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

by

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Abstract

This paper analyses 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 uses an extended monetary policy rule that allows analysis of 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. 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 and between 2007 and 2008, while the uncertainty about the conditions in financial markets was important to the interest rate setting behavior between 2008 and 2009.

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1. Introduction

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 following Taylor (1993), Rotemberg and Woodford (1999) and Rudebusch and Svensson (1999) and Clarida et al. (2000)) in that the South African Reserve Bank (SARB henceforth) has a mandate to achieve and maintain price stability in the interest of balanced and sustainable economic growth. The SARB moved from a constant money supply growth rate rule that prevailed since 1986 to monetary policy that is 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. Although inflation targeting central banks are primarily concerned with managing the rate of inflation in practice, they do also attempt to avoid recessions or output fluctuations as well as crises due to financial instability. Goodhart (1988) argues that the original motivation for creating central banks in many countries was to limit the occurrence of financial crises, while Stein (2012) recently provided a theoretical model of how monetary policy can influence bank lending and real activity. Although the debate on whether Central Banks can improve macroeconomic stability by targeting financial asset prices is diverse, De Grauwe (2007), Mishkin (2008), Taylor (2008), former ECB president Trichet (2005), ECB Vice President Papademos (2009) argue for such intervention to offset the negative effects of financial turmoil on economic activity.

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 monetary policy reaction functions. English et al. (2003) and Gerlach-Kirsten (2004) find that inclusion of a financial spread reduces the empirical importance of interest rate smoothing. Estrella and Mishkin (1997), among others, analyze the influence of the term structure variable in monetary policy rules, while Curdia and Woodford (2010) following the proposal of Taylor (2008) and show that an adjustment for variations in credit spreads can improve upon the standard Taylor rule within a dynamic stochastic general economic model. Monetary policy reaction functions have also been augmented to include an index of financial market conditions by Montagnoli and Napolitano (2005) and Castro (2011), among others. In the context of South Africa, Naraidoo and Raputsoane (2010) and Kasai and Naraidoo (2013) have used such index of financial market conditions, while Naraidoo and Paya (2012) have shown that asset prices are important determinants of the interest rate setting behavior of the SARB using both in-sample and out-of-sample estimates.

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. 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". Mishkin (2008) laments the unfortunate reality that most existing studies on optimal monetary policy have abstracted from considerations of macroeconomic risk in the context of financial disruptions. 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 currently 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. This literature includes 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. 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. 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.

Martin and Milas (2009) appraise the impact of uncertainty about the state of the economy on monetary policy in the United States by borrowing from Svensson's (1997) model of expected inflation targeting as well as the models of optimal weights on indicators in models of monetary policy with partial information about the state of the economy by Svensson and Woodford (2003, 2004) and Swanson (2004). This framework posits that indicator variables of monetary policy 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 in usual signal extraction problems. 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 paper therefore extends the existing framework that combines Svensson (1997) together with Svensson and Woodford (2003, 2004) and Swanson (2004) to allow the indicator of financial market conditions as an extra variable on top of inflation and output. This measure of financial market conditions acts as an indicator variable for the unobservable state of the economy in an attempt to gauge the impact of its volatility on the setting of the policy interest rate in South Africa. The contributions of this paper are two fold, first, it is the first attempt to assess the impact of uncertainty about the true state of the economy on monetary policy in South Africa. Secondly, over and above gauging the impact of inflation and output volatilities on the interest rate setting behavior of the SARB, the framework also allows the investigation of how the uncertainty in financial markets has contributed to movements in the setting of the interest rate.

The main findings of the paper suggest that the SARB monetary authorities pay close attention to the index of financial conditions when setting interest rates. This result is in line with recent works on the South African economy such as Naraidoo and Paya (2009), among others, as well as Castro (2011) for the ECB. Secondly, the paper suggest that uncertainty impact on interest rates was most marked in 2003 leading to the decrease in interest rates by about 37 basis points, an increase in interest rates by about 64 basis points in 2007-2008 after a long period of rising inflation and the onset of the global recession in 2008-2009, leading to the decrease in interest rates by about 98 basis points. Overall, the contribution of uncertainty to interest rates is dominated by the uncertainty about inflation in 2003 and between 2007 and 2008 and by the uncertainty about the financial conditions between 2008 and 2009. The estimates are in line with the findings that predated the financial crisis period, namely, the study by Martin and Milas (2009) that policymakers in the US increased interest rates by up to 140 basis points with uncertainty most marked in 1983 and reduced interest rates by up to 70 basis points during the period 1996 to 2001. Thirdly, the study supports the view of less aggressive policy under uncertainty as established by Brainard (1967) and has been supported by Estella and Mishkin (2000), Svensson (1999), Swanson (2004), Cateau (2007), Martin and Milas (2009) among others.

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) and Alexandre and Bacao (2005) 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 Bacao (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

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

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

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

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, for instance, Alexandre and Bacao (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

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

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 $j = y$, p, 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 minimize 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

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

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 minimizing $L_t = E_t \delta^2 \frac{1}{2}(\pi_{t+2} - \pi^*)^2$ 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. Increased uncertainty about the current growth rate of productivity, potential output, the natural rate of unemployment among other variables has led to questions about how monetary policy should be altered in the face of this uncertainty. 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 weights 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 $r_{zt} = r_z + r_z^{\rho} s_{\rho t}^2 + r_z^{y} s_{yt}^2 + r_z^{z} s_{zt}^2$. 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

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

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

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

where $\hat{\rho}_0$, $\hat{\rho}_i$, $\hat{\rho}_{\pi}$, $\hat{\rho}_y$ and $\hat{r}_z$ 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 analyzed using the following equation

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

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

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

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

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

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

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

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 $j = y$, p and z, while μ_{0j}, μ_{1j} and μ_{2j} are parameters.

