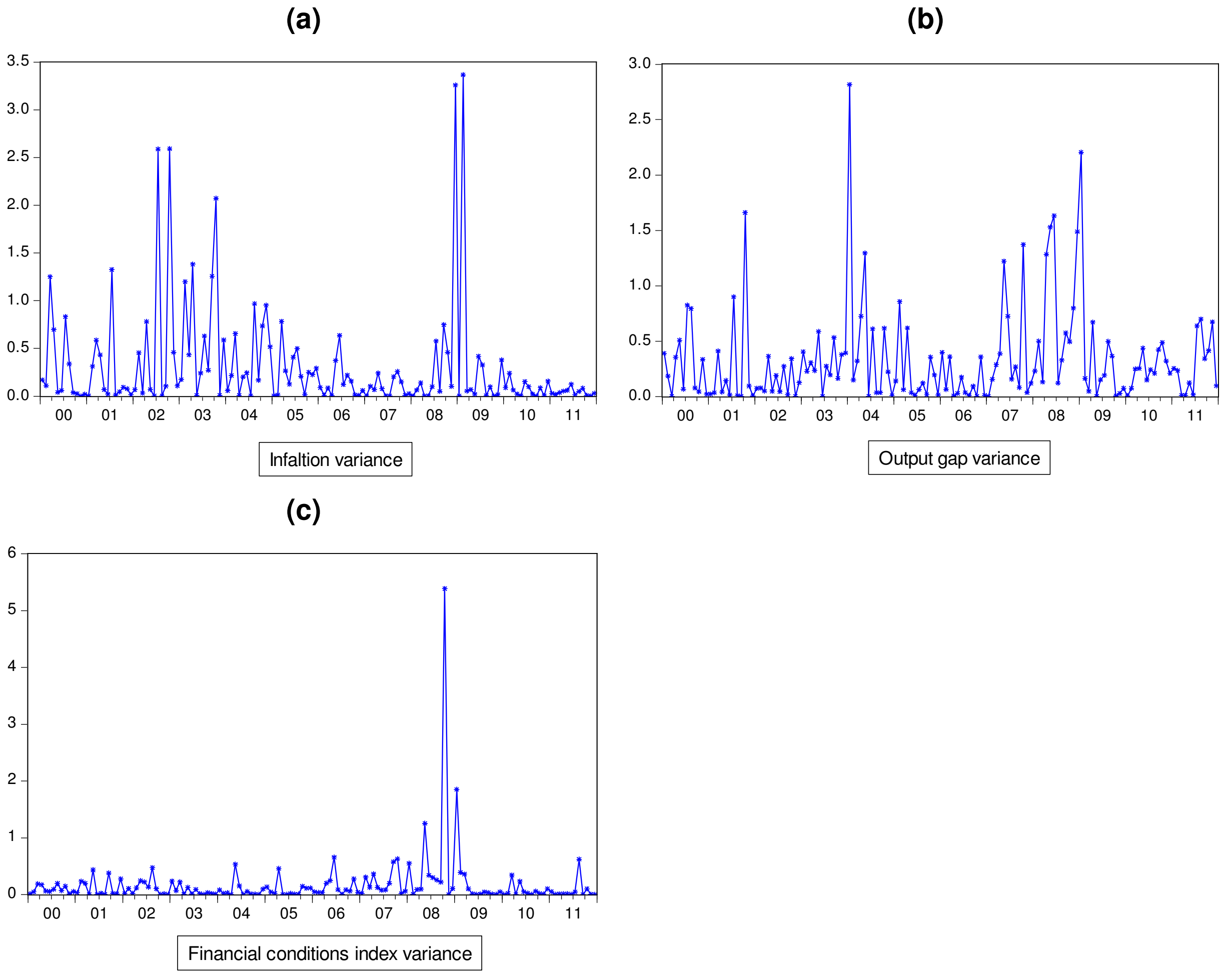

Fig. 2 Implied variances of inflation, output gap and financial conditions. The implied variances are obtained from the GARCH(1,1) models based on the residuals from the equations describing the structure of the economy.

