MONETARY POLICY AND UNCERTAINTY IN SOUTH AFRICA

by

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Declaration:

I declare that Monetary Policy and Uncertainty in South Africa is my own work and that all the sources that I have used or quoted have been indicated and acknowledged by means of complete references.

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PJ de Hart Date

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Monetary Policy and Uncertainty in South Africa

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Abstract

Even though major advances in economic theory and modelling have in some cases furthered our understanding of how the economy works, the system as a whole has become more complex. If policymakers had perfect knowledge about the actual state of the economy, the various transmission mechanisms as well as the true underlying model, monetary intervention would be greatly simplified. In reality, however, the monetary authorities have to contend with considerable uncertainty in relation to the above-mentioned factors.

This said, uncertainty has mostly been neglected in both the theoretical and empirical literature focusing on monetary policy analysis. Nonetheless, findings from a review of theoretical literature that does exist on this topic suggest that optimal central banks act more conservatively when faced with uncertainty. Similarly, empirical findings from the literature also favour conservatism. However, there is some evidence to suggest that this is not always the case. These results suggest that central banks do not always act optimally when faced with

uncertainty. The limited number of industrial country cases examined prevents any generalised view from emerging. If anything, the literature findings suggest that central bank behaviour differs across countries.

This thesis aims to contribute to the empirical literature by studying the effects of uncertainty on monetary policy in the developing country case of South Africa. In simplest terms, the thesis seeks to establish whether or not the South African Reserve Bank (SARB) responded optimally to uncertainty as suggested by theoretical models thereof. To this end, the thesis employs a theoretical model which resembles a structural rule-based approach. The optimal interest rate rule was derived given a set of structural equations relating to demand, the Phillips curve and the real exchange rate.

To incorporate uncertainty, it is assumed that the coefficients are dependent on the variances of the exogenous variables, namely inflation, the output gap and the exchange rate. The uncertainty adjusted model allows us to investigate whether monetary policy is more aggressive or passive when uncertainty about the relevant exogenous variable increases. Inflation, output gap and exchange rate uncertainty estimates were derived through GARCH-model specifications related to the structural equations as defined in the theoretical model.

The investigation considered both indirect and direct uncertainty effects with a sample period stretching from 1990 to 2011.

The findings reported in this thesis provide strong evidence in support of the notion that uncertainty plays a significant role within the South African monetary policy landscape and contributes towards explaining the SARB's actions. Furthermore, the results suggest that the SARB did in fact act optimally in responding more conservatively to target variable fluctuations on average. Also, the findings could potentially strengthen the case for inflation targeting as a monetary policy regime, as the results indicate a marked decline in the effects of uncertainty under inflation targeting than before.

Key Terms: Monetary Policy, Uncertainty, Optimal Central Bank, SARB, GARCH Model, Conservatism, Aggression

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Chapter 1

Introduction

In recent years a consensus has emerged that price and output stability are the fundamental goals of any monetary policy regime. Even more recently however, central bank focus on financial stability as a secondary monetary policy objective has gained credence mainly due to the effects of the financial recession which started in 2008. To attain these goals, monetary authorities use policy instruments to drive the economy towards a desired state. However, prior to any policy decisions being made, the monetary authorities need to understand the state of the economy. To determine both the current state as well as the effects of various interventions, policymakers use different kinds of econometric models and estimation techniques.

Even though major advances in economic theory and modelling have in some cases furthered our understanding of how the economy works, the system as a whole has become more complex. If policymakers had perfect knowledge about the actual state of the economy, the various transmission mechanisms and the true underlying model, monetary intervention would be greatly simplified.

However, in reality the monetary authorities have to contend with considerable uncertainty in relation to the above-mentioned factors. The significance of the presence of uncertainty is best described in the widely cited quote below:

"Uncertainty is not just an important feature of the monetary policy landscape; it is the defining characteristic of that landscape." (Greenspan 2003, p. 1)

Notwithstanding the influential work of Brainard (1967), uncertainty has mostly been neglected in both the theoretical and empirical literature focusing on monetary policy analysis. Recent years have witnessed a change in this trend as a number of academics and practitioners alike have acknowledged the effects of uncertainty modelling and policy analysis.

Significant progress has been made in theoretical models of uncertainty and the impact thereof within the monetary policy landscape (Estrella and Mishkin 1998, Svensson 1997, Sack 1998a, Soderstrom 1999, Wieland 2002 and Moessner 2005). The theoretical literature primarily focuses on what constitutes optimal central bank behaviour when faced with different types and degrees of uncertainty.

However, much less work has been done on the empirical counterpart to this topic. Moreover, the empirical literature is primarily concerned with a handful of industrial country investigations (Martin and Salmon 1999, Martin and Milas 2005, Shuetrim and Thompson 1999 and Chung 2005). The literature has largely ignored the effects of uncertainty on monetary policy in developing countries.

This thesis aims to contribute to the empirical literature by studying the effects of uncertainty on monetary policy in the developing country case of South Africa. In simplest terms, the thesis will try to establish whether or not the South African Reserve Bank (SARB) has responded optimally to uncertainty as suggested by theoretical models thereof.

Chapter 2 considers the definition of uncertainty in the context of the monetary policy landscape. Given the abstract nature of the subject of uncertainty, a clarification of the concept is required before attempting to establish how it affects the policy decisions of the SARB. Chapter 3 reviews the theoretical literature focusing on monetary policy in the face of uncertainty. The chapter examines what constitutes an optimal central bank policy response in the presence of uncertainty.

This theoretical understanding gives the necessary background to the question of whether or not the SARB has behaved optimally in this regard, which is studied later in this thesis. Chapter 4 reviews the sparse empirical research on the topic in some detail. A review of the empirical literature sheds light on whether central bank actions in practice resembled theoretically optimal behaviour. This review of applied work also informs and guides the methodology used to study the effects of uncertainty on the SARB in the following chapters.

In contrast to the first four chapters, which are focused on reviewing the findings from the literature, the subsequent four chapters comprise a case study of the effects of uncertainty regarding the SARB. Chapter 5 derives a theoretical uncertainty model applicable to an open-economy developing country, while chapter 6 derives uncertainty estimates from the theoretical model specifically for the case of South Africa. Finally, chapters 7 and 8 simulate the complete econometric model with data from South Africa, and interpret the results. Chapters 7 and 8 are primarily concerned with finding answers to the following related questions:

- Does the evidence suggest that the SARB took uncertainty into account when designing policy?
- If so, did the SARB's actions reflect optimal behaviour as proposed by theory?
- If the results are mixed in relation to the question above, what may have led to this outcome?

The closing chapter summarises the findings and draws the final conclusions.

Chapter 2

Defining Uncertainty in the Monetary Policy Landscape

If policymakers had perfect knowledge about the actual state of the economy and the various transmission mechanisms, as well as the true economic model, monetary intervention would be substantially simplified. In reality, however, monetary authorities face considerable uncertainty relating to the above-mentioned factors. Even though major advances in economic theory and modelling have in some cases furthered our understanding regarding the intricacies of how the economy operates, in so doing reducing the amount of uncertainty, the system as a whole has become more complex.

"Every model, no matter how detailed or how well designed conceptually and empirically, is a vastly simplified representation of the world that we experience with all its intricacies on a day-to-day basis. Consequently, even with large advances in computational capabilities and greater comprehension of economic

linkages, our knowledge base is barely able to keep pace with the ever-increasing complexity of our global economy." (Greenspan 2003, p. 1)

Given the omnipresence of such uncertainty, how should monetary authorities respond? In other words, how should central banks act when faced with differing types and degrees of uncertainty? Considering the theme of this thesis, this question ultimately reduces to what constitutes optimal behaviour for the South Africa's central bank (the SARB) assuming the presence of significant uncertainty.

Given the abstract nature of the subject of uncertainty, some clarification of this concept will be helpful before attempting to link it to the policy decisions of the SARB.

Uncertainty is generally thought of as arising from imperfect knowledge of a specific event or phenomenon. Furthermore, the degree of uncertainty is related to the amount of available information about an event as well as the accuracy of that information. With regard to the monetary policy landscape, imperfect knowledge is the norm rather than the exception. Imperfect knowledge about the actual state of the economy, linkages between key macroeconomic variables and transmission mechanisms mean that the monetary authorities must contend with significant degrees of uncertainty when making policy decisions.

The aim of this chapter is to clarify the meaning of uncertainty specifically within the context of monetary policy. As mentioned above, this exercise will be helpful before trying to understand the effects thereof on the SARB. Section 2.1 examines the three main sources of uncertainty as highlighted in the literature on this topic with specific reference to the monetary policy landscape. Section 2.2 considers a more collective and holistic view of uncertainty.

2.1 Sources of Uncertainty

In broad terms, uncertainty arises from imperfect knowledge of a specific phenomenon. With regard to monetary policy, three sources of uncertainty are highlighted in the literature. These are:

- Uncertainty about the data
- Uncertainty about the model
- Uncertainty about the parameters

The rest of this section examines each of these in turn.

2.1.1 Data uncertainty

Data uncertainty refers to the inaccuracy of economic data. Consideration of a theoretical approach to distinguish this type of uncertainty from the other sources mentioned above proves useful in this case.

To this end, Figure 2.1 below represents a reduced form Phillips-Curve equation implying a linear relationship between inflation (π_t) and the output gap (y_t), adapted from Svensson (1997). As is evident from Figure 2.1, data uncertainty influences the simple theoretical model through its impact on the actual exogenous and endogenous variables due to the inaccuracy of the data used to estimate the variable values.

Figure 2.1: Theoretical depiction of data uncertainty

Source: Adapted from Svensson (1997)

This could occur due to measurement inefficiencies or errors arising during data capturing. Although data capturing errors could theoretically be avoided, measurement inefficiency is considerably more difficult to curtail. Here, measurement inefficiency refers specifically to the process of estimating macroeconomic variables and the erroneousness thereof. In order to guide policy, central banks rely on statistical models containing estimates or approximations of economic variables. However, due to the difficulty often associated with estimating these variables, estimates are often inaccurate:

"Many of the variables that a central bank reacts to in the course of setting its interest-rate instrument are in fact poorly measured." (Dotsey and Plosser 2012, p. 2)

As an example of measurement inefficiencies, Longworth (2004) refers to the case of the output gap, defined as the difference between actual and potential output. Potential output is not observed directly, but rather has to be estimated using other relevant indicators.

According to Longworth (2004), the central bank of Canada tries to lessen the uncertainty about estimates of the output gap by using a host of other variables which are more easily observable and thus are less uncertain. One of these indicators is the difference between the actual and projected inflation rate. Thus, if actual inflation is substantially different from what was originally projected, the central bank may adjust its estimate of the output gap accordingly.

Even though "unobservable" variables, such as potential output, are normally associated with considerable uncertainty, "observable" variables are also subject to a certain degree of inherent uncertainty. To make this point, Dennis (2005) refers to actual real GDP measurements in the United States. Dennis (2005) highlights the fact that, in the United States, three estimates of real GDP are released at different intervals. These are the advance estimate, the preliminary estimate and the final estimate. The final estimate is characterised as being the most accurate, as most of the data are actually measured, rather than estimated.

Another common example of the above is evident when considering the revised South African Gross Domestic Product figures. Every 5 years or so, Statistics South Africa (Stats SA) revises the GDP estimates, acknowledging that the national accounts data rely on various sources, all of which differ with regard to accuracy, frequency and detail. The revision process involves a rebasing procedure, where the base year is changed to a more recent period. The decision regarding the base year is often influenced by the availability of recent data and often coincides with a period when a survey or other large scale data gathering initiatives took place, such as a census.

Thus in 1999, Stats SA released revised GDP estimates for the period from 1993 to 1998. The process involved changing the base year to 1995 while also incorporating data obtained from new sources. The difference between the original and the revised series, reported in Figure 2.2 below, clearly highlights a source of data uncertainty.

Figure 2.2: SA revised GDP vintage 1995

Source: Stats SA, 2009

Stats SA again revised the SA GDP estimates in 2004, when the base was changed to the year 2000 while also incorporating other updated data and using new sources. The results are reported in Figure 2.3.

This time the difference between the original and revised estimates is significantly lower than with the previous rebasing exercise. However, bearing in mind that the figure compares two estimates, rather than actual values, the gap might well be much larger in reality.

In other words, Figure 2.3 compares one estimate with another, but no conclusion is possible regarding the accuracy of the estimates as such. Rather, it is assumed that the revised series represents an improved estimate.

Figure 2.3: SA revised GDP vintage 2000

Source: Stats SA, 2009

Similarly, other macro variables are also revised on a periodic basis. For example, Statistics South Africa also reviews the inflation data. In 2013, adjustments to CPI figures are based on the Income Expenditure Survey.

Thus, in practice, there is considerable uncertainty about the accuracy of economic variables, whether they are observed or approximated. Finally, data uncertainty directly contributes to the degree of parameter and model uncertainty. Uncertainty regarding data influences both the parameters being estimated as well as the model used to represent the economy.

These two remaining uncertainty sources are considered below.

2.1.2 Model uncertainty

Model uncertainty refers to imperfect knowledge about the true economic model. Figure 2.4 below distinguishes model uncertainty from data and parameter uncertainty. Evident is the fact that model uncertainty arises due to the presence of imperfect knowledge pertaining to how the model should be constructed. In other words, which variables should be included in the model and the functional relationship between them?

Basically, this is the problem of model specification: knowing which factors influence any particular variable (Longworth, 2004). Even though theory provides a guide as to how specific economic variables influence others, reality is often substantially more complex.

Figure 2.4: Theoretical depiction of model uncertainty

Source: Adapted from Svensson (1997)

This is exacerbated by the influence of unobservable variables, which are often difficult to measure and model mathematically. In illustrating this, Longworth (2004) directs attention towards the practice of modelling inflation.

Before the introduction of rational expectations in macroeconomics during the early 1970s, the expected inflation rate was modelled on the basis of past experiences with inflation (adaptive expectations). Increasingly after this time however, inflation expectations have been modelled under the assumption that economic agents do not ignore available pertinent information and are forward-looking (rational expectations). However, there is considerable uncertainty in practice as to which approach is relevant, and as a result there exists uncertainty about the correct formulation of an inflation expectations model.

According to Longworth (2004), the central bank of Canada tries to alleviate the presence of model uncertainty by using a variety of model specifications and different techniques before arriving at final policy recommendations. Furthermore, tests are carried out to establish the sensitivity of policy recommendations with regard to different assumptions in the model.

Batini, Martin and Salmon (1999) echo this approach towards combating model uncertainty, noting that policy rules are purposefully designed to be robust across a range of different economic models. While acknowledging that a robust rule might perform poorly when compared to the optimal rule of a specific model, the optimal rule will by definition perform worse for a range of different model specifications. Thus, on aggregate, a derived robust rule would perform best across a range of different model specifications. Even though there have been attempts at investigating the plausibility and viability of robust policy rules (McCallum 1999 and Sargent 1998), consensus on how such a robust rule should be derived has yet to emerge.

Another relevant example of model uncertainty is evident when considering how business cycle indicators are computed. Composite business cycle indicators are modelled by incorporating a host of different variables into a single time series aimed at predicting turning points in the business cycle. The South African Reserve Bank publishes three composite business cycle indicators, namely the leading, coincident and lagging indicators. However, there exists considerable uncertainty with regards to which variables to include when computing these business cycle indicators.

"The time series included in the composite business cycle indicators represent only a small sample of the total number of available indicators portraying various aspects of economic activity." (Venter and Pretorius 2004, p. 67)

Venter and Pretorius (2004) highlight the fact that the choice regarding the component variables to include in the business cycle time series needs to be re-evaluated periodically. Various factors influence this decision such as structural changes to the economy and the availability of data.

2.1.3 Parameter uncertainty

Distinct from data and model uncertainty is parameter uncertainty. Parameter uncertainty refers to the inaccuracy of the estimated parameters in the models. Figure 2.5 below distinguishes parameter uncertainty from data uncertainty through the use of the same simple theoretical model as in Figure 2.1 above.

Figure 2.5: Theoretical depiction of parameter uncertainty

Source: Adapted from Svensson (1997)

When constructing models aiming to approximate the economic environment, parameters serve as estimates of the relationship between different variables within the model. In this case, the parameter estimate ("α" in Figure 2.5 above) indicates the relationship between inflation in the current period and one period lagged inflation. In other words, how does the inflation rate in the previous period influence current inflation?

As mentioned earlier, even though practitioners have sophisticated statistical techniques at their disposal to estimate the model parameters, there is still significant uncertainty regarding their accuracy.

This is partially due to the presence of data and model uncertainty. Stated differently, uncertainty regarding parameters is partly caused by uncertainty related to the data and partly to the model being used.

To make this point clear, consider first the effect of inaccurate data on parameters. Even if the model is a true representation of the economy, introducing inaccurate data would lead to inaccurate parameter estimates. Since the data used in the model are significantly different from the true data, the parameter estimates based on the inaccurate data would be significantly different to the true parameters. Secondly, even if the data were accurate, an incorrectly specified model would still lead to inaccurate parameter estimates.

A simple example illustrating this is the decision on whether there exists a linear or quadratic relationship between variables. In other words, if a variable is incorrectly added to a model in quadratic form rather than linear form, the parameter will be inaccurate. Moreover, adding unnecessary explanatory variables to the model (or omitting relevant variables) will also affect the parameters being estimated.

Finally, since there are a host of different estimation techniques, such as least squares or the method of moments, the choice of technique will also influence the final parameter estimates. Central banks try to address uncertainty about parameters using different models and techniques to establish whether the parameters are robust in respect of the different approaches. Parameter robustness suggests that the estimates are not influenced significantly by a specific model, thus alleviating the degree of uncertainty arising from imperfect knowledge of the true economic model.

2.2 Uncertainty about the State of the Economy

The section above focuses mainly on “narrow” definitions of uncertainty. Although very specific and distinct by definition, these narrowly defined sources of uncertainty are not mutually exclusive. As explained above, data uncertainty contributes directly to both model and parameter uncertainty. In addition, model uncertainty directly influences parameter uncertainty.

However, a far more general type of uncertainty confronts policymakers on a continual basis. General uncertainty in this sense refers to imperfect knowledge about the actual past, current and future states of the economy. Although closely related to imperfect data, uncertainty about the state of the economy is also concerned with imperfect knowledge of the actions of economic agents and the ultimate effect thereof in the future.

In other words, assuming that the data on hand represent a perfect reflection of the actual current state of the economy and that data for all economic variables were readily available, there would still be uncertainty regarding the future economic state due to the inability to perfectly predict agent behaviour in the future. Also, further assuming perfect knowledge regarding the relevant economic and agent behavioural models and the relationships between the economic variables (parameters), would subsequently result in perfect knowledge of the future economic state. In this case, uncertainty in all its forms would cease to exist. In other words, assuming perfect knowledge of everything means that nothing is uncertain.

Thus, in general, uncertainty about the actual state of the economy represents a summation of the narrowly defined sources of uncertainty. Figure 2.6 below attempts to summarise the definitions and underlying relationships between the different types of uncertainties.

2.3 Concluding Remarks

Even though major advances in estimation and modelling techniques have furthered our understanding of how the economy operates, policymakers are still challenged by the presence of considerable uncertainty due to the ever-evolving and increasingly complex economic system. How central banks, and more specifically the SARB, behave in the face of this uncertainty and whether such actions reflect optimal behaviour, is an important policy issue. However, before trying to answer this question it is necessary to have a clear understanding of the concept of uncertainty. Thus, this chapter focused on defining uncertainty within the monetary policy landscape.

The three main sources of uncertainty pertaining specifically to monetary policy are data, model and parameter uncertainty. Data uncertainty refers to the presence of imperfect data. This is brought about by errors made in data capturing and measurement. Although the former can in principle be avoided, measurement errors are far more common and difficult to quantify. Measurement inefficiencies refer to the difficulty in obtaining all the relevant information to measure a specific economic variable. To compensate for this lack of information, various estimates are used. Additionally, theory often relies on abstract variables which are not observable. These "unobservable" variables are thus approximated by estimates of observable variables.

Model uncertainty refers to imperfect knowledge about the true economic model. In other words, there may be considerable uncertainty about which variables are exogenous and how they influence the endogenous variables included in the model. Although theory provides a guide as to how specific economic variables influence others, the situation in practice is more complex as, for example, when two or more variables have feedback effects on each other.

Distinct from data and model uncertainty is parameter uncertainty. This is determined by the inaccuracy of the parameters within the models being used. When constructing models aiming to approximate the economic environment, parameters serve as estimates of the relationship between different variables within the model. As mentioned earlier, even though practitioners have sophisticated statistical techniques at their disposal to estimate the model parameters, there is still significant uncertainty regarding their accuracy.

Although very specific and distinct, these narrowly defined sources of uncertainty are not mutually exclusive. Data uncertainty contributes directly towards both model and parameter uncertainty. Also, model uncertainty directly influences parameter uncertainty.

Moreover, a far more general type of uncertainty confronts policymakers on a continual basis. General uncertainty in this sense refers to imperfect knowledge about the actual past, current and future states of the economy. Although closely related to imperfect data, uncertainty about the state of the economy is more concerned with imperfect knowledge regarding the actions of economic agents and the ultimate effect thereof in the future. Thus, uncertainty about the state of the economy represents a summation of the three narrow definitions of uncertainty.

As the origins of uncertainty have been considered, the next step involves investigating how optimal central banks act when confronted with significant uncertainty. Determining the optimal theoretical approach to negating the effects of uncertainty is necessary before it can be established how uncertainty influenced the actions of the SARB and whether or not those actions reflected optimal behaviour. To this end, the next chapter considers a review of the theoretical literature on this topic before investigating practical evidence and experiences in the subsequent chapter.

Chapter 3

Theoretical Review of Optimal Uncertainty Policy

The previous chapter explained how uncertainty is defined and described the main sources of uncertainty regarding the monetary policy landscape. Such an understanding is essential before considering the impact of uncertainty on the actions of the SARB.

As indicated above, the three main sources of uncertainty are data, parameter and model uncertainty. Furthermore, it was shown that these sources are not mutually exclusive and collectively contribute to a far more general source of uncertainty pertaining to the state of the economy. Uncertainty about the state of the economy takes into account the presence of imperfect knowledge in predicting future agent behaviour.

Even though this provided the necessary information on how uncertainty is defined and the various forms in which it could arise, an understanding of how optimal central banks act when confronted with this uncertainty has yet to emerge. This chapter summarises the theoretical literature on this topic. It explains how, in theory, optimal policymakers should respond when faced with uncertainty. This background is necessary before studying the effects of uncertainty on the actions of the SARB in particular and deciding whether or not its responses reflected optimal behaviour.

As chapter two distinguished between three narrow definitions of uncertainty, this chapter will follow a similar approach in categorising the various theories. The first section considers the case of parameter uncertainty. Brainard (1967) represents one of the first attempts in theoretically investigating the effects of parameter uncertainty on monetary policy, and his paper is generally regarded as the benchmark in this respect. The remaining two sections consider a review of theoretical findings pertaining to model and data uncertainty. The chapter concludes with final comments.

3.1 Theories of Parameter Uncertainty

The paper by Brainard (1967) serves as the benchmark for subsequent investigations. It is thus informative to review the Brainard case in some detail. Thereafter, deviations from the Brainard case will be considered.

3.1.1 Brainard conservatism

Brainard (1967) represents one of the first attempts to investigate the theoretical implications of uncertainty with respect to the conduct of policy. More specifically, the paper focuses on the effect of parameter uncertainty on the choice of optimal monetary policy.

Parameter uncertainty, in the Brainard sense, stems from the presence of structural changes occurring in the economy. When fundamental structural changes occur within the economy, the relationships between exogenous and endogenous variables change. Uncertainty is present when policymakers are unsure whether or not such structural changes have occurred.

To study the theoretical implications of parameter uncertainty, Brainard (1967) considers a model with one target variable and one policy instrument variable:

$$y = \theta P + \epsilon \tag{3.1}$$

(Brainard 1967, p. 412)

where y is the target variable (such as the inflation rate), P is the policy instrument (such as interest rates or government spending), θ represents the response to a policy action, and the net effect of other exogenous variables is denoted by ϵ.

Thus, uncertainty could originate from ϵ, as policymakers might be unable to accurately estimate the effects of various exogenous variables, or from θ, as policymakers might be unsure about the response of y to policy actions and whether θ will be equal to its expected value.

The first type of uncertainty, entering through the exogenous variables captured by ϵ, is not affected by the actions of policymakers. Thus, policymakers should adhere to "certainty equivalence", or in other words, they should act as if the expected values are accurate. Brainard (1967) states that in the face of uncertainty regarding ϵ, a change in policy action shifts the distribution of y but does not affect its variance.

However, regarding the second type of uncertainty entering through θ, the actions of policymakers influence both the distribution and variance of y. This is due to the multiplicative factor. Stated differently, due to P being multiplied by θ, any values of θ different from what was expected would change both the distribution and variance of y. Thus, the actions of policymakers influence the distribution of the target variable.

To show how uncertainty about the response to a policy action (θ) may affect the policy action itself (P), Brainard (1967) assumes that policymakers aim to maximise the expected value of the following utility function:

$$U = -(y - y^*)^2 \tag{3.2}$$

(Brainard 1967, p. 413)

Thus, the policymaker aims to keep the difference between the target value y* and the true value y to a minimum. Brainard (1967) further makes the following reasonable assumptions:

- the response parameter θ is a random variable[1]
- θ is correlated with the additive term ϵ from equation 3.1 so that corr$(\theta, \epsilon) \neq 0$.[2]

The variance of the target variable y is given by:

$$\sigma_y^2 = \sigma_\theta^2 P^2 + \sigma_\epsilon^2 + 2\rho\sigma_\theta\sigma_\epsilon \qquad (3.3)^3$$

(Brainard 1967, p.414)

To ascertain the optimal policy action, the expected utility derived from a specific policy action has to be calculated. This is done by substituting equation 3.1 into equation 3.2 and taking the expected value of the resulting equation:

$$E(U) = -[(\bar{\theta}P + \bar{\epsilon} - y*)^2 + \sigma_\theta^2 P^2 + \sigma_\epsilon^2 + 2\rho\sigma_\theta\sigma_\epsilon P] \qquad (3.4)^4$$

(Brainard 1967, p.414)

To find the optimal value of P, the first order derivative of equation 3.4 is set equal to zero, which results in:

$$P* = [\bar{\theta}(y^* - \bar{\epsilon}) - 2\rho\sigma_\theta\sigma_\epsilon] / [\bar{\theta}^2 + {\sigma_\theta}^2] \qquad (3.5)$$

(Brainard 1967, p.414)

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[1] Brainard (1967) stresses that even if the true population parameter were assumed to be non-random, it would have to be estimated using sample data, which would result in a random estimation variable.

[2] Brainard (1967) shows that the results hold, even if the two terms are uncorrelated.

[3] Equation 3 is obtained by substituting equation 3.1 into $\sigma_y^2 = E(y^2) - [E(Y)]^2$. Subsequently, the equation is further manipulated by using the correlation formula of $\rho_{\theta\epsilon} = [E(\theta\epsilon) - E(\theta)E(\epsilon)]/\sigma_\theta\sigma_\epsilon$.

[4] Take into account that $E(U) = -E(y-y^*)^2$. This reduces to $E(U) = -[E(y^2) - 2\bar{y}y^* - (y^*)^2]$. Also, $E(y^2)$ could be replaced by $\sigma_y^2 + \bar{y}^2$. This further reduces the formula to $E(U) = -[(\bar{y} - y^*)^2 + \sigma_y^2)$. Finally, substituting $\bar{y}$ with equation 3.1 and σ_y^2 with equation 3.3 yields the final result.

Equation 3.5 shows that policymakers should take into account the expected values and variances of the exogenous variables ϵ and the parameter θ when setting optimal policy. This is in contrast to “certainty equivalence”, where policymakers set policy assuming they know the true population parameters and thus simply use the expected values as substitutes.

Thus, if certainty is assumed, the variance of the parameter θ is equal to zero. By contrast, the variance increases as uncertainty about the parameter increases. Due to the variance of the θ parameter (σ_θ^2) which enters equation 3.5 in the denominator, any increase in the parameter variance leads to a decrease in the optimal value of $P*$. Thus it is concluded that increased uncertainty should in theory lead to a more conservative policy response.

3.1.2 Deviations from the conservatism principle

The findings by Brainard (1967), which suggest that monetary authorities should act less aggressively when faced by uncertainty, served as a benchmark for later studies. Similar findings to that of Brainard (1967) have been reported by Estrella and Mishkin (1998), Svensson (1997) and Sack (1998a).

However, Soderstrom (1999) argues that the findings of Brainard (1967) and Svensson (1997) are incomplete, as both papers investigate the special case where central banks are concerned only with inflation. In other words, uncertainty enters the central bank’s objective function only through the effect on the inflation parameter. By contrast, Soderstrom (1999) considers a more general approach by including both inflation and output in a dynamic macroeconomic model.

In examining the "time path" of policy after a shock to the model, Soderstrom's results show that the central bank's response might in some instances be more aggressive when faced with greater uncertainty about the parameters. More specifically, uncertainty regarding the "persistence of inflation" parameter results in the central bank being more aggressive, while uncertainty about the other parameters still results in the central bank being more cautious. Soderstrom (1999) attributes this result to the addition of output to the objective function of the central bank.

"In the special case analyzed by Svensson, when the weight on output stabilization in the central bank's objective function is zero, uncertainty about the persistence of inflation does not affect the policy response. For positive weights on output, however, the policy response is increasing in the variance of the persistence parameter, so policy becomes more aggressive as the amount of uncertainty increases." (Soderstrom 1999, 1)

Soderstrom (1999) argues that a central bank more concerned with output stability may be more inclined to keep inflation in check due to the added possibility of increased output volatility in the future. In the absence of the output stability objective, a central bank would be less inclined to act more aggressively in the face of increased uncertainty about the persistence of inflation.

Thus in cases where the difference between actual and target inflation remains persistently large after past policy actions to curb this trend, central banks might opt to act more aggressively due to the expectation that a weak response might again not have the desired outcome.

Kimura and Kurozumi (2003) support the general findings of Soderstrom (1999). However, they use a forward-looking model with micro foundations instead of the backward-looking model used by Soderstrom (1999). However, their model also suggests that central banks should respond more aggressively to shocks when faced with increasing uncertainty about the dynamics of inflation (inflation persistence).

Kimura and Kurozumi (2003) state that their findings differ from the conventional Brainard result due to two distinct dissimilarities in the modelling process. Firstly, Brainard used a static model, whereas Kimura and Kurozumi use a dynamic forward-looking model. The dynamic model allows for investigating the time path of inflation and inflation persistence. As inflation moves away from its target, the variance of both inflation and the output gap increases. In other words, the further these variables move away from their set targets, the greater is the level of uncertainty associated with these variables as their statistical variances have increased. Thus, central banks have to be more aggressive to move the variables back to their target levels. Secondly, Brainard (1967) assumed a fixed objective function, whereas this assumption is relaxed in the Kimura and Kurozumi (2003) study.

Moessner (2005) also uses a forward-looking dynamic model, similar to that used by Kimura and Kurozumi (2003), to study the influence of parameter uncertainty. However, the Moessner (2005) study differs in that it focuses on the case where it is assumed that the central bank acts discretionally compared to the rule-bound behaviour studied by Kimura and Kurozumi. Moessner also found evidence suggesting optimal behaviour involved central banks acting more aggressively when confronted with uncertainty about inflation persistence.

Wieland (2002) also considers the impact of parameter uncertainty on the actions of policymakers. Wieland's model, focusing on the impact of inflation persistence and the inflation-unemployment trade off, is tested through numerical simulations. The results seem to support the Brainard result, suggesting that policymakers act more conservatively in the static version of the model.
In the dynamic version of the model Wieland finds that there is room for a more aggressive policy response. However, Wieland states that optimal policy seems to balance the aggressive and conservative approaches, with the conservative response dominating in most instances.

3.2 Theories of Model Uncertainty

Investigations concerned with explaining the effects of model uncertainty on the conduct of monetary policy are typically complex and tedious in nature. Most of the findings are dependent on both the methodology as well as the associated assumptions, which make general conclusions from the literature difficult.

Regarding the methodologies used, most investigations use either a Bayesian approach or a “worst-case” method. The Bayesian approach typically aims to solve decision rules given a set of prior conditions related to the parameters in different models. Put differently, the approach aims to derive a “robust rule” which achieves the lowest average loss, derived from the loss or objective function, from all the different model classifications included in the study. By contrast, the worst-case approach aims to derive a rule which minimises the loss only in the worst case model.