3. Data description

Monthly data ranging from January 2000 to December 2012 is used in estimation and it is sourced from the South African Reserve Bank. The repurchase rate, also known as the repo rate, measures the nominal interest rate. Inflation is measured by the annual change in the consumer price index. The output gap is constructed as the deviation of the coincident business cycle indicator from its Hodrick and Prescott (1997) trend. Additional 12 months of the coincident business cycle indicator are forecasted using the autoregressive model with a lag order of 4 to tackle the end point problem when using the Hodrick and Prescott (1997) filter following Mise et al. (2005). 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. Industrial production is often used as the proxy for the output gap in monthly frequency. However, industrial production is not official data in South Africa hence the coincident business cycle indicator is used as a proxy for output in South Africa. Furthermore, industrial production, which is not official data, 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.

Castro (2011) argues that rather than targeting different asset prices as indicators of conditions in the financial market, central banks could monitor them in the form of a composite index. Therefore, the index of financial conditions 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 the Johannesburg Stock Exchange's All Share index, deflated by the consumer price index. The real effective exchange rate, which 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 indicates an 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 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, the 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 Hodrick Prescott 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 adopted 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 Fig. 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

Table 1 Descriptive Statistics of the main variables

	Mean	Max.	Min.	S. Dev.	Skew.	Kurtosis	J-Bera	Prob.
Interest rate	8.923	13.500	5.000	2.580	0.164	1.692	11.812	0.003
Inflation	5.870	13.700	0.100	2.932	0.576	3.287	9.166	0.010
Output gap	0.060	6.210	-7.650	2.613	-0.572	3.902	13.794	0.001
Fin. conditions	0.001	2.310	-3.730	0.954	-1.142	6.169	99.204	0.000
Credit spread	0.744	2.500	-3.700	0.931	-1.570	5.148	94.071	0.000
Future spread	3.676	6.500	-6.400	0.709	-1.664	6.223	139.523	0.000
REER	0.145	8.900	-13.280	6.315	-1.165	4.025	42.129	0.000
Real house price	0.254	6.340	-14.260	4.194	-1.234	4.459	53.424	0.000
Real stock price	0.018	2.010	-3.970	0.996	-0.955	5.272	57.253	0.000

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

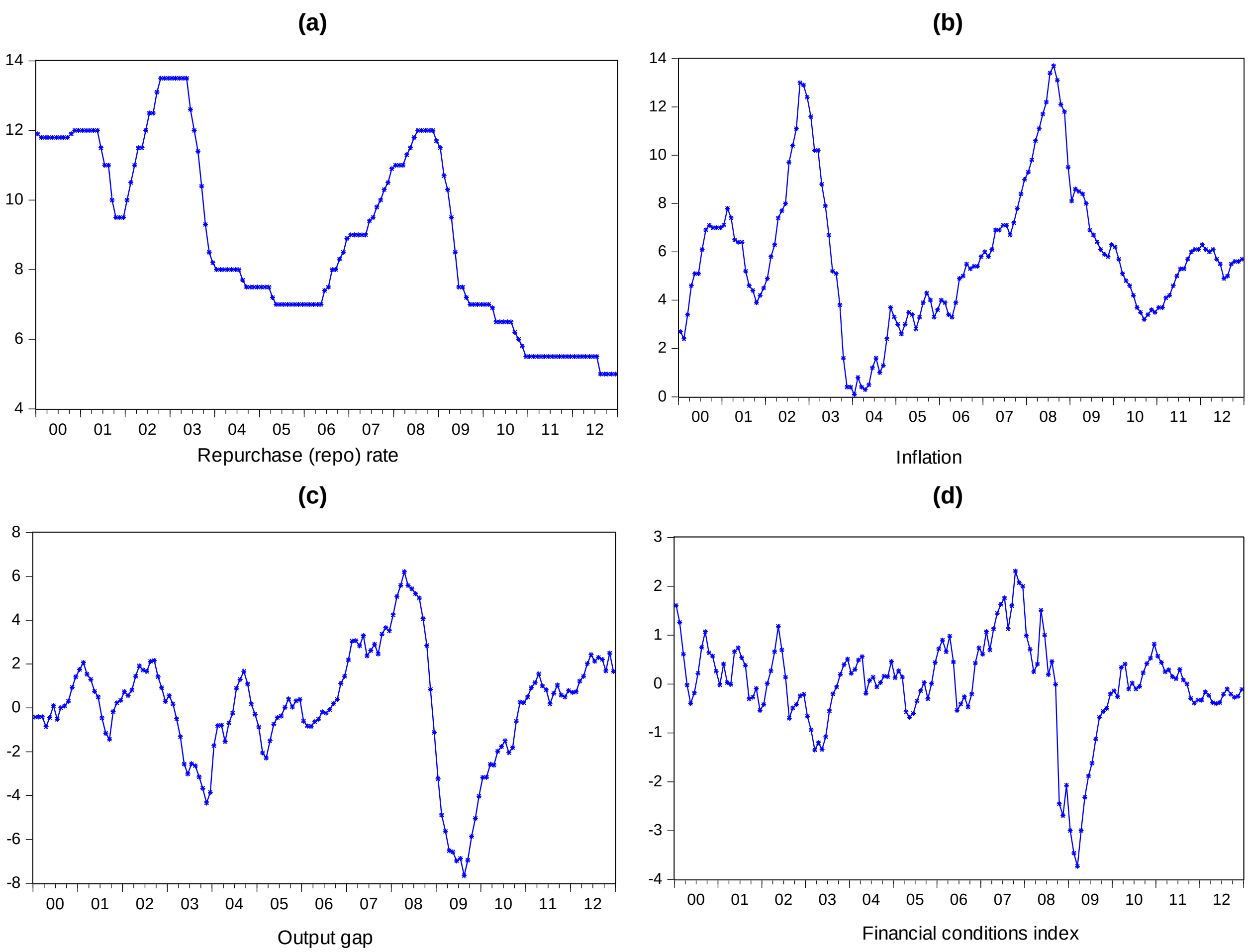

Fig. 1 Evolution of the main variables. Own calculations with data sourced from the South African Reserve bank

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 as well as the war on terror and the Iraqi war in 2003. Subsequently, the subprime crisis took hold in September 2007, the financial crisis in 2008 and the recession that followed in 2009, after which the economy started to recover slowly. All these factors resulted in stock markets reaching lows not experienced since the 1998 Asian.