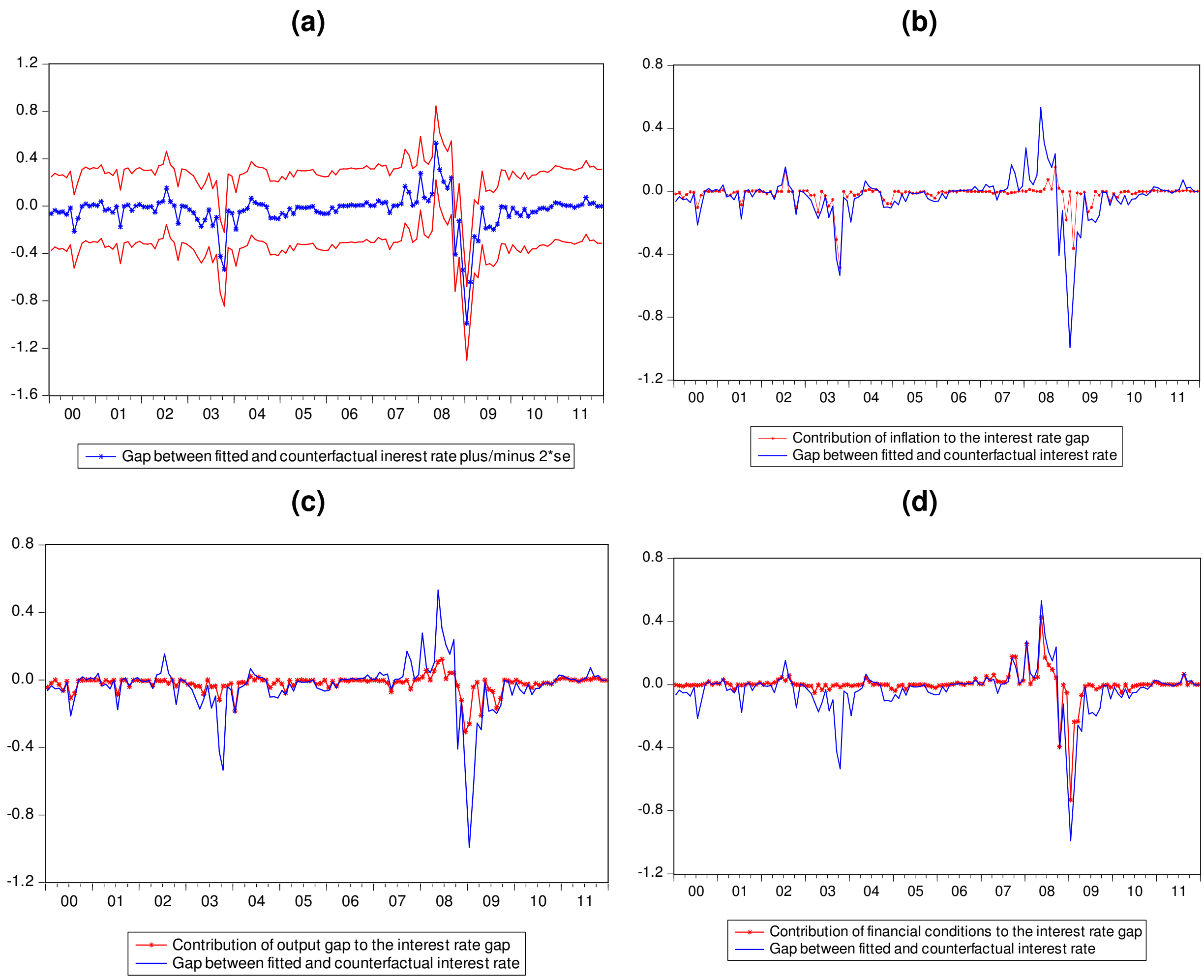

Fig. 3 Contributions of uncertainty to interest rate. The blue line is a replica of the gap between the fitted and counterfactual interest rates that shows the overall contribution of uncertainty about inflation, the output gap and the financial conditions to the interest rate