Cateau (2005) uses a combination of both the “robust” and “worst-case” approaches in examining how uncertainty influences the actions of central banks. Cateau notes that a disadvantage of the worst case approach is that it automatically assumes a more conservative and pessimistic central bank, designing policy based on the worst case scenario. Also, the worst case approach disregards the central bank’s preference for a specific model, which might be viewed as being more plausible or realistic at the time.

By contrast, the robust approach allows the central bank more flexibility in designing a robust rule with more emphasis on the model deemed to be most plausible. The obvious disadvantage of this approach is that it assumes that the central bank takes a risk management approach rather than exhibiting optimal behaviour.

Cateau (2005) assumes that the central bank is mainly concerned with two types of risk. The first-order risk focuses on the uncertainty regarding a specific model. The second-order risk focuses on the uncertainty across the set of models. Thus Cateau

(2005) uses a combination of the worst case and robust approaches. Furthermore, the central bank is permitted to be model uncertainty averse or neutral.

The worst case approach represents one end of the spectrum, signifying a central bank which is particularly averse to model uncertainty. The robust approach is the other limiting case, representing a central bank which is model uncertainty neutral. Cateau (2005) further assumes that the central bank has a choice between three different models. The first model, from Woodford (2002), is a forward-looking one. The second model, originally put forward by Rudebusch and Svensson (1999), is a backward-looking model. The third model, by Fuhrer and Moore (1995), is a combination of both forward- and backward-looking models.

Subsequently, in arriving at a result, Cateau investigates how the derived optimal rule changes when the central bank's aversion to risk is altered. Thus a strongly uncertainty averse central bank would signify conservatism. In examining the effects of various changes in the risk aversion of the central bank, the results indicated that the optimal rule tended towards the worst case approach. Put differently, Cateau (2005) found that policy became more conservative as the central bank's behaviour tended towards increased uncertainty aversion.

Onatski and Stock (2002) use the robust control approach in investigating the effects of model uncertainty. After specifying a set of likely modelling errors, the robust control method defines optimal policy (robust policy) as the policy which would minimise the maximal risk across all the modelling errors within the specific set. Onatski and Stock also use the Rudebusch and Svensson (1999) model formulation and find that the derived robust policies are more aggressive than the optimal policies in the absence of model uncertainty. In other words, Onatski and Stock (2002) find that central bankers act more aggressively when faced with model uncertainty.

3.3 Theories on Data Uncertainty

Theories on data uncertainty tend to focus on the fact that real time data are inherently less accurate than subsequently revised releases. This is mainly due to the great extent to which real time data are estimated rather than measured accurately. With subsequent data releases, a smaller component of the data is estimated, thus decreasing the uncertainty associated therewith.

To make this point clear, the study by Mahadeva (2007) proves insightful. In investigating the relationship between different data releases, Mahadeva focuses on a case study of the distribution, hotels and catering sector within the United Kingdom. Mahadeva explains that the choice of industry was guided by the fact that the data in this regard are particularly difficult to measure. The study thus focuses on a worst case scenario.

The findings indicate that the initial release was not a significant predictor of the final estimate. Mahadeva explains that this might be due to the initial release being used as a building platform by the statistical office responsible for the measurements, rather than representing an estimate as such. Another finding pertains to the sensitivity of the final estimate to the historical growth of the data. In other words, a lot of weight is put on historical trends in estimating the current variable values rather than being derived from actual current measures. Although this is a worst case scenario as mentioned above, the findings do highlight the omnipresence and significance of data uncertainty.

Ghysels, Swanson and Callan (1999) concentrate on the effect of real time data on the formulation of optimal policy rules. Empirical studies often use only revised data, as by the time the investigation is undertaken, the data have already been substantially revised. Thus, Ghysels, Swanson and Callan (1999) construct real time datasets based on the data that were available at the time of the policy decision, thereby recreating the information environment applicable at the time of policy formulation. Thus, the real time policy-setting environment is simulated from the real time data. The findings suggest that the decision models differ significantly when using only real time data compared to using both real time and revised data (not available at the time of policy decision). This implies that the central bank would have acted differently if it had had access to the more accurate revised data at the time when the decisions were being taken.

Jääskelä and Yates (2005) investigate how data uncertainty affects optimal monetary policy. They make use of a rational expectations IS-LM model as follows:

Demand-side

$$y_t = a_1 E_t y_{t+1} + (1 - a_1) \sum_{i=1}^{2} y_{t-i} - a_2(r_t - E_t \pi_{t+1}) + \mu_t$$

Supply-side

$$\pi_t = \beta_1 E_t \pi_{t+1} + (1 - \beta_1)\pi_{t-1} + \beta_2 y_t + g_t$$

(Jääskelä and Yates 2005, p. 4-5)

where y_t is output, π_t inflation, E_t the expectation conditional on information at time t, r_t the nominal interest rate, μ_t a demand shock, g_t a cost-push shock and the α's and β's are the parameters.

Also, the central bank aims to minimise the following objective function:

Objective Function

L_t = Var (π_t) + Var (y_t) + θ Var (Δr_t)

(Jääskelä and Yates 2005, p. 8)

Furthermore, the model assumes that inflation is measured perfectly while the output data are characterised by uncertainty. Three output variables are included in the model. These are a real time variable and first and second order-lagged variables. Finally, Jääskelä and Yates (2005) reasonably assume that the measurement error, or associated uncertainty, decreases from the real time data towards the second lagged variable.

The aim of the exercise is to observe how the monetary authority acts given changes in the data (thus reflecting varying degrees of uncertainty). Model simulations suggest that the monetary authority assigns less weight to recent data when it is more uncertain. Furthermore, Jääskelä and Yates (2005) find that the monetary authority's response is optimal by assuming that the difference in accuracy between recent (real time) and revised data is larger rather than smaller. In other words, the central bank should act as if the most recent data (real time) are not very accurate, thus rather be more conservative in using recent data.

3.4 Concluding Remarks

Chapter one explained how uncertainty is defined, and examined the main sources of uncertainty regarding monetary policy. However, a clear understanding of how optimal central banks should respond when confronted with such uncertainty has yet to emerge. This chapter summarised the main theoretical work on this topic and explained how optimal policymakers should act when faced with uncertainty. This gives a preview of the effects of uncertainty on the policy responses of the SARB and whether these accord with theoretically optimal behaviour.

First, this review of the relevant theory focused on the effects of parameter uncertainty on optimal monetary policy. In normal circumstances, theory suggests a more conservative approach to policymaking when significant uncertainty is present (Brainard 1967, Estrella and Mishkin 1998, Svensson 1997 and Sack 1998a).

However, certain exceptions apply which could cause the monetary authority to act more aggressively. The main exception to the conservatism principle proposed by Brainard (1967) originates in the presence of considerable inflation persistence (Soderstrom 1999, Kimura and Kurozumi 2003 and Moessner 2005). If inflation persists, optimising central banks might have to respond more aggressively. However, even in these cases, there is evidence that optimal policy requires a balance of aggressive and conservative approaches, with the conservative side dominating in most instances (Wieland, 2002).

Next, the focus turned to the theoretical implications of model uncertainty. These investigations are typically complex and tedious in nature. Most of the findings are largely dependent on both the choice of methodology as well as the associated assumptions. This makes it difficult to draw any general conclusions from the literature. With regard to the methodologies used, most investigations use either a Bayesian approach or a worst-case method. The Bayesian approach typically aims to solve decision rules given a set of prior conditions related to the parameters in different models. Put differently, the approach aims to derive a robust rule which achieves the lowest average loss, derived from the loss or objective function, from all the different model classifications included in the study. By contrast, the worst-case approach aims to derive a rule which minimises the loss only in the worst case model.

The findings from the literature are mostly inconclusive. Using a combination of the worst-case and robust-control methods, Cateau (2005) found that policy became more conservative in the face of increased uncertainty. By contrast, using the robust-control method, Onatski and Stock reported findings suggesting a more aggressive central bank response when confronted with increased uncertainty about the model.

Finally, theories on data uncertainty emphasise that real time data are inherently less accurate than subsequently revised releases. This is mainly due to the great extent to which real time data are estimated, rather than directly measured. With subsequent data releases, a smaller component of the data is estimated, thus decreasing the uncertainty associated therewith. The findings suggest that central banks would act differently given access to the more accurate revised data at the time when the decisions were being taken (Ghysels, Swanson and Callan, 1999) and that monetary authorities are better off assuming that the difference in accuracy between recent and revised data is greater rather than smaller, and thus act more conservatively (Jääskelä and Yates, 2005).

To conclude, the conservative approach to uncertainty dominates most of the literature. In other words, the majority of theoretical findings suggest that central banks should act more conservatively when faced with uncertainty. The main exception is when inflation persistence is present, in which case an optimal central bank should act more aggressively. Besides these general findings, the review of the theoretical literature also sheds light on the following key lessons which should be noted when modelling the effects of uncertainty on central bank behaviour:

- Dynamic models are more applicable than static models (Soderstrom, 1999).
- Forward-looking behaviour is more appropriate when investigating uncertainty (Kimura and Kurozumi, 2003 and Moessner, 2005).
- Models should control for inflation persistence (Kimura and Kurozumi, 2003 and Moessner, 2005).

Before modelling the effects of uncertainty on the behaviour of the SARB in chapters 5-8, the following chapter summarises the findings of the empirical literature in this regard: do central banks act optimally in practice? This question is addressed next.

Chapter 4

Central Banks and Uncertainty in Practice

The theoretical review of optimal monetary policy and uncertainty in the previous chapter suggests that optimal central banks should respond less aggressively when confronted with significant degrees of uncertainty, except in the case of significant inflation persistence. This may justify a more aggressive policy response from the central bank. However, some studies still suggest that optimal policy may require a balance between the aggressive and conservative approaches, with the conservative side dominating in most instances.

However, do central banks adhere to the conservatism principle in practice? In reality the dynamics of uncertainty and the central bank's responses to the varying conditions of uncertainty may be very different from what is suggested by theory. This is also echoed through a remark by Blinder (1998) in defence of the original Brainard (1967) conservatism finding:

"My intuition tells me that this finding is more general, or at least more wise, in the real world than the mathematics will support." (Blinder 1998, p. 12)

This chapter reviews the empirical literature on the effects of uncertainty on central bank policy responses, especially whether or not they have followed the conservatism principle in practice. These findings give some background to the methodology used to investigate the effects of uncertainty on the SARB in the following chapters.

Compared to the theoretical work on this subject, relatively little empirical research has been done. Each of the sections which follow considers a specific paper from the literature in some detail with specific focus on data, methodology and findings. The following articles will be discussed in turn:

- Martin and Salmon (1999)
- Martin and Milas (2005)
- Shuetrim and Thompson (1999)
- Chung (2005)

4.1 Martin and Salmon

Martin and Salmon (1999) considered the relevance of uncertainty for monetary policy in the United Kingdom from 1980 to 1997. They aimed to establish whether the UK case provides empirical evidence to support the Brainard Conservatism principle.

4.1.1 Methodology

In estimating the effects of uncertainty on the actions of the Bank of England, Martin and Salmon (1999) used a Vector Auto-Regression (VAR) approach similar to that used by Sack (1998a). The authors purposefully avoid modelling the economy through simple first-order difference equations. Rather, the economy is represented by a vector (*n*), y_t comprising endogenous variables following an auto-regressive process up to order q. The system as a whole is simplified as follows:

$$y_t = c + \sum_{i=1}^{q} A_i y_{t-i} + \varepsilon_t \tag{4.1}$$

(Martin and Salmon 1999, p. 18)

where A_i is a matrix of parameters, ε_t a vector of random shocks and c is a constant. Martin and Salmon explain that the shocks in equation 4.1 are likely to be correlated. However, assuming correct identification of the model results in *n* structural equations where v_t represents the uncorrelated disturbance vector as follows:

$$\mathrm{B_0 y_t = k + \sum_{i=1}^{q} B_i y_{t-i} + v_t} \tag{4.2}$$

(Martin and Salmon 1999, p. 18)

Furthermore, if correctly identified, the first *n-1* equations from 4.2 above represent the structural form of the economy and the n^{th} equation the central bank's policy reaction function[5].

[5] The authors purposefully include the interest rate as the final n^{th} endogenous variable, thus representing the interest rate response to fluctuations in the other *n-1* variables.

Next, Martin and Salmon define a state vector $\boldsymbol{x_t}$ which includes all the endogenous variables up to order *q,* with the exception of the current interest rate term. Subsequently, it is assumed that the central bank's loss function is represented by:

$$L = -\frac{1}{2} E_t \sum_{s=1}^{\infty} \beta^s \,(x_{t+s} - x^*)' G (x_{t+s} - x^*) \qquad (4.3)$$

(Martin and Salmon 1999, p. 19)

where x^* represents the vector of target values while G is a matrix of zeros except the diagonal entries which represent the weights which the central bank assigns to each target variable. Finally, the loss function in equation 4.3 above is solved to arrive at the optimal interest rate rule[6].

Uncertainty arises by assuming that the values of the state variables are not observed directly, but rather based on expectations as follows:

$$\hat{x}_t = E_{t-1} x_t \qquad (4.4)$$

(Martin and Salmon 1999, p. 19)

The same process is followed to derive an uncertainty adjusted optimal interest rate rule through substituting equation 4.4 into equation 4.3. This ultimately translates into an optimal rule where the interest rate decision is dependent on both the expected value and variance of state variables. Interest rates derived from the optimal rule excluding uncertainty are then compared to the optimal rule

[6] See Martin and Salmon (1999, p19) for computational details regarding the matrix algebra and subsequent derived optimal interest rate rule.

including uncertainty to ascertain whether uncertainty resulted in conservatism on the part of the Bank of England.

4.1.2 Data

Besides the official base interest rates, Martin and Salmon (1999) include CPIX inflation, real GDP at 1995 prices and the Dollar/Pound exchange rate as endogenous variables. Also, it is assumed that the central bank responds to the output gap rather than GDP levels. The output gap is constructed through applying a Hodrick-Prescott filter[7]. As noted above, uncertainty enters the model through the variances of the state variables.

4.1.3 Results

The results suggest that optimal interest rates assuming uncertainty tended to be smoother than optimal rules assuming no uncertainty. Also, when faced with inflation or output shocks, optimal rules under uncertainty propose a less aggressive response than optimal rules assuming no uncertainty. Furthermore, Martin and Salmon (1999) note that even though the initial response is slower under uncertainty, ultimately the same level of the interest rate is achieved. In other words, the interest rate will eventually reach the same level under both the presence and absence of uncertainty, but the dynamics are slower assuming uncertainty. These results are in line with Brainard's conservatism principle.

[7] The Hodrick-Prescott filter is a statistical method used to separate the cyclical component in a time series from the fitted trend. For more information, see Hodrick and Prescott (1980).

4.2 Martin and Milas

Martin and Milas (2005) follow a more generalised approach to investigating the effects of uncertainty on the actions of the Federal Reserve Bank. Abstaining from focusing on a specific type of uncertainty (data, model or parameter uncertainty), Martin and Milas consider a broader definition. Their investigation is concerned with the effects of uncertainty about the true state of the economy. As explained in chapter 2, uncertainty in this sense refers to imperfect knowledge about the actual past, current and future states of the economy. Although closely related to imperfect data, uncertainty about the state of the economy is also concerned with imperfect knowledge of the actions of economic agents and the ultimate effects thereof in the future.

4.2.1 Methodology

The model includes a Taylor-type rule where the weights on inflation and the output gap are not constant but are rather functions of inflation and output gap uncertainty respectively. Uncertainty is introduced through the weights on inflation and the output gap and approximated by their variances derived through General Autoregressive Conditional Heteroscedasiticity (GARCH) models of inflation and the output gap.

As a point of origin, Martin and Milas employ the Federal Funds rate target as specified by Clarida et al (1998) as follows:

$$\tilde{\imath}_t = i^* + \rho_\pi(E_t\pi_{t+1} - \pi^*) + \rho_y E_t y_{t+1} \tag{4.5}$$

(Martin and Milas 2005, p.3)

with $\tilde{\imath}_t$ representing the target federal funds rate, i^* the equilibrium interest rate, π_t the inflation rate, π^* the inflation target, y_t the output gap, E_t the expectations operator and ρ_π and ρ_y the weights on inflation and the output gap respectively.

Next, the authors assume the actual interest rate adjusts towards the target rate as follows:

$$i_t = \rho_i(L)i_{t-1} + (1 - \rho_i)\,\tilde{\imath}_t \tag{4.6}$$

(Martin and Milas 2005, p.4)

where $\rho_i(L) = \rho_{i1} + \rho_{i2}L \dots\dots \rho_{in}L^{n-1}$

Substituting equation 4.6 into 4.5 yields:

$$i_t = \rho_o + \rho_i(L)i_{t-1} + (1 - \rho_i)(\rho_\pi E_t\pi_{t+1} + \rho_y E_t y_{t+1}) \tag{4.7}$$

(Martin and Milas 2005, p.4)

where $\rho_o = (1 - \rho_i)(i^* + \rho_\pi\pi^*)$

However, as Martin and Milas (2005) explain, the model outlined in equation 4.7 above does not allow for the effects of uncertainty, as the weights are assumed to be constant. To address this issue, the authors adapt the model in equation 4.7 as follows:

$$i_t = \rho_o + \rho_i(L)i_{t-1} + (1-\rho_i)(\rho_{\pi t}E_t\pi_{t+1} + \rho_{yt}E_t y_{t+1}) \tag{4.8}$$

(Martin and Milas 2005, p.4)

with $\rho_{\pi t} = \rho_\pi + \rho_\pi^\pi \sigma_{\pi t}^2 + \rho_\pi^y \sigma_{yt}^2$

$\rho_{yt} = \rho_y + \rho_y^\pi \sigma_{\pi t}^2 + \rho_y^y \sigma_{yt}^2$

The variance terms above, σ_{yt}^2 and $\sigma_{\pi t}^2$, represent measures of uncertainty of the output gap and inflation respectively. These variances are derived through GARCH models of inflation and the output gap equations as follows:

Inflation Equation

$$\pi_t = \pi_{t-1} + \gamma_1 y_{t-1} + \varepsilon_t$$

where $\sigma_{\pi t}^2 = \omega_0 + \omega_1 \varepsilon_{t-1}^2 + \omega_2\, \sigma_{\pi t-1}^2$

Output Gap Equation[8]

$$y_t = \delta_0 + \delta_1 y_{t-1} + \delta_2 y_{t-2} + \delta_3(\bar{\iota} - \bar{\pi})_{t-1} + \tau_t$$

(Martin and Milas 2005, p.14)

where $\sigma_{yt}^2 = \varphi_0 + \varphi_1 \tau_{t-1}^2 + \varphi_2\, \sigma_{yt-1}^2$

The approach above differs from studies that rely solely on the standard deviation or variance of the various endogenous regressors as approximations to uncertainty. Using GARCH models in this case allows for capturing the volatility of

[8] See Martin and Milas (2005, p.14) for definitions and an explanation of $\bar{\iota}$ and $\bar{\pi}$.

the remaining unexplained residuals after controlling for the explainable effects of the regressors. Thus, only "unexplainable" effects are captured as uncertainty, as the models outlined above control for deviations in the data which can be explained and as a result are known rather than representing uncertainty.

After calculating uncertainty through the GARCH models above, the authors investigate the behaviour of the parameters in equation 4.8 to establish whether such uncertainty resulted in a more passive or aggressive response from the central bank. For example, $\rho_\pi^\pi < 0$ would suggest a more passive response when faced with increased uncertainty about inflation. The model outlined above also allows for investigating the effect of inflation uncertainty on the response to the output gap and vice versa. This is observed through ρ_π^y and ρ_y^π.

Finally, comparing the predicted interest rates from equation 4.7 (assuming no uncertainty) and equation 8 (assuming uncertainty) allows for gauging the overall effect of uncertainty on interest rates. This is achieved through measuring the difference between what the interest rates would have been, assuming no uncertainty and the resulting interest rates if uncertainty was taken into account by the central bank.

4.2.2 Data

Martin and Milas (2005) investigate the case of the United States from 1983 to 2003. The Federal funds rate is used as the model interest rate, the annual change in the Consumer Price Index as the inflation rate and the difference between the logarithm of GDP and the logarithm of potential GDP as the output gap measure. As noted above, uncertainty is measured through applying the GARCH estimation technique to the assumed structural equations.

4.2.3 Results

Simulating the model with data from the United States, the results indicate that policymakers acted less aggressively towards inflation and output when these variables were more uncertain. Furthermore, greater uncertainty about one variable induced a greater response to the other variable. In other words, when uncertainty about inflation was greater, the Fed responded more aggressively to changes in output.

Applying a similar approach to the case of the United Kingdom, Martin and Milas (2006) found results which support the findings for the United States. Once again, the results suggest less aggressive behaviour when policymakers are faced with greater uncertainty.

4.3 Shuetrim and Thompson

Shuetrim and Thompson (1999) investigate the discretionary policy case of Australia. Although the authors focus on parameter uncertainty, similar to the original study by Brainard (1967), their methodology and treatment of uncertainty is distinctly different from the “rule-based” approach commonly used by other studies investigating the same phenomenon.

4.3.1 Methodology

Instead of designing and estimating structural economic equations from theory, Shuetrim and Thompson use a model of the Australian economy as developed by the Reserve Bank of Australia. The model consists of seven structural equations explaining the dynamics of output, prices, labour costs, import prices, real exchange rate, nominal exchange rate and the real interest rate[9]. Model parameters are obtained through applying Ordinary Least Squares (OLS) estimation from a sample period ranging from 1980 to 1997.

Next, the authors assume that the central bank is concerned with minimising the following intertemporal loss function:

$$Loss = E_t[\alpha \sum_{j=1}^{h} gap_{t+j}^2 + \beta \sum_{j=1}^{h} \left(\pi_{t+j} - \pi^*\right)^2 + \gamma \sum_{j=1}^{h} \left(i_{t+j} - i_{t+j-1}\right)^2] \quad (4.9)$$

(Shuetrim and Thompson 1999, p.6)

where i_t is the short-term interest rate, gap the output gap, π inflation and π^* the inflation target. The central bank preferences are denoted by α, β and γ respectively. The atypical third term in the loss function represents the central bank's preference to avoid large single period changes in the interest rate (interest rate smoothing).

[9] See Shuetrim and Thompson (1999, p.7) for detailed model specifications.

The model excluding uncertainty is solved by estimating the structural equations and obtaining estimates of the parameters. These parameters are assumed to be the true population parameters. Subsequently, the structural equations and estimated parameters are then substituted into the loss function in equation 4.9 above. The minimisation problem is solved and the central bank's preference weights observed, thus reflecting the central bank's preference in the absence of parameter uncertainty.

Parameter uncertainty is induced through using the parameter variances and the associated distributions. This is often labelled as the frequency-sampling technique. The authors randomly draw a large number of different parameter estimates from each respective parameter distribution. Instead of assuming any particular parameter "draw" as the true population parameter set, all the parameter estimates for each exogenous variable in the structural equations are simulated through the model. The loss function is subsequently minimised across various different parameter draws from the respective parameter distribution to finally arrive at the central bank's preference weights[10].

In essence, the uncertainty adjusted model assumes that the central bank aims to minimise the loss across all the possible structural parameter permutations. This technique may be thought of as a risk minimisation approach on the part of the central bank.

[10] Shuetrim and Thompson (1999) employ a multivariate vector model to this end. For more information in this regard, see Shuetrim and Thompson (1999, p.14-16)

The difference between the model without uncertainty and the model including parameter uncertainty is observed after inducing various types of shocks to the system.

4.3.2 Data

As mentioned above, Shuetrim and Thompson study the effects of parameter uncertainty on the actions of the Australian central bank over a sample from 1980 to 1997. A structural model originally designed by the Australian Reserve bank is used to characterise the dynamics of the Australian economy. Due to the elaborate nature of the model, discussing all the different measures used is beyond the scope of this chapter. Instead, only the main variables will be discussed briefly[11].

Output is measured by real non-farm gross domestic product. The output gap is measured as actual output less a production function-based measure of potential output. Furthermore, the nominal cash rate is used as the interest rate variable, and the consumer price index as the price level. All variables enter the model in logarithm form. Finally, model parameters are estimated using Ordinary Least Squares (OLS).

4.3.3 Results

Surprisingly, the findings reflect that policymakers might be more aggressive when the degree of uncertainty is higher. Shuetrim and Thompson find that for shocks to

[11]For detailed information on all variables and their respective definitions, see Shuetrim and Thompson (1999, p. 7).

output, import prices, inflation and labour costs, the responses taking account of parameter uncertainty are more aggressive. Only when real exchange rate shocks were simulated did the response reflect conservatism when taking uncertainty into account.

The results, in contrast to Brainard Conservatism, are explained as being a consequence of the persistence of shocks and the ineffectiveness of policy. However, Shuetrim and Thompson note that even though the findings are in stark contrast to conventional Brainard Conservatism, the results are greatly dependent on the model specification, parameter estimates and the type of shocks analysed.

A key distinguishing feature of the model relates to the specific inclusion of an interest rate smoothing preference in the central bank's loss function. In other words, the model used by Shuetrim and Thompson implicitly assumes that the central bank tends towards conservatism through a preference of minimising interest rate deviations. This is due to interest rate smoothing type behaviour closely resembling conservatism, as in both cases the central bank prefers not to change the interest rate substantially from one period to another.

Although other studies typically include a lagged interest rate term towards controlling for the effects of interest rate smoothing[12], this is not modelled as a central bank objective. Thus, in such cases, optimal behaviour is not influenced by the central bank's preferences to interest rate deviations, and no assumption is

[12] See for example Martin and Milas (2005).

made about the central bank's inclination to either conservatism or aggression. The different approach employed by Shuetrim and Thompson (1999) might thus act to "absorb" conservatism-type behaviour and thus lead to their contrary results.

4.4 Chung

Chung (2005) investigates how changes in inflation and output uncertainty affect the Federal Reserve's interest rate response. Similar to other studies, uncertainty is derived through the variances of inflation and output respectively. The methodology is explored in more detail below.

4.4.1 Methodology

Chung uses a generalised Auto Regressive Conditional Heteroscedasticity Structural Vector Auto Regression (GARCH-SVAR) approach to study the effects of uncertainty on the central bank's interest rate responses. Chung motivates the choice in estimation technique on the basis that it simultaneously allows for variances to be derived through GARCH processes while also enabling the investigation of how policy reacts in response to shocks.

As a point of origin, Chung assumes a standard reduced-form VAR in matrix notation as follows:

$$Y_t = C + \emptyset_1 Y_{t-1} + \ \dots \dots + \emptyset_p Y_{t-p} + u_t \qquad (4.10)$$

$u_t = (0, \Omega)$

(Chung 2005, p.4)

where Y_t is a vector of endogenous variables, $\emptyset_p$ is a diagonal matrix of lagged coefficients, C a matrix of constants and Ω the covariance matrix of the residuals. The vector Y_t contains endogenous variables such as the inflation rate, output gap, unemployment and the federal funds rate. However, the equation above does not allow for structural economic dynamics. In other words, equation 4.10 does not explain the interdependencies amongst the variables contained in the model. These interdependencies are necessary to estimate the GARCH variances needed to approximate inflation and output gap uncertainty. To this end, Chung assumes the following structural counterpart to equation 4.10 above:

$$\mathrm{B}_0 Y_t = K + \mathrm{B}_1 Y_{t-1} + \ \dots\dots + B_p Y_{t-p} + \epsilon_t \qquad (4.11)$$

$$\epsilon_t = \mathrm{B}_0 u_t$$

(Chung 2005, p.5)

where B is a matrix with coefficients explaining the inter-relationships between the endogenous variables and $K = \mathrm{B}_0 C$. Thus, the structural equation parameters are captured through the coefficients in B[13].

[13] Chung (2005) derives these coefficients through assuming B is a lower triangular matrix identified through a Cholesky decomposition of Ω. For more details in this regard, see Chung (2005, p. 5).

After following a similar approach to Jorda and Salyer (2003) by allowing the structural equations to evolve through GARCH processes, Chung finally arrives at the following model[14]:

$$\mathrm{B}_0 Y_t = K + \mathrm{B}_1 Y_{t-1} + \ \ldots \ldots + B_p Y_{t-p} + \Psi G_t + \epsilon_t \qquad (4.12)$$

$$G_t = (H_t \mathrm{i} \ldots H_{t-p+1} i)'$$

(Chung 2005, p.6)

where Ψ is a coefficient matrix containing the GARCH effects and H_t is the covariance matrix of the residuals ϵ_t. Thus, Ψ captures the effect of uncertainty on the interest rate response (*i)*.

4.4.2 Data

The model outlined above contains four variables aimed at representing the Federal Reserve's main target variables and policy instrument. These variables are the industrial output gap, unemployment gap, inflation gap and the federal funds rate. The quarterly sample stretches from 1960 to 2003. The data are obtained from the Congressional Budget Office publications.

4.4.3 Results

The results reported by Chung are mixed. First, the results indicate that the Federal Reserve responded less aggressively when confronted by a positive shock in order

[14] The transitional steps taken to arrive at equation 4.12 are beyond the scope of this chapter. For more details in this regard, see Chung (2005, p. 5).

to dampen the economic expansion. By contrast, the Federal Reserve acted more aggressively after a negative shock, in so doing stimulating the economy to prevent a substantial downturn. Thus, based on these findings, the Federal Reserve is seemingly more lenient when a particular shock implies economic expansion rather than a contraction. This behaviour may partly be explained by the asymmetric nature of business cycles. Keyens (1936) explains this phenomenon as follows:

"the substitution of a downward for an upward tendency often takes place suddenly and violently, whereas there is, as a rule, no such sharp turning point when a upward is substituted for a downward tendency" (Keyens, 1936)

The asymmetric nature of business cycles, that recessions are often more severe and last for shorter time horizons than compared to expansions, has been reported in a number of empirical studies (Neftci 1984, Acemoglu and Scott 1997; Beaudry and Koop 1993). Thus, based on this evidence, the Federal Reserve might be prompted to act more aggressively in the face of a negative shock seeing as the effect on the economy would be more severe than compared to the case of a positive shock.

4.5 The SARB and Uncertainty

The preceding sections reviewed the empirical literature focusing on the actions of central banks in the face of uncertainty. Seeing as this thesis is concerned with investigating the effects of uncertainty for the developing country case of South

Africa, it would be useful to devote this section to a review of how the South African Reserve Bank (SARB) has addressed uncertainty in practice.

Aron and Muellbauer (2006) explain that the SARB followed three broad monetary policy systems since the 1960's. The first regime, in operation until the early 1980's, was a liquid asset ratio-based system with controls on interest rates and credit.

The period from 1981 to 1985 witnessed a range of monetary policy reforms as the SARB moved to a cash reserves-based system. The discount rate was used to influence overnight lending and subsequently market interest rates. In 1986, the SARB announced money supply targets (M3) with the aim of containing inflation and encouraging real GDP growth.

However, Aron and Muellbauer (2006) note that the process and decisions around setting these targets were not transparent. Also, the money supply targets served more as guidelines than strict rules.

The effectiveness of the money supply targets was reduced mainly due to increased financial liberalisation and larger capital flows. During the early 1990's the money supply targets were replaced by an eclectic set of guidelines. These guidelines included indicators of exchange rates, asset prices, the output gap, the balance of payments, wages, credit and fiscal policy. The third system was implemented in 1998 with the introduction of the Repurchase (Repo) Interest

Rate. The Repo Rate was initially determined by the market through daily tenders of repurchase agreements but was subsequently fixed and set by the SARB[15].

Almost no information is available regarding how the SARB dealt with or aimed to address uncertainty during the period discussed above. This lack of transparency was a key characteristic of the monetary policy regimes during this period.

"Policy was very opaque in this period, and this diminished the accountability of the SARB." (Aron and Muellbauer 2006, p.4)

In 2000 the SARB formally adopted an inflation targeting monetary policy regime. Mishkin (2001) defined an inflation targeting framework as encompassing five key characteristics as follows:

- → A public announcement of a numerical target for inflation.
- → Institutional commitment to price stability as the primary monetary policy objective.
- → The implementation of various information sources above and beyond monetary aggregates and exchange rates when making policy decisions.
- → Improved transparency.
- → Increased accountability.

[15] For more information regarding the conduct and frameworks of monetary policy during this period, see Aron and Muellbauer (2006).

Van der Merwe (2004) provides four reasons to explain the rationale for the SARB's decision to implement a formal inflation targeting regime. Firstly, a formal inflation targeting framework is considerably more transparent and the objective and actions of the central bank are usually better understood by the general public. Secondly, inflation targeting results in better coordination between monetary policy and other policies if the target is consistent with other policy objectives. Thirdly, inflation targeting results in improved accountability. In cases where the SARB failed to reach the inflation target, appropriate reasons need to be provided as to why this was the case. Again, this disciplines the central bank while also improving the public's understanding of policy. Finally, Van der Merwe (2004) notes that inflation targeting assists in anchoring inflation expectations assuming the inflation targets are credible. This should subsequently serve to lower actual future inflation.