4. Empirical results

Generalized 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 91 day treasury bill rate, M3 growth, and the yield on the 10-year government bond. Preliminary analysis involved applying a battery of unit root tests that suggested that the inflation rate series follow a nonstationary process where the p-values of the Augmented Dickey Fuller and Elliott-Rothenberg-Stock tests are around 0.10. The Phillips Perron test suggests that the null of nonstationarity is not rejected at the 10 percent level of significance and the Kwiatkowski-Phillips-Schmidt-Shin test does not reject the null of stationarity at the 10 percent level of significance. However, inflation is treated as stationary in line with common practice in the estimation of monetary policy reaction functions. It is also worth noting that Nobay et al. (2010) showed that the inflation rate in the US to be a globally mean reverting process within a nonlinear framework.

The first step involves estimating the counterfactual monetary policy reaction function described in equation (12). The monetary policy reaction functions without and with financial conditions are also estimated to assess the usefulness of the financial index variable and the results are reported in column (i) and (ii) of Table 2, respectively. These counterfactual monetary policy reaction functions are certainty equivalent because the interest rate is independent of all higher

Table 2 Estimates of monetary policy reaction functions

Coefficients	Model without financial conditions		Model with financial conditions	
	Without uncertainty Column (i)	With uncertainty Column (ii)	Without uncertainty Column (iii)	With uncertainty Column (iv)
$\rho(L)$	0.951642*** (0.002581)	0.960680*** (0.003063)	0.969895*** (0.000867)	0.962283*** (0.001195)
ρ_0	6.563257*** (0.117296)	5.322334*** (0.167417)	6.533525*** (0.089343)	4.916302*** (0.074945)
ρ_π	1.425143*** (0.048880)	1.418542*** (0.077117)	1.757738*** (0.047581)	1.552402*** (0.035129)
ρ_π^π		-1.165406*** (0.119937)		-0.941553*** (0.058969)
ρ_π^y		0.438454*** (0.051515)		0.670616*** (0.040243)
ρ_π^z				-0.695070*** (0.063552)
ρ_y	0.597712*** (0.035011)	0.507667*** (0.084753)	0.635481*** (0.060985)	0.706802*** (0.060694)
ρ_y^π		1.352715*** (0.158958)		1.422271*** (0.141612)
ρ_y^y		-0.302304** (0.124747)		-0.217854** (0.086362)
ρ_y^z				0.581426*** (0.131413)
ρ_z			0.613075*** (0.072388)	0.694724*** (0.196020)
ρ_z^π				-1.573894*** (0.279373)
ρ_z^y				2.095401*** (0.296719)
ρ_z^z				-2.795101*** (0.442557)
$\bar{R}^2$	0.984028	0.988490	0.988490	0.988812
Std error	0.297466	0.272157	0.272157	0.268321
Log likelihood	-15.93472	-5.080028	-5.080028	-3.881703
J Statistic	22.334689 (0.616352)	29.262109 (0.253108)	29.262109 (0.253108)	28.020712 (0.306901)
Parameter Stability	1.747663 (0.021943)	1.298285 (0.211401)	1.890097 (0.040345)	1.226963 (0.240016)

Note: Sample: Jan 2000 to Dec 2012. The monetary policy reaction functions with no uncertainty 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 monetary policy reaction functions with uncertainty is specified as $i_t = \rho_i(L)i_{t-1} + (1-\rho_i(L))(\rho_{0t} + \rho_{\pi t}E_t\pi_{t+1} + \rho_{yt}E_t y_{t+1} + \rho_{zt}E_t z_{t+1})$ 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 Terasvirta 1996).

moments of inflation, the output gap and financial conditions. The preferred specification allows for a lead of 1 month on inflation and 10 months on the output gap and 6 months on financial conditions, respectively. As a sensitivity analysis, the model with the 91 day Treasury bill rate as a measure of the interest rate was estimated. The sensitivity of the findings to alternative data definitions such as the 91-day Treasury bill rate as an alternative measure of the interest rate was assessed and the finding is that, even though the results still satisfies the Taylor principle, the response to inflation is lower than the estimates reported in Table 2.

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 the 1 percent level of significance. This finding is consistent with the recent findings for the South African economy in Naraidoo and Raputsoane (2010), Naraidoo and Paya (2012), Kasai and Naraidoo (2013) and Castro (2011) for the Eurozone, among others. The results also show that the monetary authorities increase interest rates by about 1.76 percent and 0.63 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. Both these models however fail the Eitrheim and Terasvirta (1996) parameter stability test, with the model with financial conditions providing better adjusted R squared and regression standard error. The benchmark model in Equation (12) satisfies the Hansen's J test in terms of the validity of instruments.

It is also worth noting that the inclusion of a financial indicator index rather than the variables separately in the interest rate rule is in line with Castro (2011) for the Eurozone and Naraidoo and Paya (2012) for the South African economy, who argue that, instead of attempting to target different asset prices, Central Banks could be monitoring asset prices and financial information in the form of a composite financial index. Initial in-sample analysis (in terms of regression standard error and R^2) for these benchmark models does not suggest superiority of the model with separate variables relative to the model with the composite index. Furthermore, preliminary analysis of the individual series suggests that, in general, the credit spread was the most significant financial indicator, followed by house prices, the real effective exchange rate, stock prices and, finally, by the future spread. We decided to be as parsimonious as possible with the number of variables in the measure of uncertainty exercise and therefore used the composite index.