APPENDIX

In order to derive the signs of the coefficients of equation (10) in the main text, we can write the coefficients of equation (9) as $\partial_{0t} = -\pi^*\left(1+\varphi_{\pi t}\phi_X\alpha_X\right)/\left(\phi_r\alpha_X\right) = \partial_{00} + \partial_{01}\varphi_{\pi t}$, $\partial_{\pi t} = 1+\left(1+\varphi_{\pi t}\phi_X\alpha_X\right)/\left(\phi_r\alpha_X\right) = \partial_{10} + \partial_{11}\varphi_{\pi t}$, $\partial_{yt} = \phi_X\varphi_{yt}/\phi_r = \partial_{21}\varphi_{yt}$ and $\partial_{zt} = \phi_X\varphi_{zt}/\phi_r = \partial_{21}\varphi_{zt}$ where $\partial_{00} = -\pi^*/\left(\phi_r\alpha_X\right)$, $\partial_{01} = -\pi^*\phi_X\alpha_X/\left(\phi_r\alpha_X\right)$, $\partial_{10} = 1+1/\left(\phi_r\alpha_X\right)$, $\partial_{11} = \phi_X\alpha_X/\left(\phi_r\alpha_X\right)$ and $\partial_{21} = \phi_X/\phi_r$.

$\varphi_{\pi t}$ is negatively related to the variance of the inflation equation and positively related to the variance of the output and financial markets equation. φ_{yt} is negatively related to the variance of the output equation and positively related to the variance of the inflation and financial markets equation. φ_{zt} is negatively related to the variance of the financial markets equation and positively related to the variance of the inflation and output equation. Therefore, we can write $\varphi_{\pi t} = \varphi_{10} - \varphi_{11}\sigma_{\pi t}^2 + \varphi_{12}\sigma_{yt}^2 + \varphi_{13}\sigma_{zt}^2$, $\varphi_{yt} = \varphi_{20} + \varphi_{21}\sigma_{\pi t}^2 - \varphi_{22}\sigma_{yt}^2 + \varphi_{23}\sigma_{zt}^2$ and $\varphi_{zt} = \varphi_{30} + \varphi_{31}\sigma_{\pi t}^2 + \varphi_{32}\sigma_{yt}^2 + \varphi_{33}\sigma_{zt}^2$.

Substituting these into the above equations, we derive equation (10) in the main text, where $\rho_0 = -\pi^*\left(1+\phi_X\alpha_X\varphi_{10}\right)/\left(\phi_r\alpha_X\right)$, $\rho_0^\pi = \pi^*\phi_X\alpha_X\varphi_{11}/\left(\phi_r\alpha_X\right)$, $\rho_0^y = -\pi^*\phi_X\alpha_X\varphi_{12}/\left(\phi_r\alpha_X\right)$, $\rho_0^f = -\pi^*\phi_X\alpha_X\varphi_{13}/\left(\phi_r\alpha_X\right)$, $\rho_\pi = 1+\left(1+\phi_r\alpha_X\varphi_{10}\right)/\left(\phi_r\alpha_X\right)$, $\rho_\pi^\pi = -\phi_X\alpha_X\varphi_{11}/\left(\phi_r\alpha_X\right)$, $\rho_\pi^y = \phi_X\alpha_X\varphi_{12}/\left(\phi_r\alpha_X\right)$, $\rho_\pi^z = \phi_X\alpha_X\varphi_{13}/\left(\phi_r\alpha_X\right)$, $\rho_y = \phi_X\varphi_{20}/\phi_r$, $\rho_y^\pi = \phi_X\varphi_{21}/\phi_r$, $\rho_y^y = -\phi_X\varphi_{22}/\phi_r$, $\rho_y^z = -\phi_X\varphi_{23}/\phi_r$, $\rho_z = \phi_X\varphi_{30}/\phi_r$, $\rho_z^\pi = \phi_X\varphi_{31}/\phi_r$, $\rho_z^y = \phi_X\varphi_{32}/\phi_r$ and $\rho_z^z = -\phi_X\varphi_{33}/\phi_r$. Inspection reveals that $\rho_\pi^\pi < 0$, $\rho_\pi^y > 0$, $\rho_\pi^z > 0$, $\rho_y^\pi > 0$, $\rho_y^y < 0$, $\rho_y^z > 0$, $\rho_z^\pi > 0$, $\rho_z^y > 0$ and $\rho_z^z < 0$.