The adoption of the inflation targeting framework also coincided with a more formal approach to dealing with and communicating uncertainty. The technique used to this end is the so-called "fan chart" methodology. The fan chart was first published by the Bank of England during 1996. The fan chart basically represents the central bank's inflation forecast in the form of a probability distribution. The fan chart is described more formally below:

"The fan chart uses confidence bands to depict varying degrees of certainty. The darkest band of the fan chart covers the most likely 10 per cent of probable outcomes foreseen for inflation, including the central projection. Each successive band, shaded slightly lighter and added on either side of the central band, adds a

further 10 per cent to the probability, until the whole shaded area depicts a 90 per cent confidence interval. (SARB, 2012)

The fan chart is constructed through the combination of various inputs. Based on the outcomes of the models used by the SARB, a central inflation forecast is estimated. The uncertainties around the central inflation forecast (width of the confidence bands) as well as the balance of risks (skewness of probability distribution) are incorporated based on the assumptions and decisions made by the Monetary Policy Committee (MPC).

The SARB publishes qualitative information on the view of the MPC and the associated risk probability scenarios in arriving at the forecast probability distribution. However, quantitative data with regards to the specific assumptions is not made available which prevents a thorough empirical analysis of the SARB's actions and formulation of uncertainty at different time periods.

Also, although the fan chart represents a useful technique to assist the MPC while also communicating future uncertainty to the public, individual interest rate decisions are still subjective and ultimately based on the view of the MPC at the time.

4.6 Concluding Remarks

A review of the theoretical landscape in the previous chapter provided insightful information regarding the way optimal central banks act when faced with considerable uncertainty. Under normal circumstances, Brainard Conservatism dominates the theoretical literature. The only exception to this finding arises in the presence of significant inflation persistence. This chapter reviewed some of the empirical work on the actions of central banks, taking uncertainty into account.

Martin and Salmon (1999) consider the relevance of uncertainty for monetary policy in the United Kingdom from 1980 to 1997. The authors try to establish whether the UK case provides empirical evidence to support the Brainard Conservatism principle. Using a Vector-Autoregressive (VAR) approach, the results indicate that optimal interest rates assuming uncertainty tended to be smoother than optimal rules without uncertainty. Thus, the results support Brainard Conservatism.

Martin and Milas (2005) followed a more generalised approach to investigating the effects of uncertainty on the Federal Reserve Bank in the United States. Their model includes a Taylor-type rule where the weights on inflation and the output gap are not constant but rather functions of inflation and output gap uncertainty respectively. Uncertainty is induced through the weights on inflation and the output gap and approximated by their variances derived through General Autoregressive Conditional Heteroscedasiticity (GARCH) models of inflation and the output gap. Once again, the results suggest conservatism on the part of the Fed in responding to greater levels of uncertainty.

Shuetrim and Thompson (1999) studied the discretionary policy case of Australia. They used an economic model constructed by the Australian central bank, and optimal rules are solved using a frequency-sampling technique. Surprisingly, the findings reflect that policymakers might be more aggressive when the degree of uncertainty is higher. Shuetrim and Thompson find that for shocks to output, import prices, inflation and labour costs, the responses taking account of parameter uncertainty are more aggressive. Only in the case of real exchange rate shocks did the central bank response reflect conservatism when taking uncertainty into account. The results, in contrast to Brainard Conservatism, are explained as being a consequence of the persistence of shocks and the ineffectiveness of policy.

Finally, Chung (2005) investigates how changes in inflation and output uncertainty affect the Federal Reserve’s interest rate response. Chung uses a generalised Auto Regressive Conditional Heteroscedasticity Structural Vector Auto Regression (GARCH-SVAR) approach to study the effects of uncertainty on the central bank’s interest rate responses. The results reported by Chung are mixed. First, the results indicate that the Federal Reserve responded less aggressively when confronted by a positive shock in order to dampen the economic expansion. By contrast, the Federal Reserve acted more aggressively after a negative shock, thereby stimulating the economy to prevent a substantial downturn. Thus Chung’s study suggests that the Fed is biased towards stimulating growth rather than containing inflation in the face of uncertainty.

Thus, although the empirical findings favour conservatism, there is some evidence to suggest that this is not always the case. The results suggest that central banks do not always act optimally when faced with uncertainty. Furthermore, the limited number of industrial country cases examined prevents any generalised view from emerging. If anything, the findings suggest that central bank behaviour differs across countries. The review of the empirical literature provides some possible explanations in this regard:

- Different monetary policy regimes could result in different central bank behaviour in the face of uncertainty. Empirically, neglected structural breaks could lead to spurious results.

- Although it might be expected that different countries show diverse monetary responses to uncertainty, in some cases a specific country could also act differently under different circumstances, such as opting to act aggressively in response to a negative shock and more conservatively in response to a positive shock.

- Central banks may act differently in response to different target variable uncertainty. For example, a central bank may act aggressively to inflation uncertainty while choosing to be more cautious when faced with output uncertainty.

- Particular target variable persistence could result in a more aggressive central bank response. However, the difficulty in distinguishing empirically between a more passive response to uncertainty compared to interest rate smoothing behaviour could result in the wrong conclusions being drawn. This arises due to the close resemblance between a central bank reluctant to substantially change the interest rate and a central bank acting cautiously. Econometrically, controlling for interest rate smoothing may partially absorb the conservative policy response effect and thus wrongly portray a more aggressive central bank. The VAR estimation approach is especially sensitive in this regard, as multiple lagged regressors often enter the vectors to be estimated.

Seeing as this thesis is concerned with investigating the effects of uncertainty for the developing country case of South Africa, the final section of this chapter was devoted to a review of how the South African Reserve Bank (SARB) addressed uncertainty in practice. The review highlighted that almost no information is available in this regard for the period prior to the inflation targeting regime. However, the adoption of the inflation targeting framework also coincided with a more formal approach of dealing with and communicating uncertainty. The technique used to this end is the so-called “fan chart” methodology. The fan chart basically represents the central bank’s inflation forecast in the form of a probability distribution.

The remaining five chapters empirically investigate how the South African central bank behaves in the face of uncertainty. In other words, do the SARB’s actions reflect optimal behaviour as suggested by theory? Chapter 5 derives a theoretical uncertainty model applicable to an open-economy developing country while chapter 6 derives empirical uncertainty estimates from the theoretical model. Chapters 7 and 8 then estimate the general model including the uncertainty variables, and analyse the results.

Chapter 5

An Open Economy Uncertainty-Adjusted Model

The previous three chapters reviewed the literature focusing on the way in which optimal central banks act when confronted with significant degrees of uncertainty. A first attempt at answering this question was the influential theoretical work of Brainard (1967). Brainard advocated the conservatism principle, that optimal policy be characterised by central banks acting less aggressively when faced with higher degrees of uncertainty.

Later studies supported the conservatism principle, suggesting that optimal central banks generally act more passively when faced with greater uncertainty (Estrella and Mishkin 1998; Svensson 1997; Sack 1998b and Wieland, 2002).

However, certain exceptions apply which could make central banks respond more aggressively. The main exception to the conservatism principle arises in the presence of considerable inflation persistence (Soderstrom 1999; Kimura and Kurozumi 2003; Moessner 2005). Thus, if higher than desired inflation persists, central banks may have to be more aggressive to achieve their targets.

Empirical studies investigating whether or not modern central banks adhere to the conservatism principle in practice are surprisingly scarce and focus almost exclusively on the experience of a few industrialised nations. Nonetheless, although empirical studies generally favour conservatism (Martin and Salmon 1999; Martin and Milas 2005; Chung 2005), there is sufficient evidence to suggest that this is not always the case in the face of uncertainty (Shuetrim and Thompson 1999). The limited number of industrial country cases examined prevents any generalised view from emerging. If anything, the findings suggest that central bank behaviour is not uniform across countries.

The remainder of this thesis investigates the case of the South African Reserve Bank (SARB). In this sense, the thesis represents a first attempt at investigating a developing country in an open economy setting. Ultimately, the aim is to establish whether there is sufficient evidence to support the notion that uncertainty has played a role in the SARB's policy decisions and whether those actions reflect conservatism. From this point forward, all theoretical and empirical work is that of the author, unless where explicitly otherwise stated.

This chapter is devoted to the development of an open economy theoretical model. Section 5.1 briefly considers an explanation of the methodology used in developing the theoretical model. This was deemed essential as the theoretical model serves as the basis for the subsequent empirical work in chapters 6 and 7. Section 5.2 discusses the various assumptions in relation to the structure of the economy. The final two sections are devoted to deriving both the base and uncertainty-adjusted theoretical models.

5.1 Methodology

The SARB published its core forecasting model in 2007 (SARB, 2007). The Bank explained that the model was developed from 1999 onwards and is frequently reviewed and amended to remain up to date with industry and econometric developments. The process in generating the final forecast is best described as follows:

"The forecasting cycle for the MPC meeting begins approximately five to six weeks before the scheduled MPC meeting. Data are updated and the current state of the domestic and international economy is analysed and interpreted. In producing the forecast, the knowledge and experience of internal and external sources are used. Where there are external agencies with greater expertise than the Bank producing forecasts for some exogenous variables (such as world economic growth, global inflation, and government consumption expenditure) the Bank will, in most cases, incorporate the forecasts from these agencies. The members of the MPC then finalise the assumptions and request alternative scenarios, if deemed necessary, at a special assumptions meeting. Once these assumptions are finalised, a forecast over an 8-to-12-quarter horizon (depending on the available number of quarters of

actual data) is produced. Alternative simulations highlight the significance of the transmission channels and the impulse responses to shocks." (SARB 2007, p.3)

The model in its entirety is best described as a medium-sized Type II hybrid model (Pagan, 2003). The model consists of 18 structural equations. These equations aim to describe the price formation process, exchange rates, gross domestic product and its components (wages, employment, the external sector and interest rates). The Repo Rate and government policy is assumed exogenous for forecasting purposes. Also, the Bank implements a Taylor-rule for alternative simulation analysis with equal weights assigned for inflation and the output gap.

However, replicating the SARB's model for the purpose of this investigation would be ineffective. The reasoning behind this is twofold. Firstly, this study is concerned with monetary policy over a longer time period. The model outlined above was developed with the advent of the inflation targeting regime to present a better and more detailed representation of new monetary policy objectives as well as the changing monetary policy landscape and transmission mechanisms. Thus, in order to investigate the effects of uncertainty over a larger sample, it was deemed more appropriate to employ a generic model which would apply to different regimes and allow comparability. Secondly, uncertainty isn't directly incorporated into the SARB's model. Rather, uncertainty is dealt with by scenario simulations based on the assumptions generated by the MPC. Without data pertaining to these assumptions during the inflation targeting regime as well as uncertainty estimates from the previous regime, employing the model above was deemed inappropriate. Ultimately, the theoretical and empirical models need to be able to address uncertainty and the theme of the thesis adequately. Thus, it was necessary to turn to the empirical literature on this topic for guidance.

Besides simply investigating the findings, the empirical literature review in the previous chapter allowed for scrutiny of the different techniques employed to examine the effects of uncertainty. Decisions regarding the methodology and empirical techniques are necessary prior to the development of a theoretical model, as the model will serve as the basis of the subsequent empirical study.

As is often the case with investigations into the monetary policy landscape, a clear divide is evident with regard to the methodologies employed. This divide arises due to differing preferences on the employment of either a Vector Autoregressive model (Martin and Salmon 1999) or a Rule-based structural approach (Martin and Milas 2005). Although the technical differences between these two techniques are beyond the scope of this thesis, a brief discussion will help motivate the use of one approach rather than the other.

The main difference between the two techniques revolves around the way in which economic theory is treated. Sims (1971) and subsequent work by the same author criticised the restrictive limitations of structural models and the stern reliance on theory. In opposition, Sims (1971) recommended the use of simple VAR models, where fewer theoretical assumptions are necessary. The structural-rule approach requires prior assumptions with respect to the variables included in the model, the relationships between those variables (endogenous or exogenous), lag structures and the number of lags to include for each variable. By contrast, the

VAR approach merely requires assumptions with respect to which variables to include in the model and occasionally the number of lags. Besides this, economic relationships are determined solely on the basis of the data.

This characteristic of VAR models is immediately evident when considering a simple VAR(1) model of output($y_{1,t}$) and inflation($y_{2,t}$) as follows:

Output Equation:

$$y_{1,t} = k_1 + \alpha_{1,1} y_{1,t-1} + \alpha_{1,2} y_{2,t-1} + \mu_{1,t}$$

Inflation Equation:

$$y_{2,t} = k_2 + \alpha_{2,1} y_{1,t-1} + \alpha_{2,2} y_{2,t-1} + \mu_{2,t}$$

or in matrix notation:

$$\begin{bmatrix} y_{1,t} \\ y_{2,t} \end{bmatrix} = \begin{bmatrix} k_1 \\ k_2 \end{bmatrix} + A \begin{bmatrix} y_{1,t-1} \\ y_{2,t-1} \end{bmatrix} + \begin{bmatrix} \mu_{1,t} \\ \mu_{2,t} \end{bmatrix}$$

where $A = \begin{bmatrix} \alpha_{1,1} & \alpha_{1,2} \\ \alpha_{2,1} & \alpha_{2,2} \end{bmatrix}$

The model assumes that all variables are both endogenous and exogenous and evolve with similar lag structures. In other words, the variables are treated symmetrically. Thus, rather than using theoretical relationships to construct the model, the approach relies on capturing the effects within the data.

One of the main drawbacks of this approach stems from the fact that simple VAR models often capture spurious relationships. This occurs due to the difficulty in distinguishing between correlations and causality.

By contrast, proponents of the structural rule-based approach advocate the necessity of basing any econometric model on theory, as this allows for interpreting the parameters of a model based on predicted theoretical behaviour.

However, structural models are highly sensitive to the identification of the model. This risk becomes increasingly more pertinent as the size and complexity of the model increases due to the likelihood of a growing divergence between the model and theory.

The argument against simple VAR models has resulted in the development of structural VAR models. These models take advantage of the strengths of VAR models while also imposing theoretical structure on the model (Chung, 2005). This is achieved through deliberately changing the contents of the coefficient matrix *A* in the example above, in so doing incorporating theoretical assumptions regarding relationships and lag lengths and structures. However, although very attractive on the surface, structural VARs have been criticised in the literature. The main criticism in the literature is summarised by Stock and Watson (2001) as follows:

"What really makes up the VAR shocks? In large part, these shocks, like those in conventional regression, reflect factors omitted from the model. If these factors are correlated with the included variables then the VAR estimates will contain

omitted variable bias. These considerations, when omitted from the VAR end up in the error term and (incorrectly) become part of the estimated historical shock used to estimate an impulse response." (Stock and Watson 2001, p. 13)

To date, consensus has yet to emerge on which modelling technique is superior; any decision in this regard revolves mainly around the model's reliance on theory.

In this light, this thesis opted to employ a purely structural rule-based approach to investigate the effects of uncertainty on the SARB. The reasoning behind this choice stems from the fact that the main aim of the investigation involves studying the effects of uncertainty. As a consequence, the model should aim to adequately capture what the policymaker knows about the economy and the underlying relationships between the target and policy variables.

In other words, the model should portray the economy as the monetary agents expect it to behave. Any deviations from these expectations would contribute to uncertainty. Simple VAR models often capture a range of different relationships which are not always explainable by conventional theory, but rather portray the inherent dynamics of the data. In this sense, a VAR model could conceal the true uncertainty experienced at the time.

By contrast, a structural rule-based approach allows for adequately approximating the way central bankers expect the economy to behave at the outset, and distinguishes between these effects and deviations from the expectations (uncertainty). Put differently, this thesis would argue that a structural rule-based approach enables greater control of what constitutes uncertainty, by means of theoretical assumptions on the structure of the economy. To this end, the assumed structure of the economy is discussed next.

5.2 The Structure of the Economy

It is assumed that the structure of an open economy like that of South Africa is characterised by the open-economy model used by Ball (1998). The main reason for using this structure stems from the fact that the model represents generic and conventional theory. The set of equations has also been used for analysis or as a benchmark in numerous studies investigating the monetary policy landscape (Cavoli and Rajan 2008; Mohanty and Klau 2004; Taylor 1999).

The structure of the economy is thus approximated by the following equations:

$$y_{t+1} = \phi_1 y_t - \phi_2 r_t - \phi_3 e_t + \varepsilon_{t+1} \tag{5.1}$$

$$\pi_{t+1} = \pi_t - \varphi_1 y_t - \varphi_2 (e_t - e_{t-1}) + \varpi_{t+1} \tag{5.2}$$

$$e_t = \Phi r_t + \upsilon_t \tag{5.3}$$

(Ball 1998, p.3)

where r_t denotes the real interest rate, π_t is the rate of inflation, y_t is the output gap and e_t is the real exchange rate where a decrease in e_t refers to a real depreciation of the domestic currency. Output, inflation and exchange rate shocks are denoted by ε_{t+1}, ϖ_{t+1} and υ_t respectively.

Equation 5.1, an open-economy IS-curve, suggests that the output gap in the next period is determined by the current output gap, the real exchange rate and the real interest rate. The negative relationship between the output gap and the real exchange rate stems from the latter's effect on net exports. An appreciation in the domestic currency, represented by an increase in e_t, results in a decrease in exports and an increase in imports. The relationship between the output gap and the real interest rate stems from the latter's effect on real disposable income and private investment.

Put differently, an appreciation in the domestic currency results in a decrease in net exports and subsequently a decrease in the output gap. Reasoning this way assumes that the output gap was positive to start with. If it is assumed that the output gap was negative to start with, the same logic applies. However, in this case, the output gap would become larger negative, but the statistic still declines, thus resulting in the negative relationship.

Equation 5.2 represents an open-economy Phillips curve, where inflation is determined by its own lag and lagged variables of the output gap and the change in the real exchange rate. The exchange rate affects inflation through import prices. Inflation also reacts to the income effect from the output gap.

Finally, equation 5.3 suggests a positive relationship between the real exchange rate and real interest rate. Changes in the interest rate affect the attractiveness of local assets, thus influencing the exchange rate. The exchange rate subsequently influences net exports.

As the structure of the economy has been defined, the next step is to describe the policymaker's problem. This is achieved in the next section.

5.3 The Base Model

To start with, it is assumed that the central bank seeks to minimise a standard intertemporal loss function similar to that stipulated by Svensson (1998):

$$\mathcal{L}_t = (1 - \delta)E_t \sum_{\Gamma=0}^{\infty} \delta^{\Gamma} L_{t+\Gamma}] \tag{5.4}$$

(Svensson 1998, p.166)

where E_t denotes the expectations operator, δ $(0 < \delta < 1)$ is the discount factor and L_t is the period loss function. In order to minimise equation 5.4 above, the central bank has to minimise $L_t$in each period. Formally, the period loss function is described by:

$$L_t = [\lambda_1(\pi_t - \pi^*)^2 + \lambda_2 y_t^2] \tag{5.5}$$

where π^* is the target rate of inflation. Thus, the policymaker aims to minimise the sum of the squared deviation of inflation from the inflation target and the squared difference between current output and potential output. The weights on inflation and the output gap, λ_1 and λ_2 describe the central bank's preference towards moving either inflation closer to its target value or output closer to potential output respectively. Hypothetically, $\lambda_1 = 1$ and $\lambda_2 = 0.2$ would describe a central bank considerably more concerned with keeping inflation close to its target value compared to moving the economy towards potential output.[16]

The optimal policy interest rate $\hat{\imath}_t$ is defined as the interest rate which minimises equation 5.5 subject to equations 5.1, 5.2 and 5.3. To arrive at the optimal interest rate rule, equation 5.3 is substituted into equation 5.1 and 5.2, thus eliminating e_t from the equations:

$$y_{t+1} = \phi_1 y_t - \phi_2 r_t - \phi_3(\Phi r_t + v_t) + \varepsilon_{t+1} \tag{5.6}$$

$$\pi_{t+1} = \pi_t - \varphi_1 y_t - \varphi_2(\Phi r_t + v_t - \Phi r_{t-1} - v_{t-1}) + \varpi_{t+1} \tag{5.7}$$

(Author's calculations)

Subsequently, equations 5.6 and 5.7 are substituted into equation 5.5, set equal to zero and differentiated with respect to r_t. Substituting equations 5.6 and 5.7 back into equation 5.5 and subsequently reorganising and simplifying the resulting equation is an arduous task. For simplification, these steps are not reported here. However, if necessary, these calculations will be made available upon request.

Thereafter, substituting $r_t = \hat{\imath}_t - \pi_t$ results in:

[16] The situation where $\lambda_1 = 1$ and $\lambda_2 = 0$ would describe the behaviour of a strict inflation targeting central bank (Cavoli and Rajan, 2008).

$$(\lambda_1\varphi_2^2\Phi^2 + \lambda_1 T^2)\hat{\imath}_t$$
$$= (\lambda_1\varphi_1\varphi_2\Phi + \lambda_2\phi_1 T)y_t + (\lambda_1\varphi_2\Phi + \lambda_1\varphi_2^2\Phi^2 + \lambda_1 T^2)\pi_t + (\lambda_1\varphi_2^2\Phi)e_{t-1}$$
$$-(\lambda_1\varphi_2\pi^*\Phi) - (\lambda_1\varphi_2^2\Phi + \lambda_2\phi_3 T)\upsilon_t \quad (5.8)$$

with $T = \phi_2 + \phi_3\Phi$ (Author's calculations)

Finally, substituting $e_t - \Phi r_t$ for υ_t from equation 5.3 into 5.8 above and reorganising results in:

$$\hat{\imath}_t = \emptyset_1 + \emptyset_2 y_t + \emptyset_3\pi_t + \emptyset_4 e_t + \emptyset_5 e_{t-1} \quad (5.9)$$

(Author's calculations)

where the coefficients are defined as:

$$\emptyset_1 = {-\lambda_1\varphi_2\pi^*\Phi}\Big/{\lambda_2[T^2 - \phi_3\Phi T]}$$

$$\emptyset_2 = {\lambda_1\varphi_1\varphi_2\Phi + \lambda_2\phi_1 T}\Big/{\lambda_2[T^2 - \phi_3\Phi T]}$$

$$\emptyset_3 = 1 + \left({\lambda_1\varphi_2\Phi}\Big/{\lambda_2[T^2 - \phi_3\Phi T]}\right)$$

$$\emptyset_4 = {\lambda_1\varphi_2^2\Phi + \lambda_2\phi_3 T}\Big/{\lambda_2[\phi_3\Phi T - T^2]}$$

$$\emptyset_5 = {\lambda_1\varphi_2^2\Phi}\Big/{\lambda_2[T^2 - \phi_3\Phi T]}$$

(Author's calculations)

The model above is similar to other studies investigating monetary policy using a rule-based approach such as the model outlined by Cavoli and Rajan (2008).

However, equation 5.9 deviates from the optimal policy rule derived by Cavoli and Rajan (2008) due to the re-substitution of equation 5.5 into the differentiated equation, thus resulting in the inclusion of the lagged exchange rate term.

Additionally, the constant term in equation 5.9 is the effect of incorporating an inflation target explicitly in the period loss function, rather than combining the difference between actual and target inflation as one variable as in Cavoli and Rajan (2008).

Finally, it is assumed that the central bank adjusts the actual interest rate gradually towards the desired level[17]. The adjustment process is represented by:

$$i_t = \theta i_{t-1} + (1 - \theta)\hat{\imath}_t + \mu_t \tag{5.10}$$

Substituting 10 into 9 yields:

$$i_t = \rho_1 + \rho_2 i_{t-1} + \rho_3 y_t + \rho_4 \pi_t + \rho_5 e_t + \rho_6 e_{t-1} + \mu_t \tag{5.11}$$

(Author's calculations)

where:

[17] See for example Sack and Wieland (1999) and Woodford (2002).

$\rho_1 = (1-\theta)\emptyset_1$

$\rho_2 = \theta$

$\rho_3 = (1-\theta)\emptyset_2$

$\rho_4 = (1-\theta)\emptyset_3$

$\rho_5 = (1-\theta)\emptyset_4$

$\rho_6 = (1-\theta)\emptyset_5$

The optimal interest rate specification in equation 5.11 serves as the baseline model. The structure of equation 5.11 is similar to rule-based models used by Taylor (1999), Ball (1998), Svensson (2000) and Mohanty and Klau (2004) in investigating the effect of the exchange rate in monetary policy rules.

Taylor (2001) explains that the effect of the exchange rate in equation 5.11 might be trivial, seeing that it is assumed that shocks to the exchange rate represent temporary deviations from the long term value, in which case ρ_5 would tend very close to -ρ_6.

However, if exchange rate deviations are large and persistent, the signs of the coefficients on ρ_5 and ρ_6 will be the same and the combined values thereof larger, depending of course on the central bank's preferred response to exchange rate fluctuations.

It is also important to consider the role of financial development. Financial development increases the lag between interest rate changes and the point when the change reaches maximum impact. In equation 5.11 above, this would affect the period specification of the exogenous variables. Different period specifications for the rule above are introduced in Chapter 7. Besides this, lag structures were allowed to deviate from the specification in equation 5.11 during the empirical analysis in subsequent chapters.

5.4 The Uncertainty Adjusted Model

The model outlined in equation 5.11 above is unsuitable for an investigation of the effect of uncertainty on monetary policy, due to the implicit assumption that interest rate adjustments to inflation, output and exchange rate fluctuations are constant over time.

To address this problem in a closed economy setting, Martin and Milas (2005) defined the weights on inflation and the output gap as functions of uncertainty, where uncertainty was approximated by the variances of the endogenous variables. Following a similar approach, equation 5.11 from the baseline model is altered as follows:

$$i_t = \rho_1 + \rho_2 i_{t-1} + \rho_3 e_{t-1} + \rho_{yt} y_t + \rho_{\pi t} \pi_t + \rho_{et} e_t + \mu_t \qquad (5.12)$$

(Author’s calculations)

where:

$$\rho_{yt} = \rho_y + \rho_y^{\pi} \sigma_{\pi t}^2 + \rho_y^{e} \sigma_{et}^2 + \rho_y^{y} \sigma_{yt}^2$$

$$\rho_{\pi t} = \rho_{\pi} + \rho_{\pi}^{\pi} \sigma_{\pi t}^2 + \rho_{\pi}^{e} \sigma_{et}^2 + \rho_{\pi}^{y} \sigma_{yt}^2$$

$$\rho_{et} = \rho_e + \rho_e^{\pi} \sigma_{\pi t}^2 + \rho_e^{e} \sigma_{et}^2 + \rho_e^{y} \sigma_{yt}^2$$

and σ_y^2, σ_π^2, σ_e^2 are measures of output, inflation and exchange rate uncertainty respectively.

This model allows us to investigate whether monetary policy is more or less aggressive as uncertainty about the relevant exogenous variable increases. Thus, $\rho_y^y > 0$ would signify a more aggressive interest rate response as uncertainty about output increases.

The model also allows us to see whether uncertainty about a specific variable influences the response to other variables. Thus, $\rho_y^\pi < 0$ would signify that increased uncertainty about inflation weakens the response to output fluctuations.

5.5 Concluding Remarks

The empirical review in chapter 4 suggested that the literature investigating the effects of uncertainty on monetary policy is particularly scarce and focuses almost exclusively on the experience of a few industrialised nations. Although the findings seem to favour conservatism in general, there is sufficient evidence to suggest that this might not always be the case. Furthermore, the limited number of industrial country cases examined prevents the emergence of any generalised view. If anything, the findings suggest that central bank behaviour is not uniform across countries.

In this light, this thesis is aimed at contributing to the above literature through investigating the case of the South African Reserve Bank. In this sense, the thesis represents a first attempt at investigating a developing country in an open economy setting. Ultimately, the aim is to establish whether there is sufficient evidence to support the notion that uncertainty played a role in the SARB's policy decisions and whether those actions reflect conservatism.

To this end, this chapter was devoted to deriving a theoretical model to approximate the structure of the economy as well as providing a theoretical platform for the subsequent empirical work.

The model is based on a structural rule-based approach rather than a VAR methodology. The optimal interest rate rule is derived from a set of structural equations developed by Ball (1998). The base model rule suggests that the interest rate is changed in response to deviations in a lagged interest rate term, inflation, the output gap and current and lagged exchange rate variables.

However, the base model is unsuitable for an investigation into the effect of uncertainty on monetary policy, due to the implicit assumption that interest rate adjustments to inflation, output and exchange rate fluctuations are constant over time. This is due to the assumption that the parameter values are constant over time.

To address this problem in a closed economy setting, Martin and Milas (2005) defined the weights on inflation and the output gap as functions of uncertainty.

Following a similar approach, the base model was altered to allow the coefficients in an open economy model to change over time.

To incorporate uncertainty, it is assumed that the coefficients are dependent on the variances of the endogenous variables, namely inflation, the output gap and the exchange rate. The uncertainty-adjusted model allows us to investigate whether monetary policy is more aggressive when uncertainty about the relevant exogenous variable increases.

However, prior to applying the derived model to the SARB case, it is necessary to derive empirically the uncertainty estimates. This is explored in chapter 6.

Chapter 6

Uncertainty Estimates for South Africa

Chapter 5 developed a model to approximate the structure of an open economy like South Africa as a theoretical platform for the empirical work to follow in chapters 6, 7 and 8. The model was derived using a structural rule-based approach, based on a set of structural equations obtained from Ball (1998).

This chapter derives monetary policy uncertainty estimates for South Africa. Section 6.1 provides an introduction to the data used in the empirical exercise. Section 6.2 explores the stationarity condition and investigates whether the data adhere to the requirements in this regard.

Section 6.3 explains the empirical methodology used to approximate uncertainty. The results are considered in section 6.4. Eviews 7.1 was used as the preferred econometric package for all econometric exercises in chapters 6, 7 and 8.

6.1 The Data

The sample consists of quarterly data extending from quarter 1 in 1990 to quarter 3 in 2011. The data frequency decision was guided by the simultaneous availability of all the variables needed for the empirical investigation.

All the raw data originate from South African Reserve Bank statistics (SARB, 2011), with the exception of the annual inflation rate which was retrieved from the Stats SA database (Stats SA, 2011). Each of the raw data series used to approximate the variables in the model is introduced below:

6.1.1 Inflation

As mentioned above, inflation data were retrieved from the Stats SA statistical database (Stats SA, 2011). The retrieved series contained monthly figures of Consumer Price Index (CPI) year-on-year growth rates (base year 2008). Rather than averaging the data for each quarter as with most of the other variables, the inflation rates as at the end of each quarter were included in the sample. The reason for this is twofold.

Firstly, as the retrieved data were already in annual average format, further averaging would have been excessive. As the inflation rate usually does not move significantly from one quarter to another, the annual rates as at the end of each quarter were deemed more appropriate. Also, whether the central bank assigns more weight to changes in annual rates from one quarter to the next or quarterly rates is debatable. However, the annual rate is certainly more popular in public consumption and subsequently more relevant in describing what economic agents base their decision on.

Figure 6.1 below shows the evolution of the time series over the sample period:

Figure 6.1: Inflation time series (CPI year-on-year growth rates)

Source: Stats SA, 2011

Figure 6.1 suggests that inflation peaked near the start of the sample period in 1992. The high inflation rates prior to 1994 were associated with increased isolation from the global economy. In addition, South Africa's focus on financial stability rather than containing inflation in the aftermath of the Debt Standstill of 1985 also contributed to higher inflation rates during this period . Also, escalating sanctions led to a sharp depreciation of the rand, resulting in higher imported inflation (Hanival and Maia, 2006).

Thereafter, the trend generally suggests decreasing inflation up until shortly after the turn of the century, mainly due to South Africa's re-integration into the global economy and price competition from international markets. Inflation peaked again in 2002/3 after the September 11 event in the United States of America. This followed a sharp depreciation of the rand after a global sell-off of emerging market currencies, again resulting in inflationary pressure from imports. After a sharp decline in 2003/4, inflation rose steadily until the end of quarter 2 in 2008. In the aftermath of the global financial crisis inflation declined until the second quarter of 2010.

6.1.2 Output gap

The Gross Domestic Product (GDP) series was obtained from the South African Reserve Bank (SARB) statistical database (SARB, 2011). The series contained quarterly GDP figures at constant 2005 prices. This thesis opted to steer clear of any seasonally adjusted figures or figures altered by other common smoothing mechanisms. Rather, the unadjusted GDP figures are used in this regard to prevent smoothing mechanisms from removing some of the volatility in the original data.