The next step involves estimating the system of equations that describe the structure of the economy comprising equations (14), (15) and (16) and the results are presented in Table 3. The policy rule in Equation (11) with and without the financial conditions index were also estimated and the results are reported in column (iii) and (iv) in Table 2. Equations (14), (15) and (16) were estimated using the Newey and West's robust standard errors to account for serial correlation that was detected in the inflation equation. According to the results, the signs of the coefficients on the output gap and inflation equations (14) and (15) are consistent with expectations, with the correct signs on the lagged dependent variables and on the coefficient of the real interest rate variable for the aggregate demand equation. The results on the financial conditions equation are also consistent with expectations with correct signs on lagged dependent variables, while the sign of the of the real interest rate variable in the financial conditions equation is wrong and is also statistically insignificant. Equations (14) and (16) were reestimated using the sample up to 2006 and the correct negative coefficients on the real interest rate were obtained in the financial conditions equation. However, this sign changes to positive and insignificant when the sample is extended beyond 2007. The possible change in the signs of the coefficients post 2007 may be that monetary policy has not been very effective on financial conditions measure since the onset of the financial crisis, since the interest rate dropped to very low levels in an attempt to spur economic growth.

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, following Pagan and Ullah (1988), the squared residuals of the estimated GARCH models were tested 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 Fig. 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

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

Coefficients	Output gap	Inflation	Financial conditions
θ_{y1}	1.496286*** (0.030885)		
θ_{y2}	0.548824*** (0.032374)		
θ_{yr}	0.009355*** (0.002521)		
$\theta_{\pi y1}$		0.994880*** (0.007003)	
$\theta_{\pi y2}$		0.315175*** (0.041296)	
$\theta_{\pi 1}$		0.251653*** (0.036715)	
$\theta_{\pi 2}$			
θ_{z1}			1.402572*** (0.041208)
θ_{z2}			0.456396*** (0.043093)
θ_{zr}			-0.000923 (0.002238)
$\bar{R}^2$	0.954560	0.959484	0.809097
Std error	0.557041	0.590224	0.416991
DWStat	2.128323	1.249245	2.363139
J Statistic	46.961882 (0.495412)	18.114440 (0.837494)	27.149529 (0.348456)
ARCH test	0.017578 (0.982600)	1.377090 (0.255500)	1.345934 (0.199200)
Parameter Stability	1.365752 (0.189296)	1.410362 (0.167836)	1.359773 (0.192335)

Note: Sample: Jan 2000 to Dec 2012. The output gap equation is specified as $y_t = \theta_{y1} y_{t-1} - \theta_{y2} y_{t-2} - \theta_{yr}\left(i_{t-1} - \pi_t\right) + \xi_{yt}$, the inflation equation is $\pi_t = \theta_{\pi y1}\pi_{t-1} + \theta_{\pi y2}\pi_{t-2} + \theta_{\pi 1} y_{t-1} - \theta_{\pi 2} y_{t-2} + \xi_{\pi t}$ and the financial conditions equation is $z_t = \theta_{z1} z_{t-1} - \theta_{z2} z_{t-2} - \theta_{zr}\left(i_{t-1} - \pi_t\right) + \xi_{zt}$. All the models were estimated with robust standard errors. *, **, *** 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. Parameter stability is an F test of parameter stability (Eitrheim and Teräsvirta 1996).