The series is portrayed in Figure 6.2 below:

Figure 6.2: Output time series (Quarterly GDP at Constant 2005 Prices)

Source: SARB, 2011

The trend suggests stagnant or even negative growth until around 1993, mainly due to the effects of trade and financial sanctions against the apartheid regime in the decade prior to 1994. Thereafter, growth rates improved significantly and reached levels around 4% before declining steadily in 1998, mainly due to the effects of the Asian economic crisis and the high domestic interest rates at the time (Hanival and Maia, 2006). The period from 1998 to 2003 witnessed comparatively volatile growth rates, with GDP growth improving to above 4% in 2000 after recovering from the shocks of the emerging market crises, only to decline again in the aftermath of the September 11 event in the United States. From 2004 to 2008, a clear increasing GDP trend is visible, indicative of improved growth rates over the period. Thereafter, a small decline in growth is evident, mainly as a result of the global financial crisis.

However, the model outlined in chapter 5 includes the output gap, rather than actual output or GDP. Here, the output gap is defined as the difference between actual and potential output. In order to derive the output gap from the series above, a Hodrick-Prescott filter was used to obtain the GDP trend. This trend was used to approximate potential output. Subsequently, the output gap was measured as the difference between the logarithm of gross domestic product (GDP at constant prices) and the logarithm of trend GDP (potential output).

Figure 6.3: Output gap time series (Difference in Actual and Potential Output)

Source: Author’s calculations

6.1.3 Interest rates

The official policy instrument in this respect is the Repo Rate, which was preceded by the Bank Rate during the previous monetary policy framework[18]. However, due to the high correlation between the above mentioned policy rates and the prime interest rate, the decision was made to use the latter as the policy instrument for the purpose of the empirical investigation. This decision avoided having to combine the Repo and Bank Rate datasets as data was available for the Prime interest rate over the entire sample period.

Both the nominal and real interest rate series were obtained from the South African Reserve Bank (SARB) statistical database (SARB, 2011). The South African Nominal Prime Overdraft Rate is used as the policy instrument variable (nominal interest rate). The South African Real Prime Overdraft Rate was used as the real interest rate. For the purpose of the empirical investigation, both variables were transformed using the logarithm operator.

The two raw variables (not in log form) are briefly explored in Figures 6.4 and 6.5 below:

[18] The Repo rate was introduced during 1998 and was initially determined by the market in daily tenders of repurchase agreements. The Repo Rate was subsequently fixed, mainly due to the fact that the interbank market often didn't clear effectively. A fixed Repo Rate also served as a better signal of central bank intention. For more information regarding the changes during this transition period, see Aron and Muellbauer (2006).

Figure 6.4: Nominal interest rate time series (Quarterly Average South African Nominal Prime Overdraft Rate)

Source: SARB, 2011

The quarterly average prime interest rate depicted above peaked towards the end of 1998 and the start of 1999, shortly before the advent of a formal inflation targeting monetary policy framework. Interest rates during the 1990s were on average significantly higher than after the implementation of the inflation targeting framework. In the 1990s, the South African Reserve Bank (SARB) was mainly concerned with containing money supply increases. The SARB was also actively involved in the foreign exchange market. The domestic currency remained weak and under pressure mainly due to the fact that South Africa’s inflation rate was higher than that of its major trading partners. The SARB also intervened when the currency experienced marked volatility, such as during the Asian Crises in 1998.

Thereafter, with the exception of a few peaks around 2002/3 and 2008/9, interest rates declined on average towards the end of the sample period. The 2002/3 peak was the result of the SARB anticipating rising inflation due to the depreciation of the rand after the September 11 event in the United States. The same reasoning applies for the 2008/9 peak, when the SARB raised interest rates over concern of the impact of the global financial crises.

Figure 6.5: Real interest rate time series (Quarterly Average South African Real Prime Overdraft Rate)

Source: SARB, 2011

Figure 6.5 above depicts the evolution of the real prime overdraft rate over the sample period. Clearly evident is the fact that real interest rates were significantly higher from 1996 to 2000 than the sample average. Thereafter, real interest rates hovered around a relatively stable trend between 6% and 8% up until 2007/8. Thereafter, the real interest rate dropped slightly towards the end of 2008, but recovered close to pre-shock levels before decreasing again in 2011.

6.1.4 Exchange rate

The monthly real effective exchange rate of the rand (base year 2000), weighted on the basis of trade in manufactured goods with the 15 largest trading partners, was used to approximate the real effective exchange rate used in the empirical investigation.

The data were retrieved from the South African Reserve Bank (SARB) statistical database (SARB, 2011). For the purposes of the empirical investigation, the variable was transformed using the logarithm operator.

The real effective exchange rate (not in log form) is considered in Figure 6.6 below:

Figure 6.6: Real effective exchange rate time series (Quarterly Average Real Effective Exchange Rate)

Source: SARB, 2011

From the figure above it is clear that the rand depreciated on average from around 1993 until the end of 2001. During this period, the currency faced continued pressure due to the high level of domestic inflation compared to major trading partner economies (Hanival and Maia, 2006). The trough in 2001 followed the shock induced by the September 11 attacks in the United States. Thereafter, a sharp appreciating trend is evident from 2002 to the start of 2006. Thereafter, the real effective exchange rate depreciated slightly before recovering towards the end of 2010 to levels similar to those experienced during the start of 2006. The trough in 2008 was again the result of the global financial crisis.

6.2 Unit root tests

Stationarity implies that the mean and variance of a specific variable are constant over time and that the covariance depends only on the lag between the two time periods and not on the actual time periods during which it is measured. Stationarity is important because using non-stationary variables makes standard hypotheses testing invalid and could lead to spurious regression results.

This section will briefly discuss the tests, outcomes and transformations in ensuring that the various variables used in the empirical investigation satisfy the stationarity condition. In most cases, the augmented Dickey-Fuller unit root test was used to assess whether a variable was stationary. In ambiguous cases, the Phillips-Perron unit root test was also used to verify results. The stationarity tests, including the complete test equations, are reported in appendix A.

Once it has been verified that a specific series is in fact non-stationary and thus contains one or more unit roots, the next step involves identifying the type of transformation that is required to remove the unit root. Usually, this transformation depends on the type of trend present in the series. A common rule of thumb in this case is:

- → **Deterministic trend:** In this case, the remedial measure usually involves removing the deterministic trend through extracting the residuals of a regression on a time or linear trend.
- → **Stochastic trend:** This case is usually addressed through using the difference operator or applying certain filters, such as for example the Hodrick-Prescott filter (HP filter).

The latter case is particularly challenging due to the choice of employing either the difference operator or some kind of filter, such as the HP filter. Furthermore, the literature seems divided on this issue. The literature review by Aadland (2002) adequately summarises the case for using the difference operator towards achieving stationarity:

"Over the last two decades, the First Difference (FD) filter has been a popular method for removing the trend from non-stationary time series. This is due in large part to Nelson and Plosser (1982), who argue that many macroeconomic time series are difference, rather than trend stationary. When a series is measured in natural logarithms, the resulting FD-filtered series are approximate growth rates

and have been commonly used to represent the business-cycle fluctuations of a time series. The problem, however, with treating growth rates of series as business-cycle fluctuations is that the FD filter tends to exacerbate high-frequency noise and introduce a phase shift. Despite these criticisms, many prominent studies of business-cycle phenomena continue to examine the growth rates of macro series. (Aadland 2002, p. 2)

The case for the HP filter is summarised by the following:

An advantage of the HP filter, relative to the FD filter, is that it does not exacerbate high-frequency noise and does not introduce a phase shift into the data. As a consequence, the HP filter, introduced by Hodrick and Prescott (1980), has arguably become the "industry standard" for de-trending data in empirical macroeconomics. The HP filter, however, is not without its critics. It has been criticized for generating spurious cycles in difference stationary data; altering the persistence, variability and co-movement of time series; and (similar to the FD filter) for passing through high-frequency or "irregular" variation.

(Aadland 2002, p. 3)

However, as alluded to by Aadland (2002) above, the HP Filter has arguably remained the industry standard. Furthermore, the first difference operator represents the data as growth rates rather than in level form and often removes some of the variability in the data due to the nature of the operation. In contrast, the HP filter merely removes the long term trend and the short-term cyclical component remains in level form. Due the importance of short-term fluctuations for the investigation into the effects of uncertainty, this thesis opted for using the HP filter rather than the difference operator. The processes for transforming each variable are now discussed in turn below:

6.2.1 Inflation

The inflation variable was non-stationary for all specifications of the ADF test equation. In other words, the inflation variable proved non-stationary when an intercept was included in the test equation and remained non-stationary when a trend and intercept were considered simultaneously. In the latter case the test statistic improved, although not sufficiently. Thus, the null hypotheses of a unit root could not be rejected at a 5% significance level for all cases. The case of the inclusion of an intercept in the test equation is presented below as an example:

Null Hypothesis: INFLATION has a unit root
Exogenous: Constant

		t-Statistic	Prob.
Augmented Dickey-Fuller test statistic		-2.067297	0.2583
Test critical values:	1% level	-3.512290	
	5% level	-2.897223	
	10% level	-2.585861	

Table 6.1: Inflation unit root tests (Augmented Dickey Fuller Stationarity Test: Intercept)

Source: Author's calculations

Upon closer examination, it became evident that the variable was stationary around a stochastic trend. The remedial measure used was to subtract a Hodrick-

Prescott filter-generated trend. The resulting series proved stationary, as is evident through considering the results in Table 6.2 below:

Null Hypothesis: INFLATION has a unit root
Exogenous: None

		t-Statistic	Prob.
Augmented Dickey-Fuller test statistic		-2.813504	0.0054
Test critical values:	1% level	-2.593468	
	5% level	-1.944811	
	10% level	-1.614175	

Table 6.2: Inflation residuals root tests (Augmented Dickey Fuller Stationarity Test: HP trend residuals)

Source: Author’s calculations

6.2.2 Output gap

The output gap variable proved stationary as per the Augmented Dickey-Fuller (ADF) stationarity test for all specifications of the test equation. The simple case of the inclusion of an intercept is provided in Table 6.3 as an example:

Null Hypothesis: OUTGAP has a unit root
Exogenous: Constant

		t-Statistic	Prob.
Augmented Dickey-Fuller test statistic		-4.356988	0.0007
Test critical values:	1% level	-3.512290	
	5% level	-2.897223	
	10% level	-2.585861	

Table 6.3: Output gap unit root test (Augmented Dickey Fuller Stationarity Test: Intercept)

Source: Author’s calculations

6.2.3 Interest rates

With regard to the nominal interest rate, the ADF test seemed to indicate stationarity around a deterministic trend. The nominal interest rate variable was non-stationary for both cases when an intercept was included and excluded.

However, the ADF test statistic improved dramatically when a linear trend and intercept were included in the test equation as reported in Table 6.4, thus indicating that the variable might be trend stationary.

Null Hypothesis: PRIME RATE has a unit root
Exogenous: Constant, Linear Trend

		t-Statistic	Prob.
Augmented Dickey-Fuller test statistic		-3.214919	0.0885
Test critical values:	1% level	-4.069631	
	5% level	-3.463547	
	10% level	-3.158207	

Table 6.4: Nominal interest rate unit root test (Augmented Dickey Fuller Stationarity Test: Intercept & Trend)

Source: Author's calculations

To this end, the nominal interest rate variable was transformed through extracting the residuals from a regression on a constant and linear trend, which resulted in a stationary variable.

Null Hypothesis: PRIME has a unit root
Exogenous: None

		t-Statistic	Prob.
Augmented Dickey-Fuller test statistic		-3.264491	0.0014
Test critical values:	1% level	-2.592452	
	5% level	-1.944666	
	10% level	-1.614261	

Table 6.5: Nominal interest rate residuals unit root test (Augmented Dickey Fuller Stationarity Test: Deterministic Trend Residuals)

Source: Author's calculations

The real interest rate variable proved to be non-stationary for all specifications of the test equation. The example where an intercept was included in the test equation is presented in Table 6.6 below:

Null Hypothesis: REAL_PRIME has a unit root
Exogenous: Constant

		t-Statistic	Prob.
Augmented Dickey-Fuller test statistic		-2.086326	0.2507
Test critical values:	1% level	-3.508326	
	5% level	-2.895512	
	10% level	-2.584952	

Table 6.6: Real interest rate unit root test (Augmented Dickey Fuller Stationarity Test: Intercept)

Source: Author's calculations

The same remedial measure was used to transform the real interest rate variable after further inspection revealed that the presence of a deterministic trend was likely. The subsequent transformed variable proved stationary at a 5% significance level.

Null Hypothesis: REAL PRIME has a unit root
Exogenous: None

		t-Statistic	Prob.
Augmented Dickey-Fuller test statistic		-2.381265	0.0175
Test critical values:	1% level	-2.592129	
	5% level	-1.944619	
	10% level	-1.614288	

Table 6.7: Real interest rate residuals unit root test (Augmented Dickey Fuller Stationarity Test: Deterministic Trend Residuals)

Source: Author's calculations

6.2.4 Exchange rate

The exchange rate variable was non-stationary for all specifications of the ADF test equation. The case where an intercept was included is reported in Table 6.8 below:

Null Hypothesis: REAL_EXCHANGE has a unit root
Exogenous: Constant

		t-Statistic	Prob.
Augmented Dickey-Fuller test statistic		-2.087136	0.2504
Test critical values:	1% level	-3.508326	
	5% level	-2.895512	
	10% level	-2.584952	

Table 6.8: Real effective exchange rate unit root test (Augmented Dickey Fuller Stationarity Test: Intercept)

Source: Author's calculations

Upon closer examination, it became evident that the variable was stationary around a stochastic trend. The remedial measure used was to subtract a Hodrick-

Prescott filter generated trend. The resulting series proved stationary as reported in Table 6.9 below:

Null Hypothesis: REER has a unit root
Exogenous: Constant

		t-Statistic	Prob.
Augmented Dickey-Fuller test statistic		-3.519954	0.0097
Test critical values:	1% level	-3.508326	
	5% level	-2.895512	
	10% level	-2.584952	

Table 6.9: Real effective exchange rate residual unit root test (Augmented Dickey Fuller Stationarity Test: Stochastic Trend Residuals)

Source: Author's calculations

6.3 Estimation Methodology

The empirical model to be estimated, as derived in Chapter 5, is outlined below for reference:

$$i_t = \rho_1 + \rho_2 i_{t-1} + \rho_3 e_{t-1} + \rho_{yt} y_t + \rho_{\pi t}\pi_t + \rho_{et} e_t + \mu_t \quad (6.1)$$

where $\rho_{yt} = \rho_y + \rho_y^{\pi}\sigma_{\pi t}^2 + \rho_y^{e}\sigma_{et}^2 + \rho_y^{y}\sigma_{yt}^2$

$$\rho_{\pi t} = \rho_\pi + \rho_\pi^{\pi}\sigma_{\pi t}^2 + \rho_\pi^{e}\sigma_{et}^2 + \rho_\pi^{y}\sigma_{yt}^2$$

$$\rho_{et} = \rho_e + \rho_e^{\pi}\sigma_{\pi t}^2 + \rho_e^{e}\sigma_{et}^2 + \rho_e^{y}\sigma_{yt}^2$$

and σ_y^2, σ_π^2, σ_e^2 are measures of output, inflation and exchange rate uncertainty respectively. However, prior to estimating the model above, approximations of uncertainty are necessary as inputs to the model. More specifically, estimates of σ_y^2, σ_π^2, σ_e^2 are necessary before solving the model.

With regard to the methodology used to derive uncertainty estimates, it has become common practice to approximate uncertainty about a variable with the variance of that variable. The rationale behind this rests upon the notion that the difficulty in approximating a variable is directly associated with the volatility thereof. In other words, higher volatility is akin to more uncertainty about the variable's accuracy. Furthermore, immediately apparent from the empirical review in Chapter 4 was the popularity of Generalised Autoregressive Conditional Heteroscedasticity (GARCH) models towards deriving uncertainty estimates (Martin and Milas 2005; Chung 2005).

This popularity stems from the technique's characteristic of allowing variable variances to be non-constant and subsequently controlling for the associated heteroscedasticity.

The aim of estimating uncertainty through GARCH-type models is to capture the volatility of the remaining unexplained residuals after controlling for the explainable effects of the regressors. In this sense, GARCH models allow for removing the variation in the data which are explainable; thus all that remains is the unexplainable portion which causes uncertainty.

Thus, inflation, output gap and exchange rate uncertainty estimates are derived through GARCH model specifications related to the structural equations as defined in Chapter 5. These equations are:

$$y_{t+1} = \phi_1 y_t - \phi_2 r_t - \phi_3 e_t + \varepsilon_{t+1} \tag{6.2}$$

$$\pi_{t+1} = \pi_t - \varphi_1 y_t - \varphi_2 (e_t - e_{t-1}) + \varpi_{t+1} \tag{6.3}$$

$$e_t = \Phi r_t + \upsilon_t \tag{6.4}$$

(Ball 1998)

To derive each of the variable variances, the structural equations were used as points of reference. In other words, the structural equations aim to approximate what monetary agents know about the dynamics of the economy. The residual variance series from the GARCH model would thus represent the uncertainty associated with the specific variable.

Thus, the empirical exercise aimed to specify the GARCH models similar to the structure of the equations above. However, strict adherence to the time period specifications in the structural models was deemed unnecessary. Rather, time periods and lag structures were allowed to deviate from the structural models, provided that the model proved a better fit. The reason for this is twofold.

First, although theory adequately explains the relationships between the various model variables, the period definition is less clear. In other words, whether *t* in the structural equations refers to an annual, quarterly or a monthly period is open to interpretation.

Second, the variables might exhibit different cycles such that adhering strictly to a fixed period structure could result in low model explanatory power. In turn, this could exaggerate the derived uncertainty as a result of misspecification.

Thus, after exploring a range of alternative models, certain specifications were identified that were deemed most appropriate towards capturing uncertainty through the resulting residual variance series. To ensure that these equations were not incorrectly specified, the squared residuals of all the equations were subjected to tests for neglected serial autocorrelation. This is necessary to prevent uncertainty estimates from being inconsistent or biased.

These equations and the corresponding serial correlation tests are described in turn below:

6.3.1 Output gap GARCH

The empirical investigation suggested that a GARCH (1, 2) model provided the best fit in relation to the output gap equation. The equation was modelled as follows:

$$y_t = \phi_0 + \phi_1 y_{t-4} - \phi_2 r_{t-1} - \phi_3 e_{t-1} + \varepsilon_t \qquad \text{Output Gap Equation}$$

$$\sigma_{yt}^2 = \psi_1 + \psi_2 \varepsilon_{t-1}^2 + \psi_3 \varepsilon_{t-2}^2 + \psi_4 \sigma_{yt-2}^2 \qquad \text{GARCH (1, 2)}$$

The results are reported in Table 6.10 below. The equation seems well specified as all the coefficients are statistically significant. The only exception was the exchange rate variable, which proved difficult to estimate satisfactorily. The latter is also evident when considering the R-squared statistic, indicating that the variables included in the output gap test equation only explain about 44 percent of the variation in the dependent variable, thus suggesting that a large proportion of the variation in the output gap model is unexplainable after observing the effects of the included known regressors.

Coefficient	Value	Std Error
ϕ_0	0.003149	0.00112
		(0.0049)
ϕ_1	0.783852	0.046863
		(0.0000)
ϕ_2	0.026025	0.008981
		(0.0038)
ϕ_3	0.047905	0.033693
		(0.1551)
R-Squared		0.44075
ARCH LM Prob (F-stat)		0.9994

Table 6.10: Output gap GARCH specification

Source: Author's calculations

Next, the squared residuals from the output gap GARCH equation were tested for neglected serial autocorrelation up to order three. The results are reported in Table 6.11 below (detailed ARCH LM tests are reported in Appendix B):

Test for neglected serial autocorrelation up to order three

Heteroskedasticity Test: ARCH

F-statistic	0.005439	Prob. F(3,76)	0.9994
Obs*R-squared	0.017171	Prob. Chi-Square(3)	0.9994

Table 6.11: Output gap GARCH ARCH LM test

Source: Author's calculations

The results provide strong evidence against the presence of neglected serial autocorrelation, as the null hypothesis of no ARCH up to order three in the residuals cannot be rejected.

6.3.2 Inflation GARCH

With regard to inflation, the empirical investigation suggested that a GARCH (1,1) model provided the best fit with the data. The inflation equation was modelled as follows:

$$\pi_t = \varphi_1 \pi_{t-1} - \varphi_2 y_{t-1} - \varphi_3 (e_{t-1} - e_{t-2}) + \varpi_t \qquad \text{Inflation Equation}$$

$$\sigma^2_{\pi t} = \kappa_1 + \kappa_2 \varpi^2_{t-1} + \kappa_3 \sigma^2_{\pi t-1} \qquad \text{GARCH (1, 1)}$$

The results are reported in Table 6.12 below. The equation seems well specified as all the coefficients are statistically significant. In contrast to the output gap equation, the regressors included in the inflation equation explain around 65 percent of the variation of the dependent variable, suggesting comparatively less inherent uncertainty.

Coefficient	Value	Std Error
φ_1	0.770085	0.041727
		(0.0000)
φ_2	0.140769	0.042561
		(0.0009)
φ_3	-0.2192	0.048958
		(0.0000)
R-Squared		0.64969
ARCH LM Prob (F-stat)		0.4189

Table 6.12: Inflation GARCH specification

Source: Author's calculations

Again, the squared residuals from the inflation GARCH equation were tested for neglected serial autocorrelation up to order three. The results are reported in Table 6.13 below (detailed ARCH LM tests are reported in Appendix B):

Test for neglected serial autocorrelation up to order three

Heteroskedasticity Test: ARCH

F-statistic	0.953861	Prob. F(3,78)	0.4189
Obs*R-squared	2.901870	Prob. Chi-Square(3)	0.4070

Table 6.13: Inflation GARCH ARCH LM test

Source: Author's calculations

The results provide strong evidence against the presence of neglected serial autocorrelation, as the null hypothesis of no ARCH up to order three in the residuals cannot be rejected.

6.3.3 Exchange rate GARCH

A GARCH (1,1) model provided the best fit with the exchange rate data. The equation was modelled as follows:

$$e_t = \Phi_1 e_{t-1} + \Phi_2 r_{t-1} + \Phi_3 r_{t-4} + v_t \qquad \text{Exchange Equation}$$

$$\sigma_{et}^2 = \gamma_1 + \gamma_2 v_{t-1}^2 + \gamma_3 \sigma_{et-1}^2 \qquad \text{GARCH (1, 1)}$$

The results are reported in Table 6.14. The equation seems well specified as all the coefficients are statistically significant.

However, the exchange equation specification differs from the theoretical counterpart due to the inclusion of a lagged exchange rate regressor. Exclusion of the latter resulted in a regression equation with very low explanatory power.

The decision to include the lagged exchange rate term was based upon the fact that the theoretical specification describes a long-term phenomenon, whereas the aim is rather to capture short-term uncertainty by controlling for known information.

Coefficient	Value	Std Error
Φ_1	0.712868	0.06195
		(0.0000)
Φ_2	0.000507	0.00005
		(0.0000)
Φ_3	-0.00762	0.00013
		(0.0000)
R-Squared		0.54853
ARCH LM Prob (F-stat)		0.4759

Table 6.14: Exchange rate GARCH specification

Source: Author's calculations

The squared residuals from the exchange rate GARCH equation were tested for neglected serial autocorrelation up to order three. The results are reported in Table 6.15 below (detailed ARCH LM tests are reported in Appendix B):

Test for neglected serial autocorrelation up to order three

Heteroskedasticity Test: ARCH

F-statistic	0.840433	Prob. F(3,76)	0.4759
Obs*R-squared	2.568780	Prob. Chi-Square(3)	0.4630

Table 6.15: Exchange rate GARCH ARCH LM test

Source: Author's calculations

The results again provide strong evidence against the presence of neglected serial autocorrelation, as the null hypothesis of no ARCH up to order three in the residuals also cannot be rejected.

6.4 Uncertainty Estimates

Uncertainty estimates were obtained from the residual variances of the GARCH model specifications in the previous section. All the uncertainty estimates derived seem plausible. All the uncertainty variables were transformed through applying the logarithm operator and subsequently testing for the presence of unit roots. These estimates and the corresponding stationarity tests are presented below:

6.4.1 Output Gap uncertainty

The derived output gap uncertainty series is illustrated in Figure 6.7 below. The results indicate that output gap uncertainty was high from 1992 to 1994, the period prior to the advent of democracy during which South Africa experienced particularly slow growth (Faulkner and Loewald, 2008). Output gap uncertainty was again particularly high from 1997 to 1999, during the Asian crisis, and again from 2009 to 2010, due to the effects of the global recession on GDP growth in South Africa.

The SARB's fan chart published during 2009 reflected particular uncertainty with regards to the domestic growth outlook. More specifically, uncertainty about a deeper global slowdown and a considerable moderation in domestic growth induced a significant downward bias on the SARB's inflation forecast (SARB, 2009).

Figure 6.7: Output gap uncertainty estimates

Source: Author's calculations

The output gap uncertainty variable proved stationary according to the augmented Dickey-Fuller unit root test (detailed unit root tests are reported in Appendix A).

Null Hypothesis: LVAROUTGAP has a unit root
Exogenous: Constant

		t-Statistic	Prob.
Augmented Dickey-Fuller test statistic		-4.328428	0.0008
Test critical values:	1% level	-3.512290	
	5% level	-2.897223	
	10% level	-2.585861	

Table 6.16: Output gap uncertainty unit root test

Source: Author's calculations

6.4.2 Inflation uncertainty

The derived inflation uncertainty series is presented in Figure 6.8 below. As expected, the results indicate that on average the inflation variable shows the least amount of uncertainty.

Inflation was measured as most uncertain between 1997 and 1999, during the Asian Crisis and shortly prior to the implementation of the inflation targeting regime. Particularly high uncertainty is again evident towards the end of 2001.

Thereafter, inflation uncertainty decreased up to 2009. The subsequent increase corresponds to the effects of the global economic recession, which effectively spread to South Africa during the latter half of 2008. Again, the SARB's fan chart at the time reflected considerable uncertainty with regards to the inflation forecast:

"The heightened levels of uncertainty and the rate of change in global developments make recent forecasts subject to higher risk than is usually the case." (SARB 2009, p. 35)

Alternative risk probability scenarios contributing to this increase in uncertainty included movements in the foreign-exchange rate of the rand and oil prices. Also, the SARB noted that larger-than-anticipated electricity price increases exerted an upward bias on the inflation forecast at the time.

Figure 6.8: Inflation uncertainty estimates

Source: Author's calculations

The ADF test result for the inflation uncertainty variable was more ambiguous as the evidence was not convincing in proving either the presence or absence of a unit root (Table 6.17). The decision was thus made not to transform the variable which might unnecessarily remove some of the variability in the inflation rate.

Null Hypothesis: LVARINF has a unit root
Exogenous: Constant

		t-Statistic	Prob.
Augmented Dickey-Fuller test statistic		-2.573668	0.1024
Test critical values:	1% level	-3.508326	
	5% level	-2.895512	
	10% level	-2.584952	

Table 6.17: Inflation uncertainty unit root test

Source: Author's calculations

6.4.3 Exchange rate uncertainty

The derived exchange rate uncertainty series is presented in Figure 6.9 below. Exchange rate uncertainty is high on average compared to the other variables, with the peak corresponding to the drastic depreciation of the currency in 2001 following the events of September, 11. Again, this increased uncertainty about the exchange rate was highlighted when the SARB published the inflation forecast fan chart during 2001 (SARB, 2001).

Figure 6.9: Exchange rate uncertainty estimates

Source: Author's calculations

The exchange rate uncertainty variable proved stationary according to the ADF test, as shown in Table 6.18 below:

Null Hypothesis: LVARREER has a unit root
Exogenous: Constant

		t-Statistic	Prob.
Augmented Dickey-Fuller test statistic		-3.651414	0.0067
Test critical values:	1% level	-3.512290	
	5% level	-2.897223	
	10% level	-2.585861	

Table 6.18: Exchange rate uncertainty unit root test

Source: Author's calculations

6.5 Summary

To review, the objective of this thesis is to establish whether uncertainty affected the actions of the SARB and whether those actions reflected conservatism. A first step towards achieving this objective involved deriving a theoretical model to approximate the structure of the economy for the subsequent empirical analysis.

The next step towards achieving the stated objective involves deriving estimates for uncertainty pertaining to the South African economy. This chapter estimated inflation, output gap and exchange rate uncertainty using GARCH-model specifications related to the structural equations as set out in the theoretical model. The structural equations approximate what monetary agents know about the dynamics of the economy. The residual variance series from the GARCH model thus represents the uncertainty associated with each specific variable. The derived uncertainty estimates are plausible.

What remains is to substitute the uncertainty estimates into the uncertainty-adjusted model as set out in Chapter 5. Solving this model and obtaining the structural parameters allows us to investigate the SARB's policy bias towards either conservatism or aggression. This issue is explored next.

Chapter 7

The Effects of Indirect Uncertainty on the South African Reserve Bank

The previous chapter derived inflation, output gap and exchange rate uncertainty estimates through GARCH-model specifications related to the structural equations as defined in the theoretical model in Chapter 5.

The next step entails solving the models to ascertain whether the SARB took uncertainty into account and, if so, whether the SARB's actions reflect optimal behaviour as stipulated by theory. This is the aim of this chapter.

Section 7.1 explores the methodology. Subsequent sections consider the results of the different models estimated. Section 7.2 presents the results when estimating the indirect uncertainty model. Section 7.3 explores goodness of fit criteria along with the appropriate diagnostics. Section 7.4 considers the possibility of sample breaks and the effect thereof on the results. The final section aims to quantify the impact of uncertainty on the actions of the SARB before closing with the concluding remarks.

7.1 Methodology

This section considers the methodology used to study the effects of uncertainty on the actions of the SARB. More specifically, the section explores the model, the time period specifications and the different uncertainty-related scenarios.

7.1.1. The model

To review, the uncertainty-adjusted model derived in Chapter 5 assumed that the coefficients are dependent on the variances of the endogenous variables, namely inflation, the output gap and the exchange rate. This model allows us to see whether monetary policy is more or less aggressive when uncertainty about the relevant exogenous variable increases.

However, the model assumes that uncertainty only influences monetary policy indirectly through affecting interest rate responses to inflation, output gap and exchange rate fluctuations. In other words, uncertainty plays a role only when the central bank responds to fluctuations in target variables, and as such influences the magnitude of the response. Since direct uncertainty will be added to the model in Chapter 8, it is important to clarify the distinction between the effects of direct and indirect uncertainty. Thus, for clarity, indirect and direct uncertainty effects are defined below:

- **Indirect uncertainty effects:** Uncertainty influences only the response to a fluctuation in the target variable. For example, the central bank raises the interest rate following an increase in expected inflation which is considered likely to be sustained and thus reflected in actual future inflation. However, the central bank raises the interest rate by a smaller margin due to uncertainty about the rate of inflation. In the absence of uncertainty, the central bank would still have changed the interest rate, but the magnitude of the change would have been different. For this reason, uncertainty enters the regression equation through the coefficient of the specific independent variable.

- **Direct uncertainty effects:** The effect of uncertainty regardless of responding to a fluctuation in the target variable. This case is distinctly different as the central bank is not responding to a fluctuation in a target variable. Rather, the central bank changes the policy instrument based solely on uncertainty about a particular target variable. For example, even if the inflation rate is stable, the central bank raises the interest due to uncertainty about whether the status quo would be maintained going forward. In the absence of uncertainty, the central bank would not have changed the interest rate, all else held constant. For this reason, uncertainty enters the regression equation directly and captures the effect of a change in uncertainty about the target variable.

As mentioned above, this chapter is concerned only with indirect uncertainty effects. The model below, derived in Chapter 5, is thus appropriately renamed the indirect-uncertainty model:

Indirect-Uncertainty Model:

$$i_t = \rho_1 + \rho_2 i_{t-1} + \rho_3 e_{t-1} + \rho_{yt} y_t + \rho_{\pi t} \pi_t + \rho_{et} e_t + \mu_t$$

(Author's calculations)

where $\rho_{yt} = \rho_y + \rho_y^{\pi} \sigma_{\pi t}^2 + \rho_y^{e} \sigma_{et}^2 + \rho_y^{y} \sigma_{yt}^2$

$$\rho_{\pi t} = \rho_\pi + \rho_\pi^{\pi} \sigma_{\pi t}^2 + \rho_\pi^{e} \sigma_{et}^2 + \rho_\pi^{y} \sigma_{yt}^2$$

$$\rho_{et} = \rho_e + \rho_e^{\pi} \sigma_{\pi t}^2 + \rho_e^{e} \sigma_{et}^2 + \rho_e^{y} \sigma_{yt}^2$$

and σ_y^2, σ_π^2, σ_e^2 are measures of output, inflation and exchange rate uncertainty respectively.