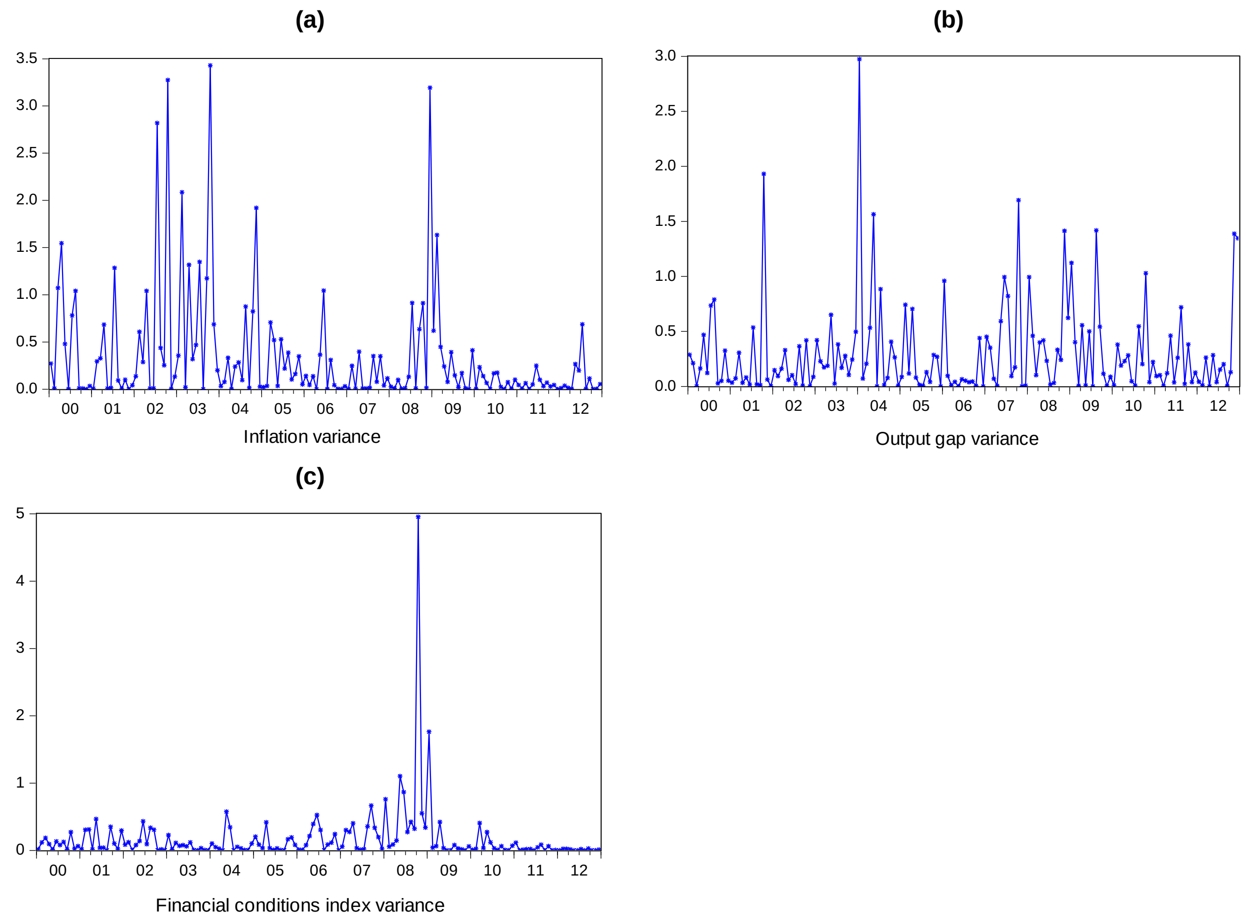

Fig. 2 Implied variances of inflation, output gap and financial conditions. The implied variances are obtained from the $\mathrm{GARCH}(1,1)$ models based on the residuals from the equations describing the structure of the economy.

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 noncertainty equivalent monetary policy reaction function described in equation (11) is then estimated with and without the index of financial conditions and the results are presented in Table 2, column (iii) and (iv) respectively, while the results for this noncertainty equivalent monetary policy reaction function without financial conditions are reported in Table 2, column (i) and (ii) respectively. The lead structure and the set of instruments in the counterfactual monetary policy reaction function above are maintained to keep consistency. The parameters ρ_0^{π}, ρ_0^{y} and ρ_0^{z} were not statistically significant and were excluded in the estimation. The remaining estimated coefficients are all statistically significant and the models satisfy the

Hansen's J test for the validity of instruments. The noncertainty monetary policy reaction functions have lower standard errors and better log-likelihood than their certainty equivalent counterparts. The Eitrheim and Terasvirta (1996) parameter stability test suggests parameter stability in the noncertainty equivalent monetary policy reaction functions. The coefficients corresponding to the weights on inflation and the output gap show that the monetary authorities increase the interest rates by 1.55 percent and 0.71 percent for a 1.00 percent increase in inflation and the output gap, respectively. The monetary authorities increase interest rates by 0.69 percent for a 1.00 standard deviation increase in financial conditions. The results of noncertainty equivalent monetary policy reaction function described in equation (11) are largely consistent with those of the noncertainty equivalent monetary policy reaction function without financial conditions together with their benchmark counterfactual monetary policy reaction function counterparts.

The coefficients corresponding to the volatility of the indicator variables in equation (11) 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, $\rho_y^\pi > 0$, and financial conditions, $\rho_y^z > 0$. Similar results are found 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 $\rho_z^y > 0$. The findings that 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, $\rho_z^\pi < 0$, are particularly interesting. 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 and Wynne (2003), and D'Agostino 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.

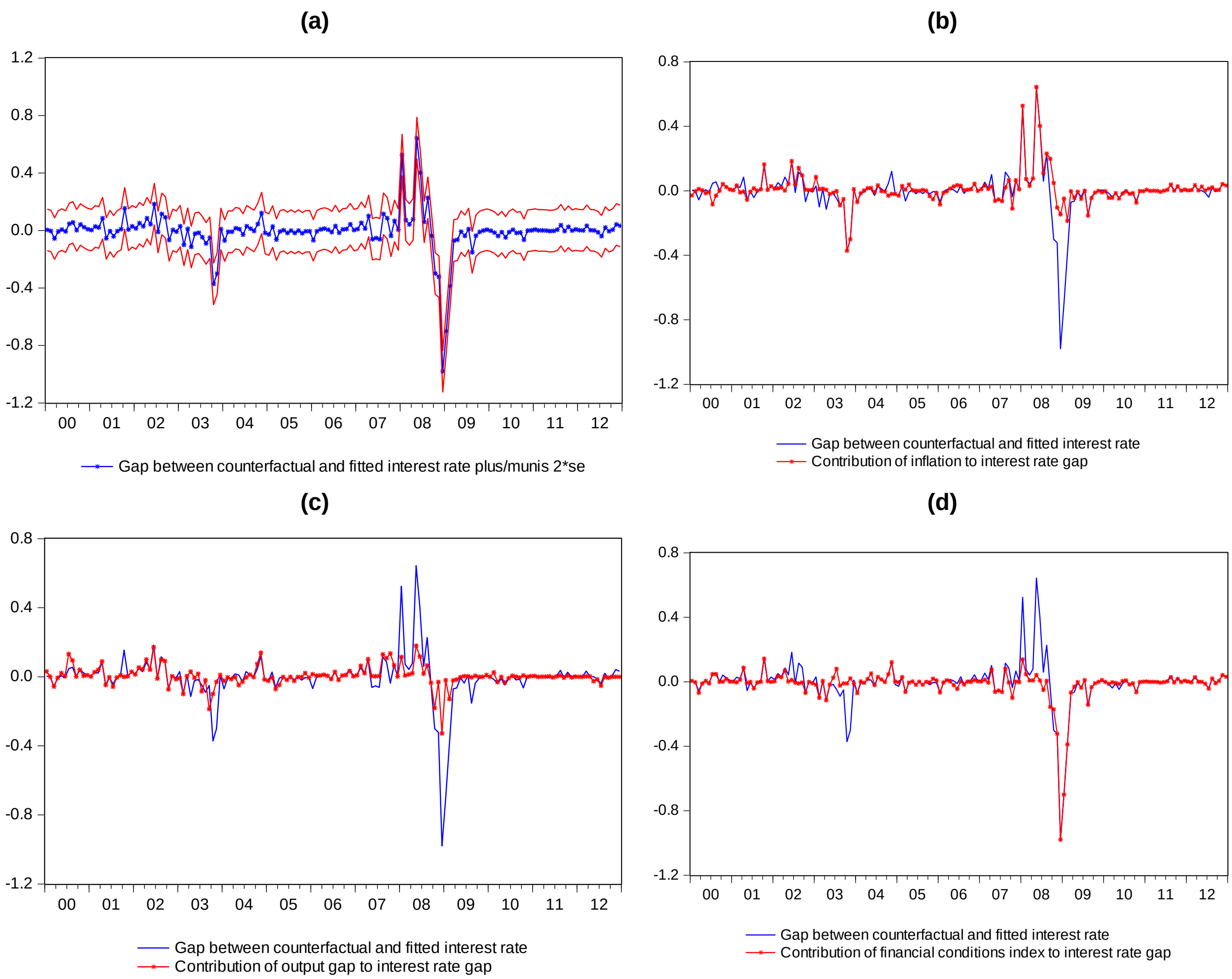

Fig. 3 Contributions of uncertainty to interest rate. The blue line is a replica of the gap between the fitted and counterfactual interest rates that shows the overall contribution of uncertainty about inflation, the output gap and the financial conditions to the interest rate

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 Fig. 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 37 basis points in 2003 and this was mostly accounted for by the uncertainty about inflation as illustrated in quadrant (b) of Fig. 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 64 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 and rising inflation and hence explained the hike in interest rates.

Subsequent to the onset of the global recession, uncertainty led to the decrease in interest rates by about 98 basis points by early 2009. This was largely accounted for by the uncertainty about the financial conditions as illustrated in quadrant (d) of Fig. 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 between 2007 and 2008 as well as by the uncertainty about the financial conditions between 2008 and 2009. The results generally suggest that uncertainty about inflation was important at the beginning of the sample and just prior to the onset of the global financial crisis, while the uncertainty about financial conditions was important during the financial crisis period. This suggests that the domestic inflation developments and the movements in financial markets largely contributed to the uncertainty in domestic interest rates compared to uncertainty about the output gap. It is also worth mentioning that the preferred noncertainty equivalent monetary policy reaction function with financial conditions is able to explain the large drop in interest rates when faced with the uncertainty during the financial crisis period, which could not be explained by any other models that did not account for this variable.

The noncertainty equivalent monetary policy reaction function described in equation (11) was recursively estimated over expanding windows of data to illustrate the differential effect of uncertainty and financial conditions before and after the global financial crisis. The first data window runs from 2000:M1 to 2006:M12, while each successive data window is extended by one observation, hence, the last data window runs from 2000:M1 to 2012:M2 delivering 62 expanding windows. From a policy point of view, this allows us to identify the evolution of the estimated model parameters over time. The sequences of expanding windows in which the sample size for estimation is increased by one observation in each successive window are used, as opposed to sequences of fixed-length rolling windows. This is because the increasing windows by one observation is more desirable as opposed to sequences of fixed-length rolling windows given that such estimation is parameter intensive and hence requires more data to be accurate.