The indirect-uncertainty model allows us to investigate whether monetary policy is more or less aggressive when uncertainty about the relevant exogenous variable increases. Thus, $\rho_y^y > 0$ would signify a more aggressive interest rate response as uncertainty about output increases.

The model also allows us to see whether uncertainty about a specific variable influences the response to other variables. Thus, $\rho_y^{\pi} < 0$ would signify that increased uncertainty about inflation weakens the response to output fluctuations.

7.1.2. Time period specifications

In examining the effects of uncertainty on the actions of the SARB, different period specifications of the derived interest rate rule above were estimated. The decision to consider a range of different specifications was guided by the fact that there is no clear consensus in the literature regarding the optimal rule in characterising the behaviour of the South African central bank.

For instance, Woglom (2003) uses a backward-looking variant of the Taylor Rule in identifying the way in which the advent of inflation targeting affected monetary policy. On the other hand, the influential work of Clarida et al (1998) seems to have prompted a shift towards the use of forward-looking interest rate rules, as employed in the South African context by Aron and Muellbauer (2000)[19].

Another variant commonly employed in the literature is the “hybrid” model, characterised as being a combination of the present period and forward-looking rules as it may specify a central bank responding to expected future inflation and the current output gap.

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[19] Besides using a forward-looking rule, Aron and Muellbauer (2000) also tested backward-looking, current period and hybrid rules.

In the context of this chapter, the time period rule specifications are represented as follows:

Backward-Looking Rule

$$i_t = \rho_1 + \rho_2 i_{t-1} + \rho_3 e_{t-2} + \rho_{yt} y_{t-1} + \rho_{\pi t} \pi_{t-1} + \rho_{et} e_{t-1} + \mu_t$$

Present-Period Rule

$$i_t = \rho_1 + \rho_2 i_{t-1} + \rho_3 e_{t-1} + \rho_{yt} y_t + \rho_{\pi t} \pi_t + \rho_{et} e_t + \mu_t$$

Hybrid Rule

$$i_t = \rho_1 + \rho_2 i_{t-1} + \rho_3 e_{t-1} + \rho_{yt} E(y_{t+1}) + \rho_{\pi t} E(\pi_{t+1}) + \rho_{et} e_t + \mu_t$$

Forward-Looking Rule

$$i_t = \rho_1 + \rho_2 i_{t-1} + \rho_3 e_t + \rho_{yt} E(y_{t+1}) + \rho_{\pi t} E(\pi_{t+1}) + \rho_{et} E(e_{t+1}) + \mu_t$$

The present-period reaction function is similar to the original theoretical model noted above. The backward-looking rule is the result after shifting the time periods of the exogenous regressors in the theoretical rule back by one period, suggesting a central bank which considers single-period lagged information when making current period interest rate decisions, possibly due in practice to the unavailability of accurate data at the time of the decision. This excludes shifting the lagged interest rate time period, as it was included to capture interest rate smoothing behaviour from the previous interest rate value to the current value.

The forward-looking interest rate rule considers the case of a central bank making decisions regarding the interest rate in the current period based on expectations of future target variable values. Thus in the estimation exercise, actual future values are substituted for expected values.

Finally, a hybrid model was also estimated, characterised by the case where the inflation and output gap variables are forward-looking whereas the exchange rate terms are similar to the present period specification.

In all cases, uncertainty is assumed to be a current-period phenomenon. In other words, in all cases outlined above, uncertainty was treated as being considered in the present time, rather than in the past or future. It seems more plausible to assume that policymakers consider current uncertainty rather than to act on the basis of how uncertain they were in the past or how uncertain they think they will be in the future. Regarding the backward-looking specification, it is assumed that even though the central bank acts in response to lagged variables, uncertainty is derived through estimates of current-period values. The cases for present-period, hybrid and forward-looking central banks differ as current values are known.

7.1.3. Uncertainty scenarios

In addition, for each time period rule outlined above, four different model specifications were considered representing different uncertainty-related scenarios, as follows:

Model A: No Uncertainty

$$\rho_{yt} = \rho_y$$

$$\rho_{\pi t} = \rho_\pi$$

$$\rho_{et} = \rho_e$$

Model A considers the scenario where uncertainty has no influence on the actions of the central bank. The model is similar in essence to a simple Taylor rule augmented by the presence of the exchange rate variable, as in Taylor (1999), Ball (1998), Svensson (2000) and subsequently Mohanty and Klau (2004).

Model B: Inflation and Output Gap Uncertainty

$$\rho_{yt} = \rho_y + \rho_y^y \sigma_{yt}^2$$

$$\rho_{\pi t} = \rho_\pi + \rho_\pi^\pi \sigma_{\pi t}^2$$

$$\rho_{et} = \rho_e$$

Model B assumes that the effects of inflation and output gap uncertainty are significant, while uncertainty surrounding the exchange rate variable is insignificant. If the exchange rate term is discarded, the model resembles the closed economy uncertainty model employed by Martin and Milas (2005).

Model C: Inflation, Output Gap and Exchange Rate Uncertainty

$$\rho_{yt} = \rho_y + \rho_y^y \sigma_{yt}^2$$

$$\rho_{\pi t} = \rho_\pi + \rho_\pi^\pi \sigma_{\pi t}^2$$

$$\rho_{et} = \rho_e + \rho_e^e \sigma_{et}^2$$

Model C is an extension of the previous model as it assumes that exchange rate uncertainty also affects central bank behaviour. The decision to distinguish between Models B and C was guided by the fact that such effects have not been studied in mainstream empirical work, prompting a stepwise approach in this regard.

Model D: Intra-Uncertainty Effects

$$\rho_{yt} = \rho_y + \rho_y^{\pi}\sigma_{\pi t}^2 + \rho_y^{e}\sigma_{et}^2 + \rho_y^{y}\sigma_{yt}^2$$

$$\rho_{\pi t} = \rho_\pi + \rho_\pi^{\pi}\sigma_{\pi t}^2 + \rho_\pi^{e}\sigma_{et}^2 + \rho_\pi^{y}\sigma_{yt}^2$$

$$\rho_{et} = \rho_e + \rho_e^{\pi}\sigma_{\pi t}^2 + \rho_e^{e}\sigma_{et}^2 + \rho_e^{y}\sigma_{yt}^2$$

Model D specifically investigates whether uncertainty about a specific variable might influence the response towards fluctuations in other target variables. Martin and Milas (2005) used a similar approach with the exception of the exchange rate equation.

Estimates of the parameters in the equations outlined above were obtained through Ordinary Least Squares (OLS). However, in most cases, results obtained from Breusch-Pagan-Godfrey tests for the presence of heteroscedasiticity were inconclusive. To this end, Generalised Method of Moments (GMM) estimates were also derived. Below follows a brief discussion of the results obtained for each time period rule specification.

For simplicity, only the GMM results are reported below. The complete regression outputs including the LS regression results are reported in Appendix C.

7.2 Indirect-Uncertainty Model Estimation

This section considers the estimation results of the indirect-uncertainty model described above. Each of the different time period specifications is discussed in turn below:

7.2.1. Backward-looking results

The results of the backward-looking specification are reported in Table 7.1 below. The fact that Model A excludes any uncertainty regressors allows for comparison with findings from other rule-based investigations. Immediately apparent is the high degree of interest rate smoothing, considering both the size and significance of the coefficient. This suggests that the central bank was reluctant to change the interest rate substantially from one period to another, rather opting for smaller incremental adjustments. In a sense, this type of behaviour mirrors that of a central bank being more conservative in the face of uncertainty. Thus, controlling for this effect could negate or absorb some of the cautionary behaviour of the central bank when responding to uncertainty.

The relatively large coefficient of the lagged interest rate term is common amongst findings in the literature (Woglom, 2003; Aron and Muellbauer, 2000; Mohanty and Klau, 2004) and remained robust throughout the estimation exercises.

$$i_t = \rho_1 + \rho_2 i_{t-1} + \rho_3 e_{t-2} + \rho_{yt} y_{t-1} + \rho_{\pi t} \pi_{t-1} + \rho_{et} e_{t-1} + \mu_t$$

Backward-looking	Model A	Model B	Model C	Model D
Coefficient	GMM	GMM	GMM	GMM
ρ_1	-0.00183 (0.2848)	0.00006 (0.5934)	0.000601 (0.6368)	0.001738 (0.3561)
ρ_2	0.823959 (0.0000)***	0.81817 (0.0000)***	0.822347 (0.0000)***	0.875466 (0.0000)***
ρ_3	0.464325 (0.0035)***	0.359224 (0.0000)***	0.2330 (0.0001)***	0.250407 (0.0100)***
ρ_π	0.339423 (0.0013)***	-0.27709 (0.0219)**	-0.23065 (0.0325)**	-0.20076 (0.2594)
ρ_y	0.25641 (0.0023)***	0.156586 (0.0034)***	0.116942 (0.0513)**	0.066288 (0.4378)
ρ_e	-0.53344 (0.0020)***	-0.31052 (0.0021)***	0.119351 (0.3383)	0.278961 (0.0798)*
ρ_π^π		-0.09782 (0.0000)***	-0.08742 (0.0000)***	-0.54387 (0.0328)**
ρ_y^y		-0.02564 (0.0003)***	-0.02312 (0.0092)***	0.088692 (0.4618)
ρ_e^e			0.049091 (0.0006)***	-0.21976 (0.2821)
ρ_π^y				0.27642 (0.0505)*
ρ_π^e				0.189537 (0.4198)
ρ_y^π				0.357518 (0.0502)
ρ_y^e				-0.50312 (0.0005)***
ρ_e^π				-0.36048 (0.0099)***
ρ_e^y				0.624774 (0.0024)***
Adj. R-Squared	0.867299	0.906783	0.913552	0.892568
Σe^2	0.04568	0.031106	0.028436	0.032265
J-Statistic Prob.	0.523702	0.864791	0.920151	0.836493
Parameter Stab	0.0000	0.0000	0.0000	0.0000
PP Prob.	0.0000	0.0000	0.0000	0.0000

Numbers in parentheses are the probability values of the standard errors. The instruments are a constant and five lags of the variables in the estimated rule. The J-statistic is a test of over-identifying moment conditions. The parameter stability test values are the probabilities of a Chi Square statistic generated through the Andrews-Fair-Wald Breakpoint test. PP refers to Phillips-Peron unit root tests. ***, **, * represent coefficient significance at 1%, 5% and 10% respectively.

Table 7.1: Backward-looking regression results: Full sample

Source: Author's calculations

Furthermore, the model seems to suggest a greater response to inflation fluctuations compared to output gap fluctuations. This is in contrast to the findings reported by Woglom (2003), where the results indicated a larger coefficient on the output gap variable over a sample from 1990 to 1999. Also, Woglom (2003) reported a negative coefficient on the output gap, whereas the results derived from Model A suggest positive signs on both the output gap and inflation. Aron and Muellbauer (2000) reported the opposite, suggesting a negative inflation response and positive output gap response over a sample stretching from 1986 to 1997, also using lagged variables as regressors. Aron and Muellbauer's estimate of the inflation response turned positive only after controlling for financial liberalisation. Ncube and Tshuma (2010) found positive coefficients on both regressors using lagged values. The inconsistent results from the literature might stem from differences in sample periods, model specifications, estimation techniques or differences in the way variables are measured.

The exchange rate terms enter the model significantly. However, as suggested by Taylor (2001), the combined countercyclical effect is comparatively small. A similar result was reported by Woglom (2003).

When uncertainty is added in Models B and C, the explanatory power of the models is increased. The uncertainty variables enter the equations significantly, suggesting relatively small effects. Interestingly, the results suggest that a backward-looking SARB reacted more cautiously to both inflation and the output gap when these variables were more uncertain, while acting more aggressively towards exchange rate fluctuations when the variable was more uncertain. However, the sign of the inflation variable turned negative in both cases and the one-period lagged exchange rate variable turned insignificant when exchange rate uncertainty was included.

The results from Model D, including uncertainty cross-effects, seem to indicate that uncertainty about one variable did not influence the response to other variables over the sample period. The fit of the model also decreased significantly in the GMM case. Experimenting with different combinations of variables included in the test equation did not produce differing results.

7.2.2. Present-period results

The results of the present-period specification are reported in Table 7.2 below. Model A, excluding uncertainty effects, suggests fairly similar results to those reported in the backward-looking case. However, the output gap coefficient was only marginally significant in the GMM case. The signs on both the inflation and output gap coefficients were positive, with the inflation coefficient again proving larger. These results are similar to those reported by Aron and Muellbauer (2000) using current-period regressors. Furthermore, Mohanty and Klau (2004) found positive inflation and output coefficients; however, both the current and lagged exchange rate terms were negative.

The explanatory power of the models increased when uncertainty was included in Models B and C. However, though the inflation and output gap coefficients retained positive signs and remained significant, the sizes seemed to be inflated. Also, in model C the current-period exchange rate term entered insignificantly. The uncertainty variables entered significantly only in some cases, suggesting a more aggressive response from the central bank when uncertainty increased.

$$i_t = \rho_1 + \rho_2 i_{t-1} + \rho_3 e_{t-1} + \rho_{yt} y_t + \rho_{\pi t} \pi_t + \rho_{et} e_t + \mu_t$$

Present-period	**Model A**	**Model B**	**Model C**	**Model D**
Coefficient	**GMM**	**GMM**	**GMM**	**GMM**
ρ_1	-0.00107 (0.5710)	-0.00253 (0.0812)*	-0.00011 (0.9402)	0.001875 (0.5575)
ρ_2	0.802604 (0.0000)***	0.846242 (0.0000)***	0.823292 (0.0000)***	0.853334 (0.0000)***
ρ_3	0.66787 (0.0006)***	0.536572 (0.0013)***	0.554715 (0.0000)***	0.602979 (0.0094)***
ρ_π	0.667356 (0.0000)***	3.106668 (0.0014)***	1.138601 (0.0478)**	5.457214 (0.1626)
ρ_y	0.153109 (0.1079)	1.740109 (0.0851)*	1.666356 (0.0480)**	-5.79912 (0.1294)
ρ_e	-0.80544 (0.0000)***	-0.53654 (0.0002)***	2.281242 (0.1353)	3.77872 (0.1936)
ρ_π^π		0.27159 (0.0101)**	0.051874 (0.4401)	-0.18023 (0.4266)
ρ_y^y		0.182756 (0.1279)	0.173891 (0.0756)*	-0.1437 (0.6654)
ρ_e^e			0.345393 (0.0745)*	0.347743 (0.4315)
ρ_π^y				0.27272 (0.3083)
ρ_π^e				0.477973 (0.2818)
ρ_y^π				0.446804 (0.2364)
ρ_y^e				-1.06318 (0.0322)**
ρ_e^π				-0.27066 (0.2643)
ρ_e^y				0.452282 (0.1745)
Adj. R-Squared	0.889772	0.910201	0.914046	0.887018
Σe^2	0.037944	0.029966	0.028273	0.033932
J-Statistic Prob.	0.845456	0.806788	0.879147	0.776422
Parameter Stab	0.0000	0.0000	0.0000	0.0000
PP Prob.	0.0000	0.0000	0.0000	0.0000

Numbers in parentheses are the probability values of the standard errors. The instruments are a constant and five lags of the variables in the estimated rule. The J-statistic is a test of over-identifying moment conditions. The parameter stability test values are the probabilities of a Chi Square statistic generated through the Andrews-Fair-Wald Breakpoint test. PP refers to Phillips-Peron unit root tests.
***, **, * represent coefficient significance at 1%, 5% and 10% respectively.

Table 7.2: Present-period regression results: Full sample

Source: Author's calculations

As with the backward-looking specification, Model D, including uncertainty cross-effects, seemed to indicate that uncertainty about one variable did not influence the response to other variables over the sample period, as most of the coefficients proved statistically insignificant.

7.2.3. Hybrid model results

The hybrid model, reported in Table 7.3, performed comparatively well in general, with the exception of the exchange rate terms which proved insignificant in the GMM base model excluding uncertainty effects. The inflation and output gap variables remain significant and retain positive signs throughout Models A, B and C. Once again, the inflation coefficient was larger than the output gap coefficient. The exchange rate terms turned significant in Model B, again suggesting a small negative effect in the GMM case.

However, when exchange rate uncertainty was added, the current period exchange rate term seemed inflated and unrealistically large. Upon closer examination, it was determined that this was caused by the presence of multicollinearity between the current exchange rate term and the exchange rate uncertainty variable. When the current period exchange rate variable was dropped from the equation, the exchange rate uncertainty coefficient remained significant and positive. The results regarding uncertainty suggest a more cautious response to inflation and output gap uncertainty and a more aggressive response to exchange rate uncertainty. Again, Model D did not yield meaningful results.

$$i_t = \rho_1 + \rho_2 i_{t-1} + \rho_3 e_{t-1} + \rho_{yt} E(y_{t+1}) + \rho_{\pi t} E(\pi_{t+1}) + \rho_{et} e_t + \mu_t$$

Hybrid-model	**Model A**	**Model B**	**Model C**	**Model D**
Coefficient	**GMM**	**GMM**	**GMM**	**GMM**
ρ_1	-0.000008 (0.9686)	0.00009 (0.4874)	0.001543 (0.2417)	0.005939 (0.0674)
ρ_2	0.885209 (0.0000)***	0.82748 (0.0000)***	0.807404 (0.0000)***	0.849929 (0.0000)***
ρ_3	0.270414 (0.1895)	0.429462 (0.0003)***	0.465131 (0.0002)***	0.610732 (0.0002)***
ρ_π	0.676142 (0.0000)***	0.347572 (0.0003)***	0.304016 (0.0007)***	0.252375 (0.0851)
ρ_y	0.261518 (0.0009)***	0.265024 (0.0000)***	0.194826 (0.0000)***	0.101419 (0.1808)
ρ_e	-0.27202 (0.3130)	-0.45899 (0.0003)***	3.155095 (0.0217)**	7.103803 (0.0233)**
ρ_π^π		-0.04159 (0.000)***	-0.04459 (0.0000)***	-0.25745 (0.2618)
ρ_y^y		-0.0157 (0.0702)***	-0.02291 (0.0039)***	0.36105 (0.0386)**
ρ_e^e			0.449676 (0.0131)**	0.528497 (0.1164)
ρ_π^y				0.082664 (0.5480)
ρ_π^e				0.143021 (0.5553)
ρ_y^π				0.19418 (0.2942)
ρ_y^e				-0.61256 (0.0117)*
ρ_e^π				-0.61256 (0.3251)
ρ_e^y				0.588735 (0.0103)**
Adj. R-Squared	0.910841	0.914731	0.917780	0.877287
Σe^2	0.030264	0.028044	0.026649	0.036264
J-Statistic Prob.	0.933164	0.871154	0.914112	0.902942
Parameter Stab	0.0000	0.0000	0.0000	0.0000
PP Prob.	0.0000	0.0000	0.0000	0.0000

Numbers in parentheses are the probability values of the standard errors. The instruments are a constant and five lags of the variables in the estimated rule. The J-statistic is a test of over-identifying moment conditions. The parameter stability test values are the probabilities of a Chi Square statistic generated through the Andrews-Fair-Wald Breakpoint test. PP refers to Phillips-Peron unit root tests. ***, **, * represent coefficient significance at 1%, 5% and 10% respectively.

Table 7.3: Hybrid model regression results: Full sample

Source: Author's calculations

7.2.4. Forward-looking results

The most striking finding from the forward-looking models was the insignificance of the forward-looking exchange rate terms, seeing as this suggests that the central bank is not forward looking with respect to the exchange rate.

However, the output gap and inflation coefficients remained positive and significant throughout. The inflation coefficient was also consistently larger than the output gap coefficient, suggesting that the central bank is more concerned with keeping inflation close to its target value than compared to the output gap.

With regard to Models B and C, the inflation (ρ_{π}^{π}) and output gap (ρ_{y}^{y}) uncertainty terms proved significant and negative, again suggesting a more cautious response when uncertainty increases (The output gap coefficient was slightly insignificant in the Model LS case.) Again, the inflation uncertainty coefficient was more negative than the output gap uncertainty coefficient in both cases. This suggests that, in this setting, the central bank is more cautious with regard to responses to inflation than compared to the output gap.

Again, Model D did not yield any significant estimates, suggesting that no cross-uncertainty effects were present.

$$i_t = \rho_1 + \rho_2 i_{t-1} + \rho_3 e_t + \rho_{yt} E(y_{t+1}) + \rho_{\pi t} E(\pi_{t+1}) + \rho_{et} E(e_{t+1}) + \mu_t$$

Forward-looking	**Model A**	**Model B**	**Model C**	**Model D**
Coefficient	**GMM**	**GMM**	**GMM**	**GMM**
ρ_1	0.000108 (0.9489)	0.000421 (0.7308)	-0.00032 (0.7386)	0.0034 (0.0673)
ρ_2	0.86986 (0.0000)***	0.816867 (0.0000)***	0.827967 (0.0000)***	0.844985 (0.0000)***
ρ_3	0.130828 (0.2343)	0.07350 (0.3980)	-1.94458 (0.1130)	0.6748 (0.7555)
ρ_π	0.721908 (0.0000)***	0.421965 (0.0000)***	0.468513 (0.0000)***	0.519768 (0.0000)***
ρ_y	0.231777 (0.0019)***	0.246769 (0.0000)***	0.286989 (0.0000)***	0.217106 (0.0057)***
ρ_e	-0.16498 (0.3165)	-0.12747 (0.2359)	-0.04364 (0.6496)	-0.12156 (0.3794)
ρ_π^π		-0.0338 (0.0000)***	-0.03248 (0.0000)***	0.154377 (0.4245)
ρ_y^y		-0.01703 (0.0031)***	-0.01726 (0.0017)***	0.309012 (0.0289)**
ρ_e^e			-0.24808 (0.1067)	-0.45634 (0.0748)*
ρ_π^y				0.001945 (0.9910)
ρ_π^e				-0.1946 (0.3563)
ρ_y^π				-0.0480 (0.7786)
ρ_y^e				-0.28636 (0.1241)
ρ_e^π				0.197035 (0.3103)
ρ_e^y				0.287481 (0.0926)*
Adj. R-Squared	0.89892	0.908217	0.908197	0.885230
Σe^2	0.034311	0.030186	0.029755	0.033917
J-Statistic Prob.	0.978174	0.855737	0.880032	0.737293
Parameter Stab	0.0000	0.0000	0.0000	0.0000
PP Prob.	0.0000	0.0000	0.0000	0.0000

Numbers in parentheses are the probability values of the standard errors. The instruments are a constant and five lags of the variables in the estimated rule. The J-statistic is a test of over-identifying moment conditions. The parameter stability test values are the probabilities of a Chi Square statistic generated through the Andrews-Fair-Wald Breakpoint test. PP refers to Phillips-Peron unit root tests. ***, **, * represent coefficient significance at 1%, 5% and 10% respectively.

Table 7.4: Forward-looking regression results: Full sample

Source: Author's calculations

7.3 Goodness of Fit and Diagnostics

This section explores the goodness of fit statistics for each of the regressions reported above. Also, the regressions are submitted to the usual diagnostic tests to verify validity.

7.3.1. Goodness of fit

The adjusted R-squared, sum of squared residuals and the significance of the coefficients as measures of goodness of fit were used to identify the best model for each of the different uncertainty scenarios. The results are summarised in Table 7.5 below. The results indicate that the hybrid model performed best across all model specifications, with the exception of Model D. These results suggest that the SARB was forward-looking with respect to inflation and the output gap, but not so in relation to the exchange rate. Model D did not provide meaningful results in most cases. Comment with regard to the model providing the best fit is thus reserved in this case.

Again, the inflation and output gap coefficients are positive and significant throughout Models A to C. Also, the coefficient on inflation remained persistently larger than the corresponding coefficient on the output gap, suggesting that the SARB was more concerned with keeping inflation close to its target level than with the output gap.

	Model A	Model B	Model C	Model D
	Hybrid Model	Hybrid Model	Hybrid Model	Backward-Looking
Coefficient	**GMM**	**GMM**	**GMM**	**GMM**
ρ_1	-0.000008 (0.9686)	0.00009 (0.4874)	0.001543 (0.2417)	0.001738 (0.3561)
ρ_2	0.885209 (0.0000)***	0.82748 (0.0000)***	0.807404 (0.0000)***	0.875466 (0.0000)***
ρ_3	0.270414 (0.1895)	0.429462 (0.0003)***	0.465131 (0.0002)***	0.250407 (0.0100)***
ρ_π	0.676142 (0.0000)***	0.347572 (0.0003)***	0.304016 (0.0007)***	-0.20076 (0.2594)
ρ_y	0.261518 (0.0009)***	0.265024 (0.0000)***	0.194826 (0.0000)***	0.066288 (0.4378)
ρ_e	-0.27202 (0.3130)	-0.45899 (0.0003)***	3.155095 (0.0217)**	0.278961 (0.0798)*
ρ_π^π		-0.04159 (0.000)***	-0.04459 (0.0000)***	-0.54387 (0.0328)**
ρ_y^y		-0.0157 (0.0702)*	-0.02291 (0.0039)***	0.088692 (0.4618)
ρ_e^e			0.449676 (0.0131)**	-0.21976 (0.2821)
ρ_π^y				0.27642 (0.0505)*
ρ_π^e				0.189537 (0.4198)
ρ_y^π				0.357518 (0.0502)
ρ_y^e				-0.50312 (0.0005)***
ρ_e^π				-0.36048 (0.0099)***
ρ_e^y				0.624774 (0.0024)***
Adj. R-Squared	0.910841	0.914731	0.917780	0.892568
Σe^2	0.030264	0.028044	0.026649	0.032265
J-Statistic Prob.	0.933164	0.871154	0.914112	0.836493
Parameter Stability	0.0000	0.0000	0.0000	0.0000
PP Test Prob.	0.0000	0.0000	0.0000	0.0000

Numbers in parentheses are the probability values of the standard errors. The instruments are a constant and five lags of the variables in the estimated rule. The J-statistic is a test of over-identifying moment conditions. The parameter stability test values are the probabilities of a Chi Square statistic generated through the Andrews-Fair-Wald Breakpoint test. PP refers to Phillips-Peron unit root tests.
***, **, * represent coefficient significance at 1%, 5% and 10% respectively.

Table 7.5: Best fit models: Full sample

Source: Author’s calculations

The exchange rate coefficients were also significant for Models B and C. For model C, the coefficients seemed inflated and spurious at first glance. However, the large coefficients on the exchange rate and exchange rate uncertainty variables in Model C are due to the high level of multicollinearity between these variables. Upon removal of the current exchange rate term, the exchange rate uncertainty coefficient remained significant and positive, with the size of the estimate reduced to 0.05.

With the exception of Model D, the uncertainty variables are significant throughout. The results suggest that the SARB responded less aggressively when inflation and output gap uncertainty increased, whereas the converse seems to hold with regard to exchange rate uncertainty.

In other words, the results suggest that the SARB responded more aggressively towards exchange rate fluctuations as this variable became more uncertain.

Furthermore, it is important to note that the fit of the models seems to improve when the uncertainty variables are included. This is made clear in Figure 7.1 below:

Figure 7.1: Indirect uncertainty-adjusted R-squared statistics: Full sample

Source: Author's calculations

However, the increase in the adjusted R-Squared statistic is relatively small in most cases when the uncertainty variables are included. The largest increase, around 0.04, is evident in the backward-looking case (difference between Models A and B). In the hybrid model case, the increase is only 0.004. This suggests that even though the SARB took uncertainty into consideration, it played a comparatively small role, as is also evident in the small size of the uncertainty related coefficients[20]. Also, from the figure above, it is evident that Model C seemed to perform best, regardless of the time period specification used.

[20] Results from Martin and Milas (2005) reported a difference in R-squared statistics between the base and the uncertainty adjusted model of around 0.002 for the United States.

7.3.2. Diagnostics

All the equations passed the usual diagnostic tests (test results are reported at the bottom of each results table). In the least squares estimations, the F-test rejected the null hypothesis that all the coefficients are simultaneously equal to zero. The J-statistic reported that the null hypothesis of valid over-identifying restrictions could not be rejected in all cases. In other words, the GMM instruments satisfy the orthogonality condition as these instruments are uncorrelated with the errors. Also, the Phillips-Peron tests supported the standard ADF unit root tests that the residuals were stationary in all cases.

However, tests regarding parameter stability suggested the presence of breakpoints within the data. To this end, Quandt-Andrews breakpoint tests were used to establish the most likely breakpoint locations (the results are reported in Appendix D). Subsequently, Chow-breakpoint tests were used for the least square specification while the Andrews-Fair-Wald test was employed for the GMM specifications to verify whether breakpoints actually exist at the identified likely locations. The results indicated the presence of breakpoints around 1999, the year prior to the advent of formal inflation targeting. This is addressed in the next section below.

7.4 Sample Breaks

In addressing the problem of breakpoints around 1999, the original sample was divided into two sub-samples, corresponding to the timeframes 1990Q1 – 1999Q4 and 2000Q – 2011Q3. The same estimation procedure was followed but excluding

Model D considering the mostly insignificant estimates reported above. Although some results are reported in this section, the complete regressions for each rule specification are included in Appendix E. The individual regression outputs for each period specification are considered first. Due to the wide array of models considered, this section concludes by identifying the best fit models and discussing these results in more detail.

7.4.1. First sub-sample (1990 – 1999) results

Considering the backward-looking specification (Table 7.6), it is clear that the inflation and output gap coefficients remained significant throughout. However, the results suggest that the SARB assigned more weight to addressing output gap fluctuations than to inflation disturbances. This is evident through observing that the output gap coefficient was larger in most cases. The exchange rate terms also entered significantly, with the exception of the one period lagged variable in Model A.

Also, the results suggest the SARB was more concerned with exchange rate fluctuations than with the other two variables. The uncertainty variables entered significantly, suggesting a more conservative approach to inflation and output gap uncertainty and a more aggressive approach to exchange rate uncertainty.

	Model A	Model B	Model C
Coefficient	**GMM**	**GMM**	**GMM**
ρ_1	-0.00052 (0.7916)	-0.003408 (0.0001)***	0.005037 (0.0000)***
ρ_2	0.885942 (0.0000)***	0.857109 (0.0000)***	0.844079 (0.0000)***
ρ_3	0.667536 (0.0000)***	0.376547 (0.0000)***	0.294257 (0.0000)***
ρ_π	0.215478 (0.0761)*	-0.25154 (0.0330)**	0.068458 (0.0789)*
ρ_y	0.31621 (0.0019)***	0.150025 (0.0104)**	0.35492 (0.0000)***
ρ_e	-0.16894 (0.1895)	0.250199 (0.0000)***	0.671458 (0.0000)***
ρ_π^π		-0.09804 (0.0000)***	-0.06464 (0.0000)***
ρ_y^y		-0.04097 (0.0000)***	-0.03207 (0.0000)***
ρ_e^e			0.092652 (0.0000)***
Adj. R-Squared	0.849103	0.884769	0.904133
Σe^2	0.021981	0.015081	0.012001
F-Statistic Prob.	0.909973	0.997908	0.99603
J-Statistic Prob.	0.0007	0.0002	0.0001

Numbers in parentheses are the probability values of the standard errors. The instruments are a constant and five lags of the variables in the estimated rule. The J-statistic is a test of over-identifying moment conditions. The parameter stability test values are the probabilities of a Chi Square statistic generated through the Andrews-Fair-Wald Breakpoint test. PP refers to Phillips-Peron unit root tests.
***, **, * represent coefficient significance at 1%, 5% and 10% respectively.

Table 7.6: Backward-looking regression results: 1990 - 1999

Source: Author's calculations

The results for the present-period specification in Table 7.7 below also show that the inflation, output gap and exchange rate coefficients remain significant, with the exception of the output gap coefficient in Model A and the exchange rate coefficient in Model C.

	Model A	Model B	Model C
Coefficient	GMM	GMM	GMM
ρ_1	0.00171 (0.4837)	0.003399 (0.0180)**	0.003388 (0.1001)
ρ_2	0.886846 (0.0000)***	0.922691 (0.0000)***	0.92325 (0.0000)***
ρ_3	0.900442 (0.0000)***	0.55868 (0.0036)***	0.541125 (0.0280)**
ρ_π	0.712497 (0.0000)***	10.01401 (0.0041)***	10.17733 (0.0035)***
ρ_y	0.1229625 (0.1456)	5.14528 (0.0000)***	5.23586 (0.0000)***
ρ_e	-0.95509 (0.0000)***	-0.28555 (0.0223)***	-0.77036 (0.8536)
ρ_π^π		1.108033 (0.0067)***	1.12785 (0.0057)***
ρ_y^y		0.570584 (0.0000)***	0.580812 (0.0000)***
ρ_e^e			0.06245 (0.9031)
Adj. R-Squared	0.891527	0.902953	0.898957
Σe^2	0.015801	0.012837	0.012809
F-Statistic Prob.	0.721267	0.964384	0.946275
J-Statistic Prob.	0.0016	0.0004	0.0005

Numbers in parentheses are the probability values of the standard errors. The instruments are a constant and five lags of the variables in the estimated rule. The J-statistic is a test of over-identifying moment conditions. The parameter stability test values are the probabilities of a Chi Square statistic generated through the Andrews-Fair-Wald Breakpoint test. PP refers to Phillips-Peron unit root tests.
***, **, * represent coefficient significance at 1%, 5% and 10% respectively

Table 7.7: Present-period regression results: 1990 - 1999

Source: Author's calculations

Furthermore, in contrast to the previous specification, the results suggest a central bank more concerned with inflation than with the output gap[21]. The combined exchange rate effect also decreased considerably when compared to the previous specification.

[21]The exaggerated inflation and output gap coefficients in Models B & C are due mainly to multicollinearity, as discussed previously.

However, only the inflation and output gap uncertainty terms entered significantly. Surprisingly, the results suggest a more aggressive approach in this setting.

	Model A	Model B	Model C
Coefficient	GMM	GMM	GMM
ρ_1	0.003275 (0.0455)**	0.005366 (0.0000)***	0.004445 (0.0018)***
ρ_2	0.921979 (0.0000)***	0.872371 (0.0000)***	0.889872 (0.0000)***
ρ_3	0.512287 (0.0002)***	0.661276 (0.0000)***	0.5915589 (0.0000)***
ρ_π	0.802709 (0.0000)***	0.399335 (0.0000)***	0.456202 (0.0000)***
ρ_y	0.197435 (0.0143)**	0.197968 (0.0000)***	0.24982 (0.0000)***
ρ_e	-0.41414 (0.0049)***	-0.55155 (0.0000)***	-5.91316 (0.0035)***
ρ_π^π		-0.0189 (0.0000)***	-0.04493 (0.0000)***
ρ_y^y		-0.03048 (0.0001)***	-0.03108 (0.0017)***
ρ_e^e			-0.6857 (0.0063)***
Adj. R-Squared	0.890822	0.904385	0.903481
Σe^2	0.015904	0.012513	0.012082
F-Statistic Prob.	0.899609	0.998243	0.997035
J-Statistic Prob.	0.0001	0.0002	0.0004

Numbers in parentheses are the probability values of the standard errors. The instruments are a constant and five lags of the variables in the estimated rule. The J-statistic is a test of over-identifying moment conditions. The parameter stability test values are the probabilities of a Chi Square statistic generated through the Andrews-Fair-Wald Breakpoint test. PP refers to Phillips-Peron unit root tests.
***, **, * represent coefficient significance at 1%, 5% and 10% respectively.

Table 7.8: Hybrid model regression results: 1990 - 1999

Source: Author's calculations

The hybrid model again performed exceptionally well (Table 7.8), with all the variables included in the model proving significant throughout. Again, the results suggest a central bank more concerned with inflation than with the output gap. Also, the combined effect of the exchange rate terms is comparatively small. The uncertainty terms suggest conservative behaviour throughout. Somewhat surprising is the finding that the SARB was especially conservative when uncertainty about the exchange rate increased. Again, for the forward-looking specification most of the coefficients entered significantly, the only exception being the exchange rate coefficients in Models A and C. Also, the uncertainty coefficients suggest conservatism in all cases.

	Model A	**Model B**	**Model C**
Coefficient	**GMM**	**GMM**	**GMM**
ρ_1	0.004181 (0.0194)**	0.007143 (0.0000)***	0.00537 (0.0000)***
ρ_2	0.910125 (0.0000)***	0.865204 (0.0000)***	0.891573 (0.0000)***
ρ_3	0.010252 (0.9380)	-0.26982 (0.0000)***	-10.3394 (0.0000)***
ρ_π	0.789034 (0.0000)***	0.572188 (0.0000)***	0.623211 (0.0000)***
ρ_y	0.16376 (0.0118)**	0.257699 (0.0000)***	0.35849 (0.0000)***
ρ_e	-0.4236 (0.0045)***	0.257699 (0.0313)**	0.048961 (0.1667)
ρ_π^π		-0.02965 (0.0003)***	-0.02208 (0.0106)**
ρ_y^y		-0.02745 (0.0000)***	-0.03087 (0.0000)***
ρ_e^e			-1.27996 (0.0000)***
Adj. R-Squared	0.850975	0.879212	0.884999
Σe^2	0.021709	0.015808	0.014396
F-Statistic Prob.	0.930854	0.997869	0.996227
J-Statistic Prob.	0.0000	0.0009	0.0017

Numbers in parentheses are the probability values of the standard errors. The instruments are a constant and five lags of the variables in the estimated rule. The J-statistic is a test of over-identifying moment conditions. The parameter stability test values are the probabilities of a Chi Square statistic generated through the Andrews-Fair-Wald Breakpoint test. PP refers to Phillips-Peron unit root tests.
***, **, * represent coefficient significance at 1%, 5% and 10% respectively.

Table 7.9: Forward-looking regression results: 1990 - 1999

Source: Author's calculations

7.4.2. Second sub-sample (2000 – 2011) results

At first glance, the backward-looking specification again did not perform well (Table 7.10), with most of the coefficient estimates found to be insignificant. Thus the inflation estimate was found to be insignificant for both the Model B and C formulations. Also, the uncertainty coefficients suggest conservative behaviour with regard to inflation and output gap uncertainty, while a more aggressive approach is evident in relation to exchange rate uncertainty.

	Model A	Model B	Model C
Coefficient	GMM	GMM	GMM
ρ_1	-0.00361 (0.0252)**	-0.00360 (0.0001)***	-0.00342 (0.0003)***
ρ_2	0.616909 (0.0000)***	0.811449 (0.0000)***	0.710823 (0.0000)***
ρ_3	0.369701 (0.0045)***	0.161185 (0.0031)***	0.1300 (0.0069)***
ρ_π	0.567315 (0.0000)***	-0.12498 (0.1033)	-0.08674 (0.3229)
ρ_y	0.239089 (0.0026)***	0.16381 (0.0060)***	0.142946 (0.0050)***
ρ_e	-0.61477 (0.0000)***	0.24457 (0.0000)***	-0.12309 (0.1724)
ρ_π^π		-0.08591 (0.0000)***	-0.08312 (0.0000)***
ρ_y^y		-0.01669 (0.0061)***	-0.08312 (0.0012)***
ρ_e^e			0.012194 (0.1528)
Adj. R-Squared	0.904469	0.939665	0.939746
Σe^2	0.015724	0.009446	0.009192
F-Statistic Prob.	0.81516	0.982018	0.996763
J-Statistic Prob.	0.0042	0.0007	0.0018

Numbers in parentheses are the probability values of the standard errors. The instruments are a constant and five lags of the variables in the estimated rule. The J-statistic is a test of over-identifying moment conditions. The parameter stability test values are the probabilities of a Chi Square statistic generated through the Andrews-Fair-Wald Breakpoint test. PP refers to Phillips-Peron unit root tests.
***, **, * represent coefficient significance at 1%, 5% and 10% respectively.

Table 7.10: Backward-looking regression results: 2000 - 2011

Source: Author's calculations

Similarly to the previous specification, the present-period model (Table 7.11) did not perform well in general as a number of coefficients entered insignificantly. This is evident with the exchange rate terms and the output gap variable in Model A. With regard to uncertainty, the present-period specification predicts exactly the opposite of the backward-looking specification. Uncertainty about inflation and the output gap prompted a more aggressive response while conservatism was followed when exchange rate uncertainty increased.

	Model A	**Model B**	**Model C**
Coefficient	**GMM**	**GMM**	**GMM**
ρ_1	-0.00472 (0.0008)***	0.00757 (0.0000)***	-0.00729 (0.0000)***
ρ_2	0.690629 (0.0000)***	0.707628 (0.0000)***	0.705852 (0.0000)***
ρ_3	0.253106 (0.0126)**	0.070527 (0.2270)	0.050806 (0.2958)
ρ_π	0.812761 (0.0000)***	3.698081 (0.0000)***	3.449524 (0.0000)***
ρ_y	0.044353 (0.4767)	3.434595 (0.0000)***	3.072194 (0.0000)***
ρ_e	-0.39654 (0.0000)***	-0.19179 (0.0006)***	-0.30076 (0.5863)
ρ_π^π		0.324894 (0.0000)***	0.29894 (0.0000)***
ρ_y^y		0.373657 (0.0000)***	0.329631 (0.0000)***
ρ_e^e			-0.01512 (0.8261)
Adj. R-Squared	0.933145	0.946550	0.945704
Σe^2	0.011004	0.008368	0.008283
F-Statistic Prob.	0.888149	0.963049	0.992020
J-Statistic Prob.	0.0010	0.0005	0.0004

Numbers in parentheses are the probability values of the standard errors. The instruments are a constant and five lags of the variables in the estimated rule. The J-statistic is a test of over-identifying moment conditions. The parameter stability test values are the probabilities of a Chi Square statistic generated through the Andrews-Fair-Wald Breakpoint test. PP refers to Phillips-Peron unit root tests.
***, **, * represent coefficient significance at 1%, 5% and 10% respectively.

Table 7.11: Present period regression results: 2000 - 2011

Source: Author's calculations

The most striking finding from the hybrid model (Table 7.12) is the fact that all the exchange rate terms entered insignificantly. The uncertainty coefficients suggest a more conservative approach in this setting.

	Model A	Model B	Model C
Coefficient	**GMM**	**GMM**	**GMM**
$\boldsymbol{\rho_1}$	-0.00428 (0.0051)***	-0.00324 (0.0005)***	-0.0033 (0.0000)***
$\boldsymbol{\rho_2}$	0.794861 (0.0000)***	0.706533 (0.0000)***	0.703962 (0.0000)***
$\boldsymbol{\rho_3}$	-0.01896 (0.8484)	-0.01413 (0.6901)	0.009499 (0.7463)
$\boldsymbol{\rho_\pi}$	0.696807 (0.0000)***	0.3162013 (0.0219)**	0.160582 (0.0106)**
$\boldsymbol{\rho_y}$	0.24044 (0.0012)***	0.23176 (0.0000)***	0.240823 (0.0000)***
$\boldsymbol{\rho_e}$	-0.04908 (0.6754)	-0.0612 (0.3558)	-0.14067 (0.6683)
$\boldsymbol{\rho_\pi^\pi}$		-0.06656 (0.0000)***	-0.06505 (0.0000)***
$\boldsymbol{\rho_y^y}$		-0.0160 (0.0003)***	-0.01581 (0.0002)***
$\boldsymbol{\rho_e^e}$			-0.00467 (0.9121)
Adj. R-Squared	0.931166	0.945074	0.944027
$\boldsymbol{\Sigma e^2}$	0.011081	0.008400	0.008335
F-Statistic Prob.	0.857381	0.978568	0.995004
J-Statistic Prob.	0.0007	0.0008	0.0008

Numbers in parentheses are the probability values of the standard errors. The instruments are a constant and five lags of the variables in the estimated rule. The J-statistic is a test of over-identifying moment conditions. The parameter stability test values are the probabilities of a Chi Square statistic generated through the Andrews-Fair-Wald Breakpoint test. PP refers to Phillips-Peron unit root tests.
***, **, * represent coefficient significance at 1%, 5% and 10% respectively.

Table 7.12: Hybrid model regression results: 2000 - 2011

Source: Author's calculations

The forward-looking specification performed comparatively well. All the coefficients were significant, the only exceptions being the current period exchange rate term in Model A and the exchange rate uncertainty term in Model C. Again, the uncertainty coefficients suggest a more conservative approach as uncertainty about the respective variables increases.

	Model A	**Model B**	**Model C**
Coefficient	**GMM**	**GMM**	**GMM**
ρ_1	-0.00394 (0.0116)**	-0.00303 (0.0001)***	-0.00347 (0.0000)***
ρ_2	0.806842 (0.0000)***	0.712298 (0.0000)***	0.70723 (0.0000)***
ρ_3	0.039421 (0.5967)	-0.23613 (0.0000)***	-0.81342 (0.0685)***
ρ_π	0.765294 (0.0000)***	0.162596 (0.0229)**	0.195215 (0.0007)***
ρ_y	0.150335 (0.0558)*	0.268219 (0.0000)***	0.274407 (0.0000)***
ρ_e	-0.05384 (0.6082)	0.176789 (0.0003)***	0.168571 (0.0000)***
ρ_π^π		-0.06120 (0.0003)***	-0.06157 (0.0000)**
ρ_y^y		-0.02602 (0.0000)***	-0.02266 (0.0000)***
ρ_e^e			-0.07382 (0.1749)
Adj. R-Squared	0.929456	0.946790	0.944935
Σe^2	0.011357	0.008138	0.008200
F-Statistic Prob.	0.768175	0.982389	0.994957
J-Statistic Prob.	0.0007	0.0002	0.0002

Numbers in parentheses are the probability values of the standard errors. The instruments are a constant and five lags of the variables in the estimated rule. The J-statistic is a test of over-identifying moment conditions. The parameter stability test values are the probabilities of a Chi Square statistic generated through the Andrews-Fair-Wald Breakpoint test. PP refers to Phillips-Peron unit root tests.
***, **, * represent coefficient significance at 1%, 5% and 10% respectively.

Table 7.13: Forward-looking regression results: 2000 - 2011

Source: Author's calculations

7.4.3. Best fit models

Drawing general conclusions from the above results is complicated due to the large number of models estimated. For this reason, it might be beneficial to firstly summarise the general findings above and subsequently identify the models with the best fit. To this end, the findings reported above are summarised by considering each variable in turn:

Considering the first sub-sample results for the period 1990Q1 to 1999Q4, it is evident that the lagged interest rate coefficient remained significant throughout. The exchange rate terms also remained significant in most instances, the exceptions being Model A in the backward-looking specification, Model C in the present-period specification and Models A and C in the forward-looking specification. The inflation and output gap coefficients proved even more robust, entering significantly in all cases except for the output gap coefficient in Model A of the present-period specification and the inflation coefficient in Model A of the forward-looking specification.

The uncertainty-related coefficients were significant in all cases except one, the exchange rate uncertainty coefficient in the present-period specification. All specifications except the present-period specification indicated a more cautious approach to inflation and output gap uncertainty. However, the exchange rate uncertainty results were more volatile in this respect, suggesting caution in the hybrid and forward-looking specification but the converse in the remaining specifications.

Regarding the second sub-sample for the period 2000Q1 to 2011Q4, the lagged interest rate variable remained significant throughout, the major difference from the first sub-sample being the noticeable reduction in coefficient size in all cases, suggesting that interest rate smoothing was more prevalent during the nineties. The exchange rate coefficients are less robust than in the first sub-sample. This is clear from the hybrid specification, where the exchange rate terms were insignificant for all models. The exchange rate terms performed best in the backward- and forward-looking specifications. The inflation coefficient was significant in all cases except Models B and C in the backward-looking specification. The output gap coefficient remained significant in all cases except Model A in the present-period specification.

The inflation and output gap uncertainty-related coefficients were significant throughout, suggesting a cautious response in all cases except the present-period specification. Surprisingly, the exchange rate uncertainty coefficient never entered significantly, suggesting that the SARB did not respond to exchange rate uncertainty during the second sample, which might be an indication of behaviour under an inflation targeting regime. Thus, the results suggest that the SARB responded less aggressively to inflation and output gap uncertainty across both sample periods. Exchange rate uncertainty played a role only in the first sub-sample, suggesting a more aggressive approach. It should be noted that the model fit decreases slightly when exchange rate uncertainty is included, casting some doubt as to the effect of the coefficient, even though it entered significantly. Finally, in most cases, the response to inflation uncertainty was stronger than the response to output gap uncertainty.

Next, in order to distinguish between the specifications and related models above, “best-fit” models were identified based on the adjusted R-Squared and Sum of Squared Residual statistics. Insignificant coefficients were dropped from the equations when comparing the goodness-of-fit statistics. The results are reported in Table 7.14 below.

	Sample: 1990Q1 - 1999Q4 GMM Estimation			**Sample: 2000Q1 - 2011Q3 GMM Estimation**		
Coefficient	**Model A**	**Model B**	**Model C**	**Model A**	**Model B**	**Model C**
	Hybrid	**Hybrid**	**Backward**	**Hybrid**	**Forward**	**Forward**
$\boldsymbol{\rho_1}$	0.003275 (0.0455)**	0.005366 (0.0000)***	0.005037 (0.0000)***	-0.00428 (0.0051)***	-0.00303 (0.0001)***	-0.00347 (0.0000)***
$\boldsymbol{\rho_2}$	0.921979 (0.0000)***	0.872371 (0.0000)***	0.844079 (0.0000)***	0.794861 (0.0000)***	0.712298 (0.0000)***	0.70723 (0.0000)***
$\boldsymbol{\rho_3}$	0.512287 (0.0002)***	0.661276 (0.0000)***	0.294257 (0.0000)***	-0.01896 (0.8484)	-0.23613 (0.0000)***	-0.81342 (0.0685)**
$\boldsymbol{\rho_\pi}$	0.802709 (0.0000)***	0.399335 (0.0000)***	0.068458 (0.0789)*	0.696807 (0.0000)***	0.162596 (0.0229)**	0.195215 (0.0007)***
$\boldsymbol{\rho_y}$	0.197435 (0.0143)**	0.197968 (0.0000)***	0.35492 (0.0000)***	0.24044 (0.0012)***	0.268219 (0.0000)***	0.274407 (0.0000)***
$\boldsymbol{\rho_e}$	-0.41414 (0.0049)***	-0.55155 (0.0000)***	0.671458 (0.0000)***	-0.04908 (0.6754)	0.176789 (0.0003)***	0.168571 (0.0000)***
$\boldsymbol{\rho_\pi^\pi}$		-0.0189 (0.0000)***	-0.06464 (0.0000)***		-0.06120 (0.0003)***	-0.06157 (0.0000)**
$\boldsymbol{\rho_y^y}$		-0.03048 (0.0001)***	-0.03207 (0.0000)***		-0.02602 (0.0000)***	-0.02266 (0.0000)***
$\boldsymbol{\rho_e^e}$			0.092652 (0.0000)***			-0.07382 (0.1749)
Adj. R-Squared	0.890822	0.904385	0.904133	0.931166	0.946790	0.944935
$\boldsymbol{\Sigma e^2}$	0.015904	0.012513	0.012001	0.011081	0.008138	0.008200
F-Statistic Prob.	0.899609	0.998243	0.99603	0.857381	0.982389	0.994957
J-Statistic Prob.	0.0001	0.0002	0.0001	0.0007	0.0002	0.0002

Numbers in parentheses are the probability values of the standard errors. The instruments are a constant and five lags of the variables in the estimated rule. The J-statistic is a test of over-identifying moment conditions. The parameter stability test values are the probabilities of a Chi Square statistic generated through the Andrews-Fair-Wald Breakpoint test. PP refers to Phillips-Peron unit root tests.
***, **, * represent coefficient significance at 1%, 5% and 10% respectively.

Table 7.14: Best fit models: Split sample results

Source: Author’s calculations

Once again, the explanatory power of the models increases when uncertainty variables are included. The increase seems larger than the corresponding full sample results, equalling around 0.0135 in the first sub-sample and 0.0156 in the second sub-sample[22].

This is made clear through Figure 7.2 below:

Figure 7.2: Indirect-uncertainty adjusted R-squared statistics: First sub-sample

Source: Author's calculations

The results from Figure 7.2 emphasises that the inclusion of the uncertainty regressors improved the explanatory power of the models in each case. This is evident through observing the differences between Models A and B for each period

[22] Referring to the differences between Models A & B in Table 6.14.

specification. The hybrid model outperformed all the other period models except for the present-period specification of Model A uncertainty.

Figure 7.3: Indirect uncertainty adjusted R-squared statistics: Second sub-sample

Source: Author's calculations

The findings are similar when considering the results of the second sub-sample from 2000 to 2011 in Figure 7.3. Again, the model's explanatory power increased when the uncertainty regressors were included. However, in this sub-sample the present-period specification outperforms the hybrid specification for all the uncertainty models considered here.

7.5 Summary

This chapter attempted to investigate the effects of uncertainty on the actions of the SARB. The theoretical model derived in Chapter 4 served as the base model whilst the uncertainty estimates from the GARCH models of Chapter 5 were used to approximate uncertainty about the rate of inflation, the output gap and the exchange rate.

This chapter focused on solving the model to ascertain whether the SARB took uncertainty into account and if so, whether the SARB's actions reflect optimal behaviour as stipulated by theory.

However, the theoretical model assumes that uncertainty influences monetary policy only indirectly through affecting interest rate responses to inflation, output gap and exchange rate fluctuations. In other words, uncertainty plays a role only when the central bank responds to fluctuations in target variables. Subsequently, the model developed in Chapter 4 was renamed the indirect-uncertainty model. Thus, this chapter considered only indirect-uncertainty effects.

To solve the uncertainty-indirect model, various period specifications were considered in conjunction with differing uncertainty-related scenarios, ensuring the robustness of the results. The presence of a sample break around 1999 necessitated the sample being split into two smaller sub-samples corresponding to 1990 – 1999 and 2000 – 2011.

The results suggest that the SARB responded less aggressively to both inflation and output gap uncertainty across both sample periods. This finding supports the idea that the SARB behaves like its counterparts in other countries in following the Brainard (1967) conservatism principle. In other words, when responding to inflation and output gap fluctuations, the SARB was found to be more cautious and altered interest rates by a lower margin when more uncertain about either variable.

Exchange rate uncertainty seems to have played a significant role only in the period prior to the advent of inflation targeting. The exchange rate entered significantly only with regard to the backward-looking period specification in the formal inflation targeting sub-sample, whereas it was found to be significant for all time period specifications in the prior sub-sample. Whether the SARB's actions reflected caution or aggression in this regard was thus difficult to establish, due to the results being volatile and dependent on period specification.

The main findings from the investigation in this chapter may be summarised as follows:

- Estimated rules including uncertainty performed better than models excluding uncertainty, suggesting that the degree of uncertainty contributes towards explaining the actions of the SARB over the sample period.

- The SARB's actions seem to be consistent when compared to the findings reported for industrialized nations in that the SARB's responses to inflation and output gap uncertainty reflect conservatism.

- Exchange rate uncertainty appears to have played a role only in the sub-sample period before the advent of inflation targeting. Whether the SARB's actions reflected caution or aggression in this regard was difficult to establish, mainly due to the results being volatile and dependent on period specification.

However, as mentioned above, this chapter considered only indirect-uncertainty effects. The aim of the next chapter is to include direct-uncertainty effects to provide a holistic understanding of the SARB's actions in the face of uncertainty.

Furthermore, the next chapter will also attempt to quantify the impact of uncertainty on the SARB's actual interest rate responses.

Chapter 8

Direct Uncertainty Effects and Uncertainty Impact Estimates

As a first step to establish whether the SARB reacted optimally in the presence of uncertainty, the previous chapter set out to solve the uncertainty-adjusted model derived in Chapter 4. The GARCH estimates from Chapter 6 were used as a proxy for uncertainty about inflation, output gap and the exchange rate.

To solve the uncertainty model, Chapter 7 considered various period specifications in conjunction with different uncertainty-related scenarios, ensuring the robustness of the results. The presence of a sample break around 1999 necessitated the sample being split into two smaller sub-samples corresponding to 1990 – 1999 and 2000 – 2011.

However, the theoretical model assumes that uncertainty influences monetary policy only indirectly through affecting interest rate responses to inflation, output gap and exchange rate fluctuations. In other words, uncertainty plays a role only when the central bank responds to fluctuations in target variables. Hence this model was labelled the indirect-uncertainty model.

The preliminary results in the previous chapter showed that the SARB responded less aggressively to inflation and output gap indirect uncertainty across both sample periods, suggesting that the SARB acts similarly to industrial country central bank counterparts in following the Brainard (1967) conservatism principle. In other words, when responding to inflation and output gap fluctuations, the SARB seemed to be more cautious and altered interest rates by a lower margin when more uncertain about the specific variable. Exchange rate uncertainty appeared to play a role only in the period prior to the advent of inflation targeting. This signals a different approach to exchange rate uncertainty during the inflation targeting regime compared to the preceding regime and might be a consequence of the fact that the exchange rate wasn't an explicit target during the inflation targeting regime. Whether the SARB's actions during the first regime reflected caution or aggression in this regard was difficult to establish, mainly due to the results being volatile and dependent on period specification.

This chapter aims to build on these findings by considering whether direct uncertainty effects also played a role with regard to the SARB's decision-making. The first section briefly reviews the methodology used to add the direct effects to the model.

Thereafter, section 8.2 examines the results from the altered model. Section 8.3 considers the goodness of fit and whether the inclusion of direct uncertainty regressors improved the model.

Section 8.4 attempts to quantify the effect of uncertainty on the interest rate. Finally, section 8.5 investigates whether the SARB acted more conservatively or more aggressively. The final section concludes by summarising the main findings.

8.1 Methodology

To review, the uncertainty-adjusted model derived in Chapter 4 assumed that the coefficients are dependent on the variances of the endogenous variables, namely inflation, the output gap and the exchange rate. The model allows us to investigate whether monetary policy is more aggressive or passive when uncertainty about the relevant exogenous variable increases.

However, the model assumes that uncertainty influences monetary policy only indirectly through affecting interest rate responses to inflation, output gap and exchange rate fluctuations.

It might also be prudent to investigate whether the central bank responded directly to inflation, output gap and exchange rate uncertainty; in other words, whether the central bank responded to uncertainty regarding a target variable irrespective of a response to fluctuations in that variable.

For clarity, the distinction from the previous chapter is revisited below:

- **Indirect uncertainty effects:** Uncertainty influences only the response to a fluctuation in the target variable. For example, the central bank raises the interest rate following an increase in expected inflation which is considered likely to be sustained and thus reflected in actual future inflation. However, the central bank raises the interest rate by a smaller margin due to uncertainty about the rate of inflation. In the absence of uncertainty, the central bank would still have changed the interest rate, but the magnitude of the change would have been different. For this reason, uncertainty enters the regression equation through the coefficient of the specific independent variable.

- **Direct uncertainty effects:** The effect of uncertainty regardless of responding to a fluctuation in the target variable. This case is distinctly different as the central bank is not responding to a fluctuation in a target variable. Rather, the central bank changes the policy instrument based solely on uncertainty about a particular target variable. For example, even if the inflation rate remained stable, the central bank raises the interest due to uncertainty about whether the status quo would be maintained going forward. In the absence of uncertainty, the central bank would not have changed the interest rate. For this reason, uncertainty enters the regression equation directly and captures the effect of a change in uncertainty about the target variable.

8.1.1. The model

This new model, adjusted by adding uncertainty directly to the equation, is labelled the direct-uncertainty model (also referred to at times as the combined model, as it includes both direct and indirect uncertainty regressors) and is represented as follows[23]:

$$i_t = \rho_1 + \rho_2 i_{t-1} + \rho_3 e_{t-1} + \rho_y^* \sigma_{yt}^2 + \rho_\pi^* \sigma_{\pi t}^2 + \rho_e^* \sigma_{et}^2 + \rho_{yt} y_t + \rho_{\pi t} \pi_t + \rho_{et} e_t + \mu_t$$

where $$\rho_{yt} = \rho_y + \rho_y^\pi \sigma_{\pi t}^2 + \rho_y^e \sigma_{et}^2 + \rho_y^y \sigma_{yt}^2$$

$$\rho_{\pi t} = \rho_\pi + \rho_\pi^\pi \sigma_{\pi t}^2 + \rho_\pi^e \sigma_{et}^2 + \rho_\pi^y \sigma_{yt}^2$$

$$\rho_{et} = \rho_e + \rho_e^\pi \sigma_{\pi t}^2 + \rho_e^e \sigma_{et}^2 + \rho_e^y \sigma_{yt}^2$$

and σ_y^2, σ_π^2, σ_e^2 are measures of output, inflation and exchange rate uncertainty respectively. The direct uncertainty coefficients are represented by ρ_y^*, ρ_π^* and ρ_e^*.

8.1.2. Time period specifications

Again, due to the fact that there has yet to emerge clear consensus in the literature regarding the optimal rule in characterising the behaviour of the South African Reserve Bank, different time period specifications were estimated. These are:

[23]Note that this model still contains indirect-uncertainty regressors.

Backward-Looking Rule

$$i_t = \rho_1 + \rho_2 i_{t-1} + \rho_3 e_{t-2} + \rho_y^* \sigma_{yt}^2 + \rho_\pi^* \sigma_{\pi t}^2 + \rho_e^* \sigma_{et}^2 + \rho_{yt} y_{t-1} + \rho_{\pi t} \pi_{t-1} + \rho_{et} e_{t-1} + \mu_t$$

Present-Period Rule

$$i_t = \rho_1 + \rho_2 i_{t-1} + \rho_3 e_{t-1} + \rho_y^* \sigma_{yt}^2 + \rho_\pi^* \sigma_{\pi t}^2 + \rho_e^* \sigma_{et}^2 + \rho_{yt} y_t + \rho_{\pi t} \pi_t + \rho_{et} e_t + \mu_t$$

Hybrid Rule

$$i_t = \rho_1 + \rho_2 i_{t-1} + \rho_3 e_{t-1} + \rho_y^* \sigma_{yt}^2 + \rho_\pi^* \sigma_{\pi t}^2 + \rho_e^* \sigma_{et}^2 + \rho_{yt} E(y_{t+1}) + \rho_{\pi t} E(\pi_{t+1}) + \rho_{et} e_t + \mu_t$$

Forward-Looking Rule

$$i_t = \rho_1 + \rho_2 i_{t-1} + \rho_3 e_t + \rho_y^* \sigma_{yt}^2 + \rho_\pi^* \sigma_{\pi t}^2 + \rho_e^* \sigma_{et}^2 + \rho_{yt} E(y_{t+1}) + \rho_{\pi t} E(\pi_{t+1}) + \rho_{et} E(e_{t+1}) + \mu_t$$

As explained in Chapter 7, uncertainty is assumed to be a current-period phenomenon. In other words, in all cases outlined above, uncertainty was treated as being considered in the present time, rather than in the past or future.

8.1.3. Uncertainty scenarios

In contrast to the previous chapter, there is no need to consider a range of different uncertainty-related scenarios, as the intention of this chapter is to examine whether direct uncertainty affected the actions of the SARB. Thus, only one uncertainty scenario from Chapter 7 is considered here:

Uncertainty scenario: Inflation, Output Gap and Exchange Rate Uncertainty

$$\rho_{yt} = \rho_y + \rho_y^y \sigma_{yt}^2$$

$$\rho_{\pi t} = \rho_\pi + \rho_\pi^\pi \sigma_{\pi t}^2$$

$$\rho_{et} = \rho_e + \rho_e^e \sigma_{et}^2$$

Estimates were again obtained through Ordinary Least Squares (OLS). However, to control for the presence of heteroscedasiticity, Generalised Method of Moments (GMM) estimates were also obtained. Below follows a brief discussion of the results for each time period rule specification.

8.2 Direct-Uncertainty Model Estimation

This section considers the estimation results of the direct-uncertainty model described above. Due to the presence of sample breaks (see Chapter 7), the original sample was divided into two smaller samples corresponding to the time periods 1990 quarter 1 – 1999 quarter 4 and 2000 quarter 1 – 2011 quarter 3. Each of the different time period specifications is discussed in turn below:

8.2.1. Backward-looking model results

The results of the backward-looking specification are reported in Table 8.1 below. This specification performed comparatively well with regard to the first sub-sample period, seeing as all the coefficients entered significantly.

Also, the inflation coefficient suggests that the SARB was considerably more concerned with inflation fluctuations than with the other two structural variables.

However, the backward specification did not perform well for the second sub-sample, as a number of coefficients entered insignificantly.

With regard to the indirect uncertainty effects, the results again suggest caution in relation to inflation and output gap uncertainty. By contrast, the SARB seemed to be more aggressive towards exchange rate uncertainty in this setting for both sub-samples.

Surprisingly, the direct uncertainty coefficients entered significantly throughout. For direct inflation uncertainty, the results suggest that the SARB lowered the interest rate on average when more uncertain about the rate of inflation.