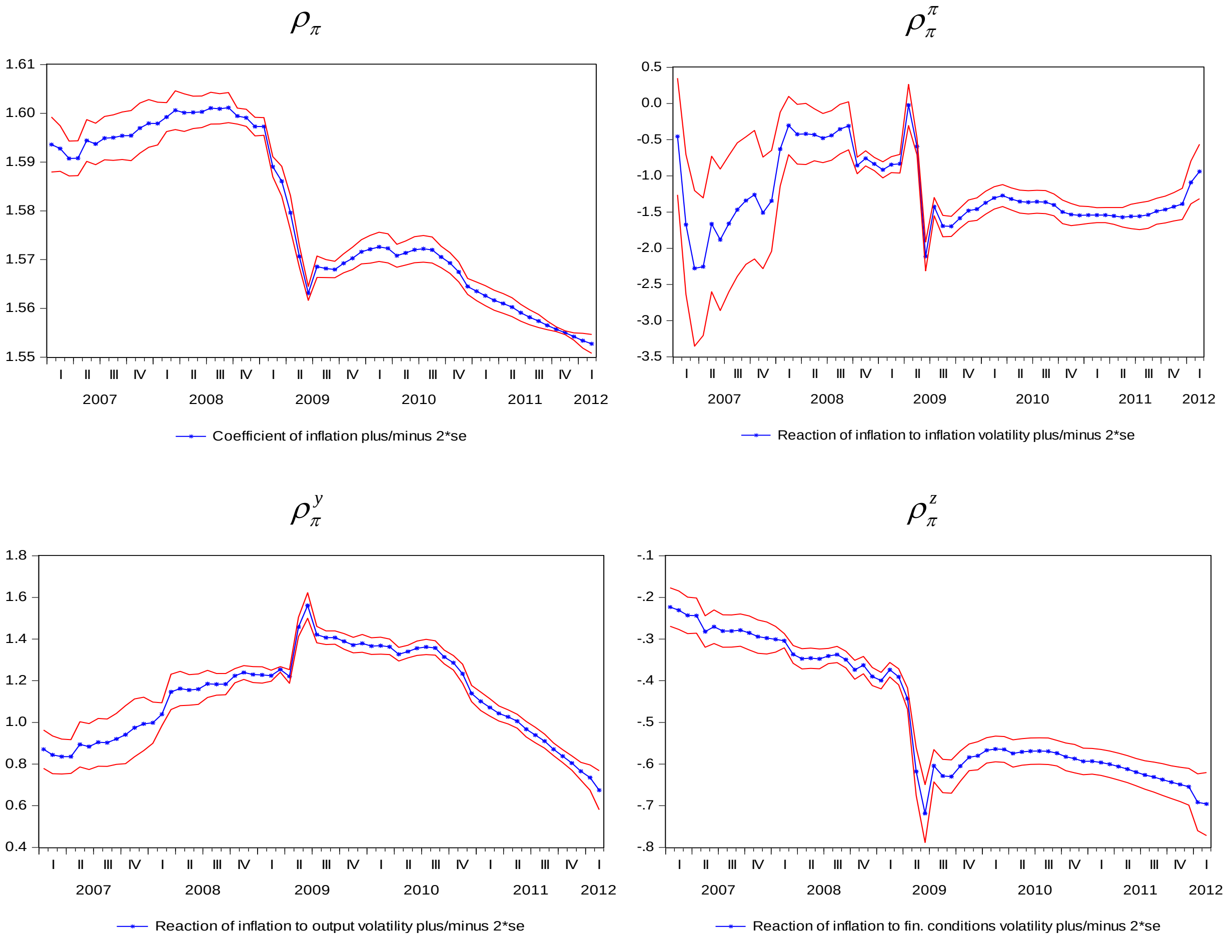

Fig. 4(a) Recursive estimates of inflation coefficients using monetary policy reaction functions with no financial conditions index

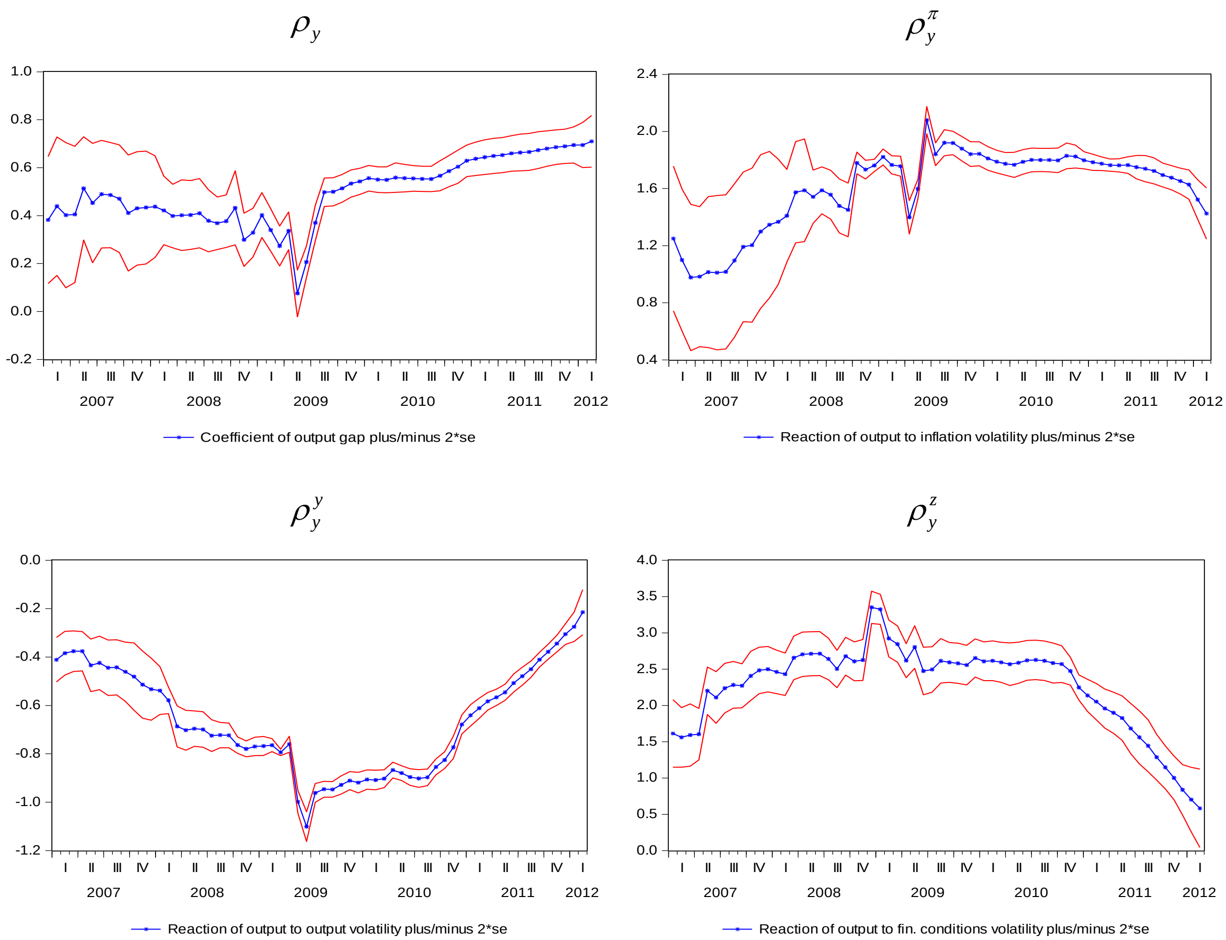

Fig. 4(b) Recursive estimates of output gap coefficients using monetary policy reaction functions with no financial conditions index