The contrast seems to hold true for direct exchange rate uncertainty while the results are mixed for direct output gap uncertainty.

$$i_t = \rho_1 + \rho_2 i_{t-1} + \rho_3 e_{t-2} + \rho_y^* \sigma_{yt}^2 + \rho_\pi^* \sigma_{\pi t}^2 + \rho_e^* \sigma_{et}^2 + \rho_{yt} y_{t-1} + \rho_{\pi t} \pi_{t-1} + \rho_{et} e_{t-1} + \mu_t$$

Backward-looking	**1990Q1 - 1999Q4**	**2000Q1 - 2011Q3**
Coefficient	**GMM**	**GMM**
ρ_1	0.32119 (0.0000)***	-0.11187 (0.0000)***
ρ_2	0.711622 (0.0000)***	0.670729 (0.0000)***
ρ_3	0.382704 (0.0004)***	-0.01694 (0.7129)
ρ_π	0.603943 (0.0000)***	-0.01876 (0.7998)
ρ_y	0.150073 (0.0630)*	0.08435 (0.0886)*
ρ_e	0.495776 (0.0000)***	-0.11875 (0.1891)
ρ_π^*	-0.01227 (0.0100)*	-0.01554 (0.0000)***
ρ_y^*	0.008243 (0.0001)***	-0.0061 (0.0000)***
ρ_e^*	0.042791 (0.0000)***	0.010872 (0.0000)***
ρ_π^π	-0.04905 (0.0001)***	-0.08183 (0.0000)***
ρ_y^y	-0.01099 (0.0020)***	-0.1599 (0.0003)***
ρ_e^e	0.076914 (0.0000)***	0.025647 (0.0000)***
Adj. R-Squared	0.935269	0.943229
Σe^2	0.006998	0.007977
J-Statistic Prob.	0.985214	0.98992
PP Prob.	0.0001	0.0017

Numbers in parentheses are the probability values of the standard errors. With regards to the GMM estimation, the instruments are a constant and five lags of the variables in the estimated rule. The J-statistic is a test of over-identifying moment conditions. PP refers to Phillips-Peron unit root tests. ***, **, * represent coefficient significance at 1%, 5% and 10% respectively.

Table 8.1: Combined effects backward-looking regression results: Split sample

Source: Author's calculations

8.2.2. Present-period model results

Similarly to the previous model, the present-period specification performed well for the first sub-sample. However, three coefficients entered insignificantly for the second-sub-sample.

$$i_t = \rho_1 + \rho_2 i_{t-1} + \rho_3 e_{t-1} + \rho_y^* \sigma_{yt}^2 + \rho_\pi^* \sigma_{\pi t}^2 + \rho_e^* \sigma_{et}^2 + \rho_{yt} y_t + \rho_{\pi t} \pi_t + \rho_{et} e_t + \mu_t$$

Present-period	**1990Q1 - 1999Q4**	**2000Q1 - 2011Q3**
Coefficient	**GMM**	**GMM**
ρ_1	0.58214 (0.0000)***	-0.04995 (0.0613)*
ρ_2	0.717218 (0.0000)***	0.704384 (0.0000)***
ρ_3	0.26191 (0.0031)***	-0.06317 (0.3859)
ρ_π	9.877642 (0.0000)***	2.417814 (0.0007)***
ρ_y	3.017859 (0.0000)***	1.988917 (0.0053)***
ρ_e	-14.6936 (0.0000)***	-0.42119 (0.3482)
ρ_π^*	0.02222 (0.0000)***	-0.00966 (0.0001)***
ρ_y^*	0.005785 (0.0001)***	-0.00414 (0.0000)***
ρ_e^*	0.040889 (0.0000)***	0.010006 (0.0000)***
ρ_π^π	1.081886 (0.0000)***	0.186405 (0.0103)**
ρ_y^y	0.335706 (0.0000)***	0.210736 (0.0081)***
ρ_e^e	-1.82633 (0.0000)***	-0.03074 (0.5876)
Adj. R-Squared	0.954623	0.947489
Σe^2	0.004906	0.007378
J-Statistic Prob.	0.982711	0.977317
PP Prob.	0.0000	0.0005

Numbers in parentheses are the probability values of the standard errors. With regards to the GMM estimation, the instruments are a constant and five lags of the variables in the estimated rule. The J-statistic is a test of over-identifying moment conditions. PP refers to Phillips-Peron unit root tests. ***, **, * represent coefficient significance at 1%, 5% and 10% respectively.

Table 8.2: Combined effects present-period regression results: Split sample

Source: Author's calculations

Also, it should be noted that the decision to treat uncertainty as a present-period phenomenon might have led to spurious results regarding the present-period specification, due to the high possibility of multicollinearity among the regressors.

This is evident when considering that some coefficients in the present-period specifications reported values above unity.

8.2.3. Hybrid model results

The results for the hybrid model are reported in Table 8.3 below. The hybrid model performed well across both sub-samples. A few coefficients were bordering on the 10% significance level.

The direct uncertainty coefficients remained significant throughout both sub-samples. The coefficients suggest that the SARB lowered interest rates on average when more uncertain about the rate of inflation and the output gap. However, the SARB raised interest rates in response to higher degrees of uncertainty with respect to the exchange rate.

With regard to indirect uncertainty, the inflation coefficient remained significant throughout. However, the output gap coefficient was significant only in the second sub-sample. Both situations suggest a more conservative approach when uncertainty increases. The exchange rate uncertainty coefficient was significant only in the first sub-sample. Surprisingly, this coefficient also suggested a more conservative approach.

$$i_t = \rho_1 + \rho_2 i_{t-1} + \rho_3 e_{t-1} + \rho_y^* \sigma_{yt}^2 + \rho_\pi^* \sigma_{\pi t}^2 + \rho_e^* \sigma_{et}^2 + \rho_{yt} E(y_{t+1}) + \rho_{\pi t} E(\pi_{t+1}) + \rho_{et} e_t + \mu_t$$

Hybrid	**1990Q1 - 1999Q4**	**2000Q1 - 2011Q3**
Coefficient	**GMM**	**GMM**
ρ_1	0.515518 (0.0000)***	-0.07284 (0.0002)***
ρ_2	0.725973 (0.0000)***	0.707398 (0.0000)***
ρ_3	0.33277 (0.0001)***	-0.07638 (0.1012)
ρ_π	0.281506 (0.0000)***	0.185598 (0.0006)***
ρ_y	-0.05918 (0.1059)	0.187357 (0.0001)***
ρ_e	-13.974 (0.0000)***	-0.59165 (0.0618)*
ρ_π^*	-0.010158 (0.0025)***	-0.0109 (0.0000)***
ρ_y^*	-0.004899 (0.0000)***	-0.00355 (0.0011)***
ρ_e^*	0.046363 (0.0000)***	0.007651 (0.0006)***
ρ_π^π	-0.06398 (0.0000)***	-0.06702 (0.0000)***
ρ_y^y	-0.01007 (0.1218)	-0.01481 (0.0006)***
ρ_e^e	-1.72598 (0.0000)***	-0.05818 (0.1442)
Adj. R-Squared	0.944218	0.947082
Σe^2	0.006031	0.007241
J-Statistic Prob.	0.98521	0.983808
PP Prob.	0.0000	0.0000

Numbers in parentheses are the probability values of the standard errors. With regards to the GMM estimation, the instruments are a constant and five lags of the variables in the estimated rule. The J-statistic is a test of over-identifying moment conditions. PP refers to Phillips-Peron unit root tests. ***, **, * represent coefficient significance at 1%, 5% and 10% respectively.

Table 8.3: Combined effects hybrid model regression results: Split sample

Source: Author's calculations

8.2.4. Forward-looking model results

The results for the forward-looking model are reported in Table 8.4 below. Once again, a few coefficients entered insignificantly.

$$i_t = \rho_1 + \rho_2 i_{t-1} + \rho_3 e_t + \rho_y^* \sigma_{yt}^2 + \rho_\pi^* \sigma_{\pi t}^2 + \rho_e^* \sigma_{et}^2 + \rho_{yt} E(y_{t+1}) + \rho_{\pi t} E(\pi_{t+1}) + \rho_{et} E(e_{t+1}) + \mu_t$$

Forward-looking	**1990Q1 - 1999Q4**	**2000Q1 - 2011Q3**
Coefficient	**GMM**	**GMM**
ρ_1	0.584611 (0.0000)***	-0.04263 (0.0426)**
ρ_2	0.703265 (0.0000)***	0.716685 (0.0000)***
ρ_3	-16.548 (0.0000)***	-0.56887 (0.1224)
ρ_π	0.348933 (0.0000)***	0.180742 (0.0012)***
ρ_y	-0.02935 (0.2123)	0.187492 (0.0000)***
ρ_e	0.017797 (0.7894)	0.141555 (0.0021)***
ρ_π^*	0.014988 (0.0001)***	-0.0088 (0.0000)***
ρ_y^*	0.005392 (0.0001)***	-0.00312 (0.0000)***
ρ_e^*	0.049083 (0.0000)***	0.008492 (0.0001)***
ρ_π^π	-0.05355 (0.0000)***	-0.06712 (0.0000)***
ρ_y^y	-0.00858 (0.0569)*	-0.01848 (0.0002)***
ρ_e^e	-2.07145 (0.0000)***	-0.03894 (0.3904)
Adj. R-Squared	0.938173	0.947327
Σe^2	0.006684	0.007208
J-Statistic Prob.	0.987047	0.984602
PP Prob.	0.0004	0.0000

Numbers in parentheses are the probability values of the standard errors. With regards to the GMM estimation, the instruments are a constant and five lags of the variables in the estimated rule. The J-statistic is a test of over-identifying moment conditions. PP refers to Phillips-Peron unit root tests. ***, **, * represent coefficient significance at 1%, 5% and 10% respectively.

Table 8.4: Combined effects forward-looking regression results: Split sample
Source: Author's calculations

However, with the exception of the indirect exchange rate uncertainty coefficient in the second sub-sample, all the uncertainty-related coefficients remained significant. The indirect effects suggest conservatism throughout while the direct uncertainty results are more volatile and time-period specific.

8.3 Goodness-of-Fit

Although the analysis above proved insightful insofar as it provided a detailed examination of each of the respective models, drawing general conclusions is tedious due to the large number of parameters estimated. For this reason, it might be beneficial to firstly summarise the general findings from above and subsequently identify the models with the best fit. To this end, the findings reported above are summarised by considering each variable in turn (see the combined results table in Appendix F).

8.3.1. Findings summary

Considering only the R-squared statistics, it would seem as if the present-period specification performed best across both sub-samples. However, it should be noted that the decision to treat uncertainty as a present-period phenomenon might have led to spurious results regarding the present-period specification, due to the high possibility of multicollinearity among the regressors when simultaneously included in the present period. This is evident when considering that some coefficients in the present-period specifications reported values above unity. This was also evident in certain other specifications, but these occurrences were more ad hoc. Thus, in analysing the results, the present-period specification findings were ignored when in obvious contrast to all other models.

Once again, the interest rate smoothing coefficient proved extremely robust and remained significant throughout both sub-sample periods. However, the size of the coefficient declined noticeably on average, particularly with regard to the first sub-sample, possibly hinting at neglected uncertainty effects being absorbed into smoothing type behaviour in traditional models. This is plausible when considering the similarities in central bank behaviour when smoothing interest rates and acting cautiously in response to uncertainty. A central bank smoothing interest rates would adjust the instrument gradually towards the desired level whilst a cautionary central bank would respond less aggressively when more uncertain.

The exchange rate variables entered mostly significantly in the first sub-sample, whereas only the present-period and forward-looking coefficients were significant in the hybrid and forward-looking specifications respectively. The inflation coefficient entered significantly, with the exception of the backward-looking specification in the second sub-sample. The output gap variable also remained significant in most instances, except for the hybrid and forward-looking specifications in the first sub-sample.

Considering indirect-uncertainty effects, the inflation and output gap coefficients were significant across samples and specifications, the only exception being the output gap indirect uncertainty coefficient in the hybrid specification of the first sub-sample, which entered slightly insignificantly. Interestingly, the exchange rate indirect uncertainty coefficient was significant for all specifications in the first sample, but for the most part entered insignificantly for the second sample. Excluding the present-period specification, the indirect inflation and output gap uncertainty coefficients predict cautionary responses. In other words, when responding to inflation and output gap fluctuations, the SARB seemed to be more cautious and altered interest rates by a lower margin when more uncertain about the specific variable. The results for the exchange rate indirect uncertainty effects are more volatile and dependent on period specification, but seemingly lean towards caution in the first sub-sample and a more aggressive response in the second sub-sample.

The direct-uncertainty coefficients entered significantly in all instances. The direct inflation and output gap uncertainty effects seem to be dependent on the specification with regard to predicting lower or higher interest rates in the first sub-sample. However, in the second sub-sample, it seems that the SARB lowered interest rates when more uncertain about inflation or the output gap, irrespective of a response to fluctuations. By contrast, it would seem that when the central bank was more uncertain about the exchange rate, interest rates were pushed higher on average.

8.3.2. Best fit models

A first step to identify the model with the best fit amongst the different time period specifications involves graphing the fitted interest rate against the actual interest rate. This allows for visual examination of which time period specification most accurately approximated actual interest rates.

Figure 8.1 graphs not only the fitted values obtained from the direct-uncertainty model above, but also includes the fitted values obtained from the base model excluding uncertainty (Model A from Chapter 7). This allows for simultaneously investigating which model performed best in each case: the uncertainty model or the base model excluding uncertainty effects.

Figure 8.1: Actual vs fitted interest rates: 1992 – 1999

Source: Author's calculations

Figure 8.1 suggests that both the base and uncertainty models seem to approximate actual interest rates accurately in general in relation to the first sub-sample. However, closer examination suggests that the uncertainty model proved a better fit regardless of time period specification. Furthermore, when comparing the different time period specifications, the present-period uncertainty specification appears to be the model with the best fit.

Figure 8.2: Actual vs fitted interest rates: 2000 - 2011

Source: Author's calculations

The results from Figure 8.2 again suggest that both models (base and uncertainty models) perform well in approximating actual interest rates. Also immediately apparent, is the fact that the uncertainty and base models seem to perform even better in the second sub-sample and both models exhibit less volatility around the actual interest rate trend. This characteristic complicates the task of identifying which model or time period specification performed best. For this reason, attention is turned to the adjusted R-squared statistics from the different models and specifications.

Figure 8.3 below reports the adjusted R-squared statistics for the different time period specifications in relation to the uncertainty model only, to establish which time period specification performed best. From the figure it is clear that the present-period specification performed best across both sub-samples. However, as noted above, the present-period specification suffered from severe multicollinearity which could have led to spurious results.

Figure 8.3: Combined uncertainty adjusted R-squared statistics: Split sample
Source: Author's calculations

Ignoring the present-period specification, the hybrid model performed best in relation to the first sub-sample (1990 – 1999) while the forward-looking model performed best in relation to the second sub-sample (2000 – 2011).

Additionally, it is important to confirm whether the inclusion of the direct uncertainty regressors improved the explanatory power of the uncertainty model in general.

Thus, in other words, did the direct uncertainty regressors improve the explanatory power of the indirect-uncertainty model outlined in Chapter 6? Figure 8.4 below compares the R-squared statistics of the indirect-uncertainty model derived in Chapter 6 with the model from this chapter which includes both indirect and direct uncertainty effects.

Figure 8.4: Combined uncertainty adjusted R-squared statistics: 1990 - 1999

Source: Author's calculations

Figure 8.4 suggests that the inclusion of the direct uncertainty effects improved the explanatory power of the model in all cases for the first sub-sample. Figure 8.5 below considers the situation for the second sub-sample:

Figure 8.5: Combined uncertainty adjusted R-squared statistics: 2000 - 2011

Source: Author's calculations

Again, Figure 8.5 suggests that the inclusion of the direct uncertainty effects improved the explanatory power of the model in all cases for the second sub-sample.

8.4 Uncertainty Impact Estimates

As suggested by Martin and Milas (2005), it is possible to gauge the impact of uncertainty on the interest rate through investigating the difference between the estimated model excluding uncertainty and the model including the uncertainty-related regressors. In other words, the model excluding uncertainty serves as an approximation of what the interest rate would have been had uncertainty not been taken into account. By contrast, the model including the uncertainty-related regressors serves as an approximation of the level of the interest rate assuming that uncertainty was indeed present and taken into account during the decision-making process. The difference then signifies the impact of uncertainty. Positive values therefore reflect that interest rates were pushed higher as a consequence of the uncertainty effect. The opposite holds for negative values.

For this purpose, the fitted values from the various regressions had to be re-engineered to arrive at values comparable to the original interest rate dataset. This process involved removing the time trend and the constant used to make the original prime interest rate variable stationary. The logarithm operator was also reversed.

Next, the difference was calculated between the fitted values of the baseline models, excluding uncertainty-related regressors, and the uncertainty models characterised by the inclusion of both direct and indirect uncertainty effects. This exercise was repeated for all the different period specifications across the two sub-samples.

The results are examined below.

8.4.1. First sub-sample: 1992 - 1999

Figure 8.6 below graphs the impact of uncertainty for the first sub-sample period, measured as the difference between the uncertainty and base models. First, it is evident that the individual impact point estimates vary considerably over time. However, the hybrid and forward-looking specifications showed very similar point estimates. This is due to the theoretical similarities between the two specifications, as they merely differ with regard to the exchange rate period specification.

Figure 8.6: Difference between uncertainty and base models: 1992 - 1999

Source: Author's calculations

However, a clear trend is evident from Figure 8.6, irrespective of the time period specification. This trend suggests that interest rates were on average pushed lower due to uncertainty up to the end of 1993. Nominal interest rates were also declining on average during this period. This reflects an uncertainty bias towards stimulating the economy during a time when GDP growth was especially poor due to trade and financial sanctions, political instability and poor economic policies aimed at reviving the economy but instead resulting in increased uncertainty and lower investment (Faulkner and Loewald, 2008) . During this time, South Africa was also struggling with chronic high inflation, and an already high interest rate proved mainly unsuccessful in curbing this trend. The central bank's uncertainty regarding the effectiveness of higher interest rates in addressing inflation and a bias towards stimulating growth could have been the main drivers behind the uncertainty impact during this period.

Thereafter, interest rates were pushed higher on average due to uncertainty up until the end of 1997. During this short interval, growth improved dramatically from levels experienced pre-1994. The central bank raised interest rates on average during this period. However, the uncertainty impact suggests that interest rates were raised more so than what would have been the case in the absence of uncertainty. This could be the result of the central bank leaning towards further reducing inflation.

A clear peak is evident in 1998, when uncertainty resulted in an interest rate significantly higher than what would have been the case in the absence of uncertainty. During this time the Asian crises was unfolding. Uncertainty might have prompted the central bank to raise interest rates more so to combat the effect of import inflation, seeing as the rand depreciated sharply during this period.

Table 8.5 provides more detail on the matter above. The average uncertainty effect over the sample period ranged from 0.55 to 0.74 (in absolute terms) depending on the time period specification. The maximum impact point estimate of 3.08 was reported by the forward-looking model while the minimum point estimate of -2.06 was reported by the present-period specification.

Statistic	*Backward*	*Present*	*Hybrid*	*Forward*
Average Effect	0.736871	0.593748	0.550586746	0.74086887
Total Effect	22.84301	18.40619	17.06818911	22.96693498
Maximum	2.785664	1.544183	2.246393148	3.085945664
Max Date	*1998Q3*	*1998Q3*	*1998Q3*	*1998Q3*
Minimum	-1.59842	-2.06875	-1.8361854	-1.88122394
Min Date	*1998Q4*	*1999Q1*	*1999Q1*	*1999Q1*

Table 8.5: Uncertainty effect statistics: 1992 – 1999

Source: Author’s calculations

As is also evident from Figure 8.6 above, the effects of uncertainty were especially prominent in the latter half of 1998 and the first half of 1999.

8.4.2. Second sub-sample: 2000 - 2011

Figure 8.7 below replicates the situation above for the second sub-sample. Immediately evident is the fact that the uncertainty impact estimates are more volatile but considerably smaller on average. Again, it is evident that the individual impact point estimates are volatile over time. The hybrid and forward-looking models seem to be most similar as was the case above.

Figure 8.7: Difference between uncertainty and base models: 2000 - 2011

Source: Author's calculations

Unlike the previous sample period, no clear trends are visible. In other words, there are no continuous periods where interest rates were pushed higher or lower as a result of uncertainty as with the previous sample. However, the effects seem more pronounced and volatile around 2002, shortly after the September 11 event in the United States. The other notable peaks and troughs are evident around 2008, during the advent of the global financial crisis. These peaks and troughs are in line with periods when the SARB experienced particularly high levels of uncertainty.

As explained in Chapter 6, the SARB expressed particular uncertainty about the exchange rate towards the end of 2001 which had a significant impact on the inflation forecast fan chart (SARB 2001). Towards the end of 2002 this uncertainty subsided slightly but remained significant[24]. The main risk probability scenario affecting the forecast at the time was the uncertainty associated with a volatile oil price due to rising tensions in Iraq. Unexpected changes in the exchange rate remained another contributing factor (SARB 2002).

In 2008 the SARB highlighted the turmoil in international financial markets as the main factor contributing to increased uncertainty. More specifically, the main upside risk to the fan chart pertained to exchange rate uncertainty while the main downside risk pertained to uncertainty about the oil price (SARB, 2008). Also, the SARB's fan chart published during 2009 reflected particular uncertainty with regards to the domestic growth outlook. More specifically, uncertainty about a deeper global slowdown and a considerable moderation in domestic growth induced a significant downward bias on the SARB's inflation forecast (SARB, 2009).

Table 8.6 confirms the observations from the figure above. The reported average uncertainty effect ranges from 0.21 to 0.31 (in absolute terms), dependent on the time period specification. This is considerably smaller than for the first sub-sample period, suggesting that uncertainty had a smaller impact under the inflation targeting regime.

Besides the average effects, it is also evident that maximum (1.01) and minimum (-0.94) impact estimates are smaller than with the previous sample, again

[24] This conclusion is reached through a crude analysis from the available fan chart graphs as no data is available in this regard.

suggesting that uncertainty played a smaller role under the inflation targeting regime.

Statistic	***Backward***	***Present***	***Hybrid***	***Forward***
Average Effect	0.31868	0.210635	0.219756	0.247187
Total Effect	14.65927	9.68921	10.10878	11.37059
Maximum	1.014197	0.564083	0.656357	0.536044
Max Date	2002Q3	2004Q2	2008Q3	2002Q4
Minimum	-0.94795	-0.47088	-0.60931	-0.85672
Min Date	2003Q4	2001Q4	2002Q2	2002Q2

Table 8.6: Difference between Uncertainty and Base Models: 2000 - 2011

Source: Author's calculations

The fact that uncertainty had a smaller impact during the inflation targeting regime is noteworthy. However, the question of whether this is due to the nature of the inflation targeting regime or whether it simply represents a spurious relationship remains. In other words, is this finding due to coincidence, correlation or causality?

A first step to address this question is to examine whether there exists evidence of causality between uncertainty and interest rate changes over the entire sample period as well as for each of the sub-samples respectively. The Granger Causality test is a common technique used for this purpose and examines whether one time series is useful in determining another[25].

Sample	Lags	Null Hypothesis:	F-Statistic	Prob.
1992Q1 2010Q3	2	UNCERTAINTY does not Granger Cause D(INTEREST)	2.5936	0.0819
		D(INTEREST) does not Granger Cause UNCERTAINTY	0.1349	0.8740
1992Q1 1999Q4	1	UNCERTAINTY does not Granger Cause D(INTEREST)	2.6707	0.1130
		D(INTEREST) does not Granger Cause UNCERTAINTY	0.8114	0.3751
2000Q1 2010Q3	4	UNCERTAINTY does not Granger Cause D(INTEREST)	2.3725	0.0717
		D(INTEREST) does not Granger Cause UNCERTAINTY	1.4126	0.2508

Table 8.7: Granger Causality Tests

Source: Author's calculations

Table 8.7 above reports the results from the Granger Causality tests. The results suggest that Granger causality is one-way from uncertainty to interest rate changes. This is evident as the null hypothesis that uncertainty does not Granger Cause interest rate changes can be rejected at the 15% significance level for all cases. The results provide strong evidence that the relationship between uncertainty and interest rate changes isn't merely due to coincidence or correlation.

A second step is to investigate whether this finding is consistent with the behaviour of the central bank during this time. As explained in chapter 4, the inflation targeting framework entailed a commitment to inflation as the primary

[25] For more information on the Granger Causality test, see Granger (1969).

monetary policy objective. The fact that the central bank has a single and clear primary objective might have contributed to lowering the impact of uncertainty. A central bank with multiple equally important objectives would assign the same weight to the associated uncertainty around each of these objectives when making policy decisions. In contrast, a central bank with a single primary objective would assign smaller uncertainty weights to secondary goals.

Another characteristic associated with inflation targeting is improved transparency. Communicating all the relevant risks and uncertainties with the public could assist with influencing market expectations and subsequently actual behaviour in the face of uncertainty, in so doing reducing the need for the central bank to take more drastic actions.

Finally, the adoption of the inflation targeting framework also coincided with a more formal approach to dealing with and communicating uncertainty. This technique is the so-called fan chart methodology. This approach signals that the central bank formally recognised the uncertainties present at the time and took these into account when making policy decisions.

This might have resulted in uncertainty estimates not being overestimated, unclear or exaggerated. However, formal empirical tests are necessary before a final conclusion in this case. Without published data from the SARB this is not possible.

8.5 Aggression or Conservatism

The previous section considered how interest rates differed due to uncertainty compared to the case where uncertainty was not taken into account. However, the analysis from the previous section does not allow for scrutinizing whether the SARB acted more aggressively or conservatively due to uncertainty. The reason for this is that the previous section considered cumulative effects. To establish whether the SARB acted conservatively or aggressively, we need to consider whether the change in the interest rate from one quarter to the next differed when uncertainty was taken into account. To make this distinction clear, it is useful to refer to Figure 8.8 below.

The previous section examined the impact of uncertainty at any given point in time, defined as the difference between the fitted base and uncertainty interest rates. For example, consider the backward-looking specification from 1992Q2 to 1993Q2. During this period, the base interest rate (no uncertainty) is continuously higher than the fitted interest rate, assuming that uncertainty was present. This suggests that interest rates were lower due to uncertainty over this period.

However, it is impossible to draw any conclusion with regard to whether the SARB acted conservatively or aggressively. To make this clear, consider the quarter from 1992Q2 to 1992Q3. In this quarter, both the base and uncertainty interest rates decreased. However, the uncertainty interest rate decreased comparatively less. In other words, even though the uncertainty interest rate remained below the base interest rate, it decreased by a smaller margin. This situation would reflect conservative behaviour.

In other words, wherever the fitted uncertainty interest rate line moves closer to the fitted base interest rate line reflects conservative behaviour. This is because uncertainty resulted in the SARB reducing or increasing the interest rate by a smaller margin than what would have been the case if uncertainty had not been taken into account. The converse would suggest aggression.

Figure 8.8: Fitted base and uncertainty interest rates: 1990-1999

Source: Author’s calculations

The same principle applies to Figure 8.9 below, which considers the second sub-sample from 2000Q1 to 2011Q3:

Figure 8.9: Fitted base and uncertainty interest rates: 2000-2011

Source: Author's calculations

However, analysing the figures above to establish conservatism or aggression is tedious. Rather, to formalise the analysis, we need to turn to the data in this regard. Firstly, the difference from one quarter to the next was calculated for the fitted base interest rate as well as for the fitted uncertainty interest rate. The difference between these values would thus indicate conservatism or aggression. The only exception would be when the two interest rate time series did not move in the same direction for a specific quarter. These cases were assumed to reflect conservatism. For example, the fitted base rate might increase from one quarter to the next, whereas the fitted uncertainty rate might decrease. This thesis argues that this reflects conservatism, as uncertainty prompted the central bank not to chase its target more aggressively, but rather to act distinctly differently from what would have been the case in the absence of uncertainty.

The following hypothetical depiction aims to further explain the methodology described above. The figure below considers a once-off quarterly change in the nominal interest rate:

Figure 8.10: Methodology to establish conservatism or aggression

Source: Author

Applying this methodology to the first sub-sample period resulted in Figure 8.11 below, where negative values reflect conservatism and positive values reflect aggression. The results suggest that the SARB’s behaviour was volatile from one quarter to the next in this regard. However, it is clear that the SARB was conservative more often than aggressive.

Figure 8.11: SARB behaviour due to uncertainty: 1990 - 1999

Source: Author

Table 8.8 below is more informative in this regard. Regardless of the time period specification, the SARB was conservative on more occasions than aggressive. Also, the average effect also suggests conservatism.

	Backward-looking	Present Period	Hybrid model	Forward-looking
Aggressive Acts	9	7	9	9
Conservative Acts	21	23	21	21
Average Effect	-0.46077	-0.54807	-0.36818	-0.69003

Table 8.8: SARB behaviour due to uncertainty: 1990 - 1999

Source: Author

Figure 8.12 replicates the situation above for the second sub-sample period. Immediately apparent is that the effect of uncertainty is considerably smaller on average. Also, the number of times the SARB was more conservative or aggressive is considerably closer than for the previous sample.

Figure 8.12: SARB behaviour due to uncertainty: 2000 - 2011

Source: Author

Table 8.9 below once again suggests that, with the exception of the hybrid model, the SARB was conservative on more occasions than aggressive. Also, the average effect also suggests conservatism in all time period cases.

	Backward-looking	Present Period	Hybrid model	Forward-looking
Aggressive Acts	17	17	25	21
Conservative Acts	28	28	20	24
Average Effect	-0.13601	-0.05449	-0.05203	-0.06852

Table 8.9: SARB behaviour due to uncertainty: 2000-2011

Source: Author

8.6 Concluding Remarks

The theoretical model used in the previous chapter assumes that uncertainty only influences monetary policy indirectly through affecting interest rate responses to inflation, output gap and exchange rate fluctuations. In other words, uncertainty plays a role only when the central bank responds to fluctuations in target variables. This chapter aimed to build on these findings by considering whether direct uncertainty effects also played a role with regard to the SARB's decision-making. The model from Chapter 7 was altered by adding direct uncertainty regressors. Besides this change, the same methodology as in the previous chapter was employed to solve the model.

The direct uncertainty effects proved significant in all instances, suggesting that the SARB responded to uncertainty about target variables irrespective of responding to fluctuations in those variables. The direct inflation and output gap uncertainty effects uniformly predict that the SARB lowered interest rates on average when more uncertain about inflation or the output gap during the inflation targeting regime. The results in this regard were inconclusive for the period prior to the advent of inflation targeting. By contrast, for both sample periods, it would seem that when the central bank was more uncertain about the exchange rate, interest rates were pushed higher on average.

The next step involved examining how well the combined uncertainty model approximates actual interest rates. This was achieved by graphing the fitted interest rates against the actual interest rates. Considering not only the uncertainty model, but the base model as well, suggested that both models provided fairly accurate approximations of the actual interest rate. However, graphical examination suggested that the combined uncertainty model proved a better fit. This finding was substantiated when investigating the adjusted R-squared statistics, suggesting that the addition of the direct uncertainty regressors improved the explanatory power of the model. Also, ignoring the present-period specification due to the high level of multicollinearity present within the model, the hybrid model performed best in relation to the first sub-sample (1990 – 1999) whilst the forward-looking model performed best in relation to the second sub-sample (2000 – 2011).

The next step involved estimating the impact of uncertainty. As suggested by Martin and Milas (2005), it is possible to gauge the impact of uncertainty on the interest rate through investigating the difference between the estimated model excluding uncertainty and the model including the uncertainty-related regressors. For this purpose, the fitted values from the various regressions had to be re-engineered to arrive at values comparable to the original interest rate dataset. This process involved removing the time trend and the constant used to make the original prime interest rate variable stationary. The logarithm operator was also reversed. The difference was calculated between the fitted values of the baseline models, excluding uncertainty-related regressors, and the uncertainty models characterised by the inclusion of both direct and indirect uncertainty effects. This exercise was repeated for all the different period specifications across the two sub-samples.

With regard to the first sub-sample (1992 – 1999), a clear trend was evident irrespective of the time period specification. This trend suggests that interest rates were on average pushed lower due to uncertainty up to around 1994. Thereafter, interest rates were pushed higher on average due to uncertainty up until the end of 1997. Thereafter, with the exception of a clear peak in Quarter 3 of 1998, interest rates were again pushed lower on average as a result of uncertainty. The average uncertainty effect over the sample period ranged from 0.55 to 0.74 depending on the time period specification. The maximum impact point estimate of 3.08 was reported by the forward-looking model whilst the minimum point estimate of -2.06 was reported by the present-period specification.