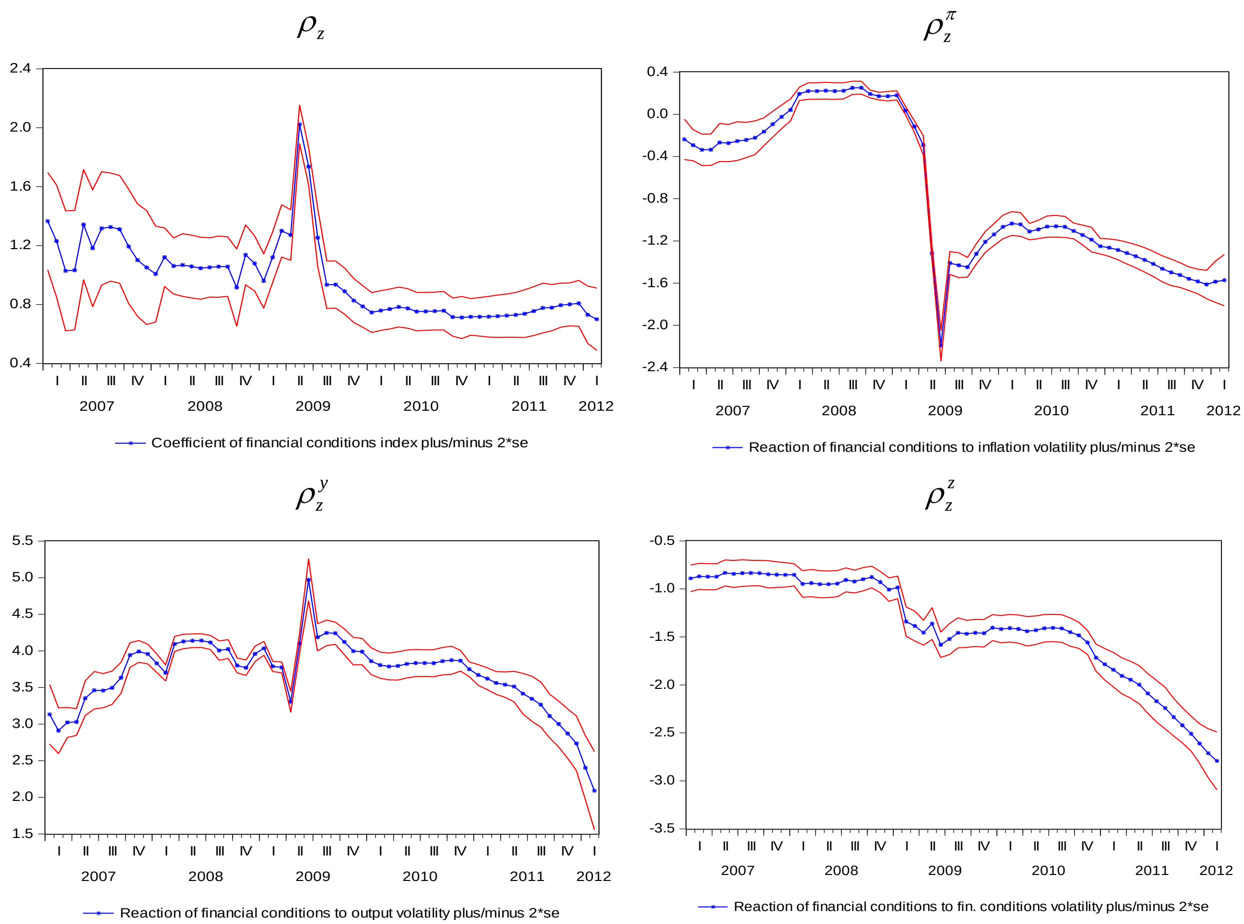

Fig. 4(c) Recursive estimates of financial conditions coefficients using monetary policy reaction functions with no financial conditions index

The plots of the recursive estimates (plus/minus 2*standard errors) of the response parameters $\rho_\pi, \rho_\pi^\pi, \rho_\pi^y, \rho_\pi^z, \rho_y, \rho_y^\pi, \rho_y^y, \rho_y^z, \rho_z, \rho_z^\pi, \rho_z^y$ and ρ_z^z for the model with financial conditions and with uncertainty, equation (11), are depicted in Fig. 4(a), Fig. 4(b) and Fig. 4(c). As shown in Fig. 4(a), the coefficient of inflation (ρ_π) is relatively stable until late 2008 after which it drops, however still satisfying the Taylor principle. The coefficient of the output gap (ρ_y) is relatively stable but drops abruptly in early 2009 where its then rises steadily, most probably due to the 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. The coefficient of the financial conditions index (ρ_z) remains relatively stable but rises dramatically from late 2008 only to fall back to its original level in late 2009. It is important to notice that the timing of the drop in the coefficient of coefficient of inflation in late 2008 coincides with that of the rise in the coefficent of financial market conditions.

Turning to the response of inflation, the output gap and the financial conditions index to uncertainty, all the graphs show a more pronounced reaction of these parameters by late 2008, with a tendency to revert to their earlier mean values. Overall the results tally with the findings in Table 2, namely that $\rho_\pi^\pi < 0$, $\rho_y^y < 0$, $\rho_z^z < 0$ and $\rho_y^\pi > 0$, $\rho_y^z > 0$, $\rho_\pi^y > 0$, $\rho_y^\pi > 0$, $\rho_y^z > 0$, $\rho_z^y > 0$ with the exception of $\rho_\pi^z < 0$ and $\rho_z^\pi < 0$. As earlier suggested, these two exceptions might 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.

5. Conclusion

This paper has analyzed 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 the indicator variables and to the uncertainty about these indicator variables. 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 and prior to the financial crisis period when inflation increased due to a contracted booming period, while the uncertainty about the conditions in financial markets was important to the interest rate setting behavior between 2008 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 conditional on availability of such data.

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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 $\rho_z^z < 0$.