The results from the second sub-sample (2000 – 2011) suggested that although the individual point estimates were more volatile, the average effect was considerably smaller. The reported average uncertainty effect ranged from 0.21 to 0.31, dependent on the time period specification. This is considerably smaller than for the first sub-sample period, suggesting that uncertainty had a smaller impact under the inflation targeting regime. Besides the average effects, it was also evident that the maximum (1.01) and minimum (-0.94) impact estimates were also smaller than with the previous sample, again suggesting that uncertainty played a smaller role under the inflation targeting regime.

The final step involved investigating whether the SARB was more conservative or aggressive when the direct uncertainty effects were included. The results suggested that regardless of the sub-sample or time period specification, the SARB was conservative on more occasions compared to being aggressive. The only exception to this was the hybrid model specification for the second sub-sample. However, here it is important to note that the forward looking model proved the best fit. Also, the average effect across both sub-sample periods also suggested conservatism.

In conclusion, the main findings from this chapter are summarised as follows:

- The inclusion of direct uncertainty regressors improved the fit of the uncertainty model.

- The results suggest that the SARB responded to uncertainty directly, irrespective of incorporating uncertainty through the response to target variable fluctuations. The SARB lowered interest rates on average when more uncertain about inflation or the output gap during the inflation targeting regime, thus preferring to stimulate the economy. By contrast, the SARB raised interest rates on average when more uncertain about the exchange rate. (For the first sub-sample, the direct uncertainty effects seem to be dependent on the model specification with regard to predicting lower or higher interest rates.)

- The average uncertainty effect from 1992 to 1999 ranged from 0.55 to 0.74 depending on the time period specification. The effects of uncertainty were especially prominent in the latter half of 1998 and the first half of 1999, shortly before the advent of the formal inflation targeting regime. The reported average uncertainty effect ranged from 0.21 to 0.31 for the period from 2000 to 2011.

- The results suggested that regardless of the sub-sample or time period specification, the SARB was conservative on more occasions compared to being aggressive. Also, the average effect across both sub-sample periods also suggested conservatism.

- The results suggest that the implementation of a formal inflation targeting regime changed the SARB's behaviour with regard to responses to uncertainty in that uncertainty had a smaller average impact and effect over the period corresponding to the inflation targeting regime.

The fact that uncertainty had a smaller impact during the inflation targeting regime is noteworthy. However, the question of whether this was due to the nature of the inflation targeting regime or whether it simply represented a spurious relationship remained. Results from Granger causality tests provide strong evidence that the relationship between uncertainty and interest rate changes was not merely due to coincidence or correlation, irrespective of the time period. Furthermore, the inflation targeting framework entailed a commitment to inflation as the primary monetary policy objective. The fact that the central bank has a single and clear primary objective might have contributed to lowering the impact of uncertainty. A central bank with a single primary objective would assign smaller uncertainty weights to secondary goals.

Another characteristic associated with inflation targeting is the improved transparency. Communicating all the relevant risks and uncertainties with the public could assist with influencing market expectations and subsequently actual behaviour in the face of uncertainty, in so doing reducing the need for the central bank to take more drastic actions.

Finally, the adoption of the inflation targeting framework also coincided with a more formal approach to dealing with and communicating uncertainty. This technique is the so-called fan chart methodology. This might have resulted in uncertainty estimates not being overestimated, unclear or exaggerated. However, formal empirical tests are necessary before a final conclusion in this case. Without published data from the SARB this is not possible.

Chapter 9

Conclusion

In recent years a consensus has emerged that price and output stability are the fundamental goals of any monetary policy regime. Even more recently however, central bank focus on financial stability as a secondary monetary policy objective has gained credence mainly due to the effects of the financial recession which started in 2008[26]. To attain these goals, monetary authorities use policy instruments to drive the economy towards a desired state. However, prior to any policy decisions being made, the monetary authorities need to understand the state of the economy. To determine both the current state as well as the effects of various interventions, policymakers use different kinds of econometric models and estimation techniques.

Even though advances in economic theory and modelling have in some cases furthered our understanding of how the economy works, the system as a whole

[26] Financial stability was not considered as a monetary policy objective during the empirical investigation in this thesis. The reason for this is that financial stability as a monetary policy goal only really gained popularity after 2008. Hence, the sample would have been too small to derive any meaningful results.

has become more complex. If policymakers had perfect knowledge about the actual state of the economy, the various transmission mechanisms as well as the true underlying model, monetary intervention would be greatly simplified. However, in reality the monetary authorities have to contend with considerable uncertainty in relation to the above-mentioned factors.

Notwithstanding the influential work of Brainard (1967), uncertainty has mostly been neglected in both the theoretical and empirical literature focusing on monetary policy analysis. Recent years have witnessed a change in this trend as a number of academics and practitioners have acknowledged the effects of uncertainty in modelling and policy analysis.

Significant progress has been made in theoretical models of uncertainty and the impact thereof within the monetary policy landscape (Estrella and Mishkin 1998, Svensson 1997, Sack 1998a, Soderstrom 1999, Wieland 2002and Moessner 2005). The theoretical literature primarily focuses on what constitutes optimal central bank behaviour when faced with different types and degrees of uncertainty.

However, much less work has been done on the empirical counterpart to this topic. Moreover, the empirical literature is primarily concerned with a handful of industrial country investigations (Martin and Salmon 1999, Martin and Milas 2005, Shuetrim and Thompson 1999 and Chung 2005). The literature has largely ignored the effects of uncertainty on monetary policy in developing countries.

This thesis contributes to the empirical literature by studying the effects of uncertainty on monetary policy in the developing country case of South Africa. In simplest terms, the thesis sought to establish whether or not the South African Reserve Bank (SARB) has responded optimally to uncertainty as suggested by theoretical models thereof. Answers were thus sought to the following questions:

- Does the evidence suggest that the SARB took uncertainty into account when designing policy?
- If so, did the SARB's actions reflect optimal behaviour as proposed by theory?
- If the results are mixed in relation to the question above, what specifically may have led to this outcome?

However, before attempting to answer these questions it was necessary to obtain a clear understanding of the concept of uncertainty.

9.1 Defining Uncertainty

The three main sources of uncertainty pertaining specifically to monetary policy are data, model and parameter uncertainty. Here, uncertainty is defined to be distinctly different from the phenomenon of risk in the sense that the probabilities of the different outcomes cannot be measured accurately.

Data uncertainty refers to the presence of imperfect data. This is brought about by mistakes made in data capturing and measurement. Although the former can in principle be avoided, measurement errors are far more common and difficult to quantify. Measurement inefficiencies refer to the difficulty in obtaining all the relevant information to measure a specific economic variable. To compensate for this lack of information, various estimates are used. Additionally, theory often relies on abstract variables which are not observable. These "unobservable" variables are thus approximated by estimates of observable variables.

Model uncertainty refers to imperfect knowledge about the true economic model. In other words, there may be considerable uncertainty about which variables are exogenous and how they influence the endogenous variables included in the model. Although theory provides a guide as to how specific economic variables influence others, the situation in practice is more complex as, for example, when two or more variables have feedback effects on each other.

Distinct from data and model uncertainty is parameter uncertainty. This is determined by the inaccuracy of the parameters within the models being used. When constructing models aiming to approximate the economic environment, parameters serve as estimates of the relationship between different variables within the model. As mentioned earlier, even though practitioners have sophisticated statistical techniques at their disposal to estimate the model parameters, there is still significant uncertainty regarding their accuracy.

Although very specific and distinct, these narrowly defined sources of uncertainty are not mutually exclusive. Data uncertainty contributes directly towards both model and parameter uncertainty. Also, model uncertainty directly influences parameter uncertainty.

Moreover, a far more general type of uncertainty confronts policymakers on a continual basis. General uncertainty in this sense refers to imperfect knowledge about the actual past, current and future states of the economy. Although closely related to imperfect data, uncertainty about the state of the economy is more concerned with imperfect knowledge regarding the actions of economic agents and the ultimate effect thereof in the future. Thus, uncertainty about the state of the economy represents a summation of the three narrow definitions of uncertainty.

The next step involved investigating how optimal central banks act when confronted with significant uncertainty. Determining the theoretically optimal response to uncertainty was necessary before it could be established how such uncertainty influenced the actions of the SARB and whether or not those actions reflected optimal behaviour.

9.2 Optimal Behaviour in Theory

The theoretical review distinguished between parameter, model and data uncertainty. For parameter uncertainty, theory suggests a more conservative approach to policymaking when significant uncertainty is present (Brainard 1967, Estrella and Mishkin 1998, Svensson 1997 and Sack 1998a). However, certain exceptions apply which could cause the monetary authority to act more aggressively. The main exception to the conservatism principle proposed by Brainard (1967) originates in the presence of considerable inflation persistence (Soderstrom 1999, Kimuraand Kurozumi 2003 and Moessner 2005). If inflation persists, optimising central banks might have to respond more aggressively. However, even in these cases, there is evidence that optimal policy requires a balance between aggressive and conservative approaches, with the conservative side dominating in most instances (Wieland, 2002).

Next, the focus turned to the theoretical implications of model uncertainty. These investigations are typically very complex. Most of the findings are dependent on both the choice of methodology as well as the associated assumptions. This makes it difficult to draw any general conclusions from the literature. With regard to the methodologies used, most investigations use either a Bayesian approach or a “worst-case” method. The Bayesian approach typically aims to solve decision rules given a set of prior conditions related to the parameters in different models. Put differently, the approach aims to derive a “robust rule” which achieves the lowest average loss, derived from the loss or objective function, from all the different model classifications included in the study. By contrast, the “worst-case” approach aims to derive a rule which minimises the loss only in the worst-case model.

The findings from the literature are mostly inconclusive. Using a combination of the “worst-case” and “robust-control” methods, Cateau (2005) found that policy became more conservative in the face of increased uncertainty. By contrast, using the “robust-control” method, Onatski and Stock reported findings suggesting a more aggressive central bank response when confronted with increased uncertainty about the model.

Theories on data uncertainty emphasise that real time data are inherently less accurate than subsequently revised releases. This is mainly due to the great extent to which real time data are estimated, rather than directly measured. With subsequent data releases, a smaller component of the data is estimated, thus decreasing the uncertainty associated therewith. The findings suggest that central banks would act differently given access to the more accurate revised data at the time when the decisions were being taken (Ghysels, Swanson and Callan, 1999) and that monetary authorities are better off assuming that the difference in accuracy between recent and revised data is greater rather than smaller, and thus act more conservatively (Jääskelä and Yates, 2005).

To summarise, the conservative approach to uncertainty dominates most of the literature. In other words, the majority of theoretical findings suggest that central banks should act more conservatively and adjust policy interest rates less when faced with greater levels of uncertainty.

However, do central banks adhere to the conservatism principle in practice? In reality the dynamics of uncertainty and the central bank’s responses to the varying conditions of uncertainty may be very different in practice from what is suggested by theory.

9.3 Monetary Policy and Uncertainty in Practice

Compared to the theoretical work on this subject, relatively little empirical research has been done. Thus, the empirical review considered specific papers from the literature in some detail with specific focus on data, methodology and findings. The following articles were investigated:

- Martin and Salmon (1999)
- Martin and Milas (2005)
- Shuetrim and Thompson (1999)
- Chung (2005)

Martin and Salmon (1999) consider the relevance of uncertainty for monetary policy in the United Kingdom from 1980 to 1997. The authors try to establish whether the UK case provides empirical evidence to support the Brainard conservatism principle. Using a Vector-Autoregressive (VAR) approach, the results indicate that optimal interest rates assuming uncertainty tended to be smoother than optimal rules without uncertainty. Thus, the results support Brainard conservatism.

Martin and Milas (2005) followed a more generalised approach to investigating the effects of uncertainty on the Federal Reserve Bank in the United States. Their model includes a Taylor-type rule where the weights on inflation and the output gap are not constant but rather functions of inflation and output gap uncertainty respectively. Uncertainty is induced through the weights on inflation and the output gap and approximated by their variances derived through General

Autoregressive Conditional Heteroscedasiticity (GARCH) models of inflation and the output gap. Once again, the results suggest conservatism on the part of the Fed in responding to greater levels of uncertainty.

Shuetrim and Thompson (1999) studied the discretionary policy case of Australia. They used an economic model constructed by the Australian central bank and optimal rules are solved using a frequency-sampling technique. Surprisingly, the findings reflect that policymakers might be more aggressive when the degree of uncertainty is higher. Shuetrim and Thompson find that for shocks to output, import prices, inflation and labour costs, the responses taking account of parameter uncertainty are more aggressive. Only in the case of real exchange rate shocks did the central bank response reflect conservatism when taking uncertainty into account. The results, in contrast to Brainard conservatism, are explained as being a consequence of the persistence of shocks and the ineffectiveness of policy.

Finally, Chung (2005) investigates how changes in inflation and output uncertainty affect the Federal Reserve's interest rate response. Chung uses a generalised Auto Regressive Conditional Heteroscedasticity Structural Vector Auto Regression (GARCH-SVAR) approach to study the effects of uncertainty on the central bank's interest rate responses. The results reported by Chung are mixed. First, the results indicate that the Federal Reserve responded less aggressively when confronted by a positive shock in order to dampen the economic expansion. By contrast, the Federal Reserve acted more aggressively after a negative shock, thereby stimulating the economy to prevent a substantial downturn. Thus Chung's study suggests that the Fed is biased towards stimulating growth rather than containing inflation in the face of uncertainty.

Thus, although the empirical findings favour conservatism, there is some evidence to suggest that this is not always the case. The results suggest that central banks do not always act optimally when faced with uncertainty. Furthermore, the limited number of industrial country cases examined prevents any generalised view from emerging. If anything, the findings suggest that central bank behaviour differs across countries.

The remainder of this thesis was dedicated to contributing to the above literature through investigating the case of the SARB. In this sense, the thesis represents a first attempt at investigating the case of a developing country in an open economy setting. Ultimately, the aim was to establish whether there is sufficient evidence to support the notion that uncertainty played a role in the SARB's policy decisions and whether those actions reflect conservatism.

9.4 The Open Economy Uncertainty-Adjusted Model

The theoretical model resembles a structural rule-based approach. The optimal interest rate rule was derived given a set of structural equations obtained from Ball (1998). The base model rule suggests that the interest rate is changed in response to deviations in a lagged interest rate term, inflation, the output gap and current and lagged exchange rate variables.

$$i_t = \rho_1 + \rho_2 i_{t-1} + \rho_3 y_t + \rho_4 \pi_t + \rho_5 e_t + \rho_6 e_{t-1} + \mu_t$$

(Author's calculations)

where $\rho_1 = (1-\theta)\emptyset_1$

$\rho_2 = \theta$

$\rho_3 = (1-\theta)\emptyset_2$

$\rho_4 = (1-\theta)\emptyset_3$

$\rho_5 = (1-\theta)\emptyset_4$

$\rho_6 = (1-\theta)\emptyset_5$

However, the base model is unsuitable for an investigation into the effect of uncertainty on monetary policy, due to the implicit assumption that interest rate adjustments to inflation, output and exchange rate fluctuations are constant over time. This is due to the assumption that the parameter values are constant over time.

To address this problem in a closed economy setting, Martin and Milas (2005) defined the weights on inflation and the output gap as functions of uncertainty. Following a similar approach, the base model was altered to allow the coefficients in the open economy model to change over time.

To incorporate uncertainty, it is assumed that the coefficients are dependent on the variances of the endogenous variables, namely inflation, the output gap and the exchange rate. The uncertainty adjusted model allows us to investigate whether monetary policy is more or less aggressive when uncertainty about the relevant independent variable increases.

$$i_t = \rho_1 + \rho_2 i_{t-1} + \rho_3 e_{t-1} + \rho_{yt} y_t + \rho_{\pi t} \pi_t + \rho_{et} e_t + \mu_t$$

(Author's calculations)

where $\rho_{yt} = \rho_y + \rho_y^{\pi}\sigma_{\pi t}^2 + \rho_y^{e}\sigma_{et}^2 + \rho_y^{y}\sigma_{yt}^2$

$\rho_{\pi t} = \rho_\pi + \rho_\pi^{\pi}\sigma_{\pi t}^2 + \rho_\pi^{e}\sigma_{et}^2 + \rho_\pi^{y}\sigma_{yt}^2$

$\rho_{et} = \rho_e + \rho_e^{\pi}\sigma_{\pi t}^2 + \rho_e^{e}\sigma_{et}^2 + \rho_e^{y}\sigma_{yt}^2$

and σ_y^2, σ_π^2, σ_e^2 are measures of output, inflation and exchange rate uncertainty respectively.

However, prior to applying the derived model to the SARB case, it was necessary to empirically derive uncertainty estimates.

9.5 Approximating Uncertainty for the South African Economy

The next step towards achieving the thesis objective involved deriving estimates for uncertainty pertaining to the South African economy. This entailed obtaining estimates of inflation, output gap and exchange rate uncertainty.

Inflation, output gap and exchange rate uncertainty estimates were derived through GARCH model specifications related to the structural equations as defined in the theoretical model. The aim of estimating uncertainty through GARCH-type models is to capture the volatility of the remaining unexplained residuals after controlling for the explainable effects of the regressors. In this sense, GARCH models remove variations in the data which are explainable. Thus all that remains is the unexplainable portion which may be regarded as a proxy for uncertainty.

To derive each of the regressor variances, the structural equations were used as points of reference. In other words, the structural equations aim to approximate what monetary agents know about the dynamics of the economy. The residual variance series from the GARCH model would thus represent the uncertainty associated with each specific variable.

The resulting uncertainty estimates all seemed plausible. As expected, the results indicated that on average the inflation variable exhibits the least amount of uncertainty. Inflation seemed to be most uncertain between 1999 and 2003, during the period of the implementation of the inflation targeting monetary policy regime. Thereafter, inflation uncertainty decreased up to 2009. The subsequent increase thereafter corresponds to the effects of the global economic recession which effectively started spilling over to South Africa during the latter half of 2008.

Output gap uncertainty was high from 1992 to 1994, the period prior to the advent of democracy in 1994 during which South Africa experienced particularly slow growth (Faulkner and Loewald, 2008). Output gap uncertainty was again particularly high from 2009 to 2010, once again due to the shock of the economic recession on GDP growth.

Exchange rate uncertainty seems high on average compared to the other variables, with the peak corresponding to the drastic depreciation of the currency in 2001 following the events of September, 11 and the speculative attack on the rand in December of that year

What remained was to substitute the empirical uncertainty estimates into the uncertainty-adjusted model as defined in the theoretical model. Solving this model and obtaining the structural parameters would allow for investigating the SARB's preference towards either conservatism or aggression.

9.6 The Effects of Uncertainty on the SARB

The final step in the investigation was essentially focused on solving the derived theoretical model to ascertain whether the SARB took uncertainty into account and if so, whether the SARB's actions reflect optimal behaviour as stipulated by theory. The investigation considered the effects of both indirect and direct uncertainty. Both cases are described below:

9.6.1. Indirect uncertainty effects

The theoretical model assumed that uncertainty only influences monetary policy indirectly through affecting interest rate responses to inflation, output gap and exchange rate fluctuations. In other words, uncertainty plays a role only when the central bank responds to fluctuations in target variables. This model was thus referred to as the indirect uncertainty model. Indirect uncertainty effects are clarified below:

- **Indirect uncertainty effects:** The effect of uncertainty when responding to a fluctuation in a target variable. Thus, uncertainty influences only the response to a fluctuation in the target variable. For example, the central bank raises the interest rate following an increase in expected inflation which is considered likely to be sustained and thus reflected in actual future inflation. However, the central bank raises the interest rate by a smaller margin due to uncertainty about the rate of inflation. In the absence of uncertainty, the central bank would still have changed the interest rate, but the magnitude of the change would have been different. For this reason, uncertainty enters the regression equation through the coefficient of the specific independent variable.

To solve the indirect uncertainty model, various period specifications were considered in conjunction with differing uncertainty-related scenarios, ensuring the robustness of the results. It is also important to control for long and variable lags with regards to the monetary policy transmission mechanisms. This is partly addressed by the different period specifications highlighted above. Furthermore, lag structures were allowed to deviate from the theoretical specifications during the empirical exercise. The presence of a sample break around 1999 necessitated the sample being split into two smaller sub-samples corresponding to 1990 – 1999 and 2000 – 2011.

The results indicated that the SARB responded less aggressively to inflation and output gap indirect uncertainty across both sample periods, suggesting that it acts similarly to industrial country central bank counterparts in following the Brainard (1967) conservatism principle.

In other words, when responding to inflation and output gap fluctuations, the SARB seemed to be more cautious and altered interest rates by a lower margin when more uncertain about either of these variables.

However, exchange rate uncertainty seemed to play a role only in the period prior to the advent of inflation targeting, seeing as the variable entered significantly only with regard to the backward-looking specification in the period characterised by formal inflation targeting, compared to being significant throughout in the former sample. Whether the SARB's actions reflected caution or aggression in this regard was difficult to establish, mainly due to the results being volatile and dependent on period specification.

9.6.2. Direct uncertainty effects

Besides indirect uncertainty, the SARB's decision-making might also have been influenced by direct uncertainty effects. The original model was altered by adding direct uncertainty regressors. Direct uncertainty effects are clarified below:

- **Direct uncertainty effects:** The effect of uncertainty regardless of responding to a fluctuation in the target variable. This case is distinctly different as the central bank is not responding to a fluctuation in a target variable. Rather, the central bank changes the policy instrument based solely on uncertainty about a particular target variable. For example, even if the inflation rate is stable, the central bank raises the interest rate due to uncertainty about whether the status quo would be maintained going forward. In the absence of uncertainty, the central bank would not have changed the interest rate, all else held constant. For this reason, uncertainty enters the regression equation directly and captures the effect of a change in uncertainty about the target variable.

Surprisingly, the direct uncertainty effects proved significant in all instances, suggesting that the SARB responded to uncertainty about target variables irrespective of responding to fluctuations in those variables. The direct inflation and output gap uncertainty effects uniformly predict that the SARB lowered interest rates on average when more uncertain about inflation or the output gap during the inflation targeting regime. The results in this regard were inconclusive for the period prior to the advent of inflation targeting. By contrast, for both sample periods it would seem that when the SARB was more uncertain about the exchange rate, it generally responded more aggressively by pushing interest rates higher.

The next step involved examining how well the uncertainty model approximates actual interest rates. This was done by comparing the fitted interest rates against the actual interest rates. Both the base and uncertainty modified models provided fairly accurate predictions of the actual interest rate. However, the uncertainty model proved a better fit to the available data. This finding was substantiated when investigating the adjusted R-squared statistics, suggesting that the addition of the direct uncertainty regressors improved the explanatory power of the model.

The next step involved estimating the impact of uncertainty. As suggested by Martin and Milas (2005), it is possible to gauge the impact of uncertainty on central banks' interest rate responses by measuring the difference between the estimated model excluding uncertainty and the model including the uncertainty-related regressors. For this purpose, the fitted values from the various regressions had to be re-engineered to arrive at values comparable to the original interest rate dataset. This process involved removing the time trend and the constant used to make the original interest rate variable stationary. The logarithm operator was also reversed. The difference was calculated between the fitted values of the baseline models, excluding uncertainty-related regressors, and the uncertainty models characterised by the inclusion of both direct and indirect uncertainty effects. This exercise was repeated for all the different period specifications across the two sub-samples.

With regard to the first sub-sample (1992 – 1999), a clear trend was evident irrespective of the time period specification (the backward-looking, present-period, hybrid or forward-looking models). This trend suggests that interest rates were on average pushed lower due to uncertainty up to the end of 1993. Nominal interest rates were also declining on average during this period. This reflects an uncertainty bias towards stimulating the economy during a time when GDP growth was especially poor due to sanctions being imposed on South Africa. During this time, South Africa was also struggling with chronic high inflation, and an already high interest rate proved mainly unsuccessful in curbing this trend. The central bank's uncertainty regarding the effectiveness of higher interest rates in addressing inflation and a bias towards stimulating growth could have been the main drivers behind the uncertainty impact during this period.

Thereafter, interest rates were pushed higher on average due to uncertainty up until the end of 1997. During this short interval, growth improved dramatically from levels experienced pre-1994. The central bank raised interest rates on average during this period. However, the uncertainty impact suggests that interest rates were raised more than what would have been the case in the absence of uncertainty. This could be the result of the central leaning towards further reducing inflation.

A clear peak is evident in 1998, when uncertainty resulted in an interest rate significantly higher than what would have been the case in the absence of uncertainty. During this time the Asian crisis was unfolding. Uncertainty might have prompted the central bank to raise interest rates more to combat the effect of import inflation, seeing as the rand depreciated sharply during this period.

The average uncertainty effect over the sample period ranged from 0.55 to 0.74 (absolute terms) depending on the time period specification. The maximum impact point estimate of 3.08 was reported by the forward-looking model whilst the minimum point estimate of -2.06 was reported by the present-period specification.

The results from the second sub-sample (2000 – 2011) suggested that although the individual point estimates were more volatile, the average effect was considerably smaller. Unlike the previous sample period, no clear trends were visible. In other words, there were no continuous periods where interest rates were pushed higher or lower as a result of uncertainty as with the previous sample. However, the effects seem more pronounced and volatile around 2002, shortly after the September 11 event in the United States. The other notable peaks and troughs are evident around 2008, during the advent of the global financial crisis.

The reported average uncertainty effect ranged from 0.21 to 0.31 (absolute terms), dependent on the time period specification. This is considerably smaller than for the first sub-sample period, suggesting that uncertainty had a smaller impact under the inflation targeting regime. Besides the average effects, it was also evident that the maximum (1.01) and minimum (-0.94) impact estimates were also smaller than with the previous sample, again suggesting that uncertainty played a smaller role under the inflation targeting regime.

The final step involved investigating whether the SARB was more conservative or aggressive when the direct uncertainty effects were included. The results suggested that regardless of the sub-sample or time period specification, the SARB was conservative on more occasions compared to being aggressive. Also, the average effect across both sub-sample periods also suggested conservatism.

9.6.3. Main findings

The main findings from the thesis are categorically summarised below:

Uncertainty relevance:

- Estimated rules including uncertainty performed better than models excluding uncertainty, suggesting that uncertainty contributed towards explaining the actions of the SARB over the sample period. Firstly, the indirect uncertainty model performed better than the base model in all instances examined. The addition of direct uncertainty regressors improved the fit and explanatory power of the models even further. The direct uncertainty regressors entered significantly throughout, suggesting that the SARB responded to uncertainty directly, irrespective of responding to fluctuations in target variables.

Aggression or conservatism:

- In general, the results suggest that, regardless of the sub-sample or time period specification, the SARB was conservative on more occasions compared to being aggressive (the only exception being the hybrid model for the period from 2000 to 2011). Also, the average effect across both sub-sample periods also suggests conservatism.

- With regard to indirect effects, the SARB's actions seem to be consistent with the findings reported for industrialized nations seeing as its indirect responses to inflation and output gap uncertainty reflect conservatism. The SARB acted optimally by responding less aggressively to inflation and output fluctuations when faced with greater uncertainty about these variables. Indirect exchange rate uncertainty played a role only in the period prior to the advent of inflation targeting. Whether the SARB's actions reflected caution or aggression in this regard was difficult to establish, mainly due to the results being volatile and dependent on period specification.

- For direct uncertainty effects, it was not possible to determine aggression or conservatism for individual variables. Rather, the model merely allowed for examining whether interest rates were pushed lower or higher on average due to uncertainty about a specific independent variable. When responding to direct uncertainty effects, the SARB lowered interest rates on average when more uncertain about inflation or the output gap during the inflation targeting regime, thus preferring to stimulate the economy on average. However, the results for the pre-inflation targeting period were inconclusive in this regard. By contrast, the SARB raised interest rates on average when more uncertain about the exchange rate, regardless of the sample used. This might indicate a preference to defend currency stability with a bias to strengthening the rand on average to prevent the effects of import inflation.

Uncertainty impact:

- The average uncertainty impact from 1992 to 1999 ranged from 0.55 to 0.74 (in absolute terms) depending on the time period specification. In other words, the nominal interest rate was on average between 0.55 to 0.74 percentage points higher or lower due to the effect of uncertainty. Also, the effects of uncertainty were especially prominent in the latter half of 1998 and the first half of 1999, shortly before the advent of the formal inflation targeting regime.

- The reported average uncertainty effect ranged from 0.21 to 0.31 (in absolute terms) for the period from 2000 to 2011. In other words, the nominal interest rate was on average between 0.21 to 0.31 percentage points higher or lower due to the effect of uncertainty.

Sample periods and monetary policy regimes:

- The results suggest that the implementation of a formal inflation targeting regime changed the SARB's behaviour with regard to responses to uncertainty in that uncertainty had a smaller average effect in the period corresponding to the inflation targeting regime.

  The fact that uncertainty had a smaller impact during the inflation targeting regime is noteworthy. However, the question of whether this was due to the nature of the inflation targeting regime or whether it simply represented a spurious relationship remained. Results from Granger causality tests provide strong evidence that the relationship between uncertainty and interest rate changes was not merely due to coincidence or correlation, irrespective of the time period. Furthermore, the inflation targeting framework entailed a commitment to inflation as the primary monetary policy objective. The fact that the central bank has a single and clear primary objective might have contributed to lowering the impact of uncertainty. A central bank with a single primary objective would assign smaller uncertainty weights to secondary goals.

Another characteristic associated with inflation targeting is the improved transparency. Communicating all the relevant risks and uncertainties with the public could assist with influencing market expectations and subsequently actual behaviour in the face of uncertainty, in so doing reducing the need for the central bank to take more drastic actions.

Finally, the adoption of the inflation targeting framework also coincided with a more formal approach to dealing with and communicating uncertainty. This technique is the so-called fan chart methodology. This might have resulted in uncertainty estimates not being overestimated, unclear or exaggerated. However, formal empirical tests are necessary before a final conclusion in this case. Without published data from the SARB this is not possible.

- Exchange rate uncertainty appeared to play a role only in the period prior to the advent of inflation targeting. This signals a different approach to exchange rate uncertainty during the inflation targeting regime compared to the preceding regime and might be a consequence of the fact that the exchange rate wasn’t an explicit target during the inflation targeting regime.

Thus, the findings reported in this thesis provide strong evidence in support of the notion that uncertainty plays a significant role within the South African monetary policy landscape. Furthermore, the results suggest that the SARB did in fact act optimally in responding more conservatively to target variable fluctuations on average. Also, the findings could potentially strengthen the case for inflation targeting as a monetary policy regime, as the results indicate a marked decline in the effects of uncertainty under inflation targeting.

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Appendix A

Unit Root Tests

A.1 Inflation Stationarity Test

Null Hypothesis: INFLATION has a unit root
Exogenous: Constant

		t-Statistic	Prob.
Augmented Dickey-Fuller test statistic		-2.067297	0.2583
Test critical values:	1% level	-3.512290	
	5% level	-2.897223	
	10% level	-2.585861	

Augmented Dickey-Fuller Test Equation
Included observations: 82 after adjustments

Variable	Coefficient	Std. Error	t-Statistic	Prob.
INF_LATION(-1)	-0.093327	0.045144	-2.067297	0.0421
D(INF_LATION(-1))	0.221185	0.094445	2.341942	0.0218
D(INF_LATION(-2))	0.104192	0.097983	1.063367	0.2910
D(INF_LATION(-3))	0.042084	0.098684	0.426451	0.6710
D(INF_LATION(-4))	-0.497671	0.096394	-5.162896	0.0000
C	0.005604	0.003732	1.501519	0.1374
R-squared	0.400022	Durbin-Watson stat		1.807190

Table A1: Inflation-Augmented Dickey Fuller Stationarity Test

The inflation variable proved non-stationary when an intercept was included in the test equation and remained non-stationary when the case for a trend and intercept was considered. However, when both the trend and intercept were included, the test statistic improved, but not sufficiently. Thus, the null hypothesis of a unit root could not be rejected at a 5% significance level for all cases. Subsequently, the inflation variable was transformed through applying a Hodrick-Prescott filter and extracting the resultant residual series. The results are reported below.

Null Hypothesis: INFLATION has a unit root
Exogenous: None

		t-Statistic	Prob.
Augmented Dickey-Fuller test statistic		-2.813504	0.0054
Test critical values:	1% level	-2.593468	
	5% level	-1.944811	
	10% level	-1.614175	

Augmented Dickey-Fuller Test Equation
Included observations: 82 after adjustments

Variable	Coefficient	Std. Error	t-Statistic	Prob.
INF(-1)	-0.260425	0.092562	-2.813504	0.0062
D(INF(-1))	0.274576	0.097730	2.809553	0.0063
D(INF(-2))	0.171234	0.101375	1.689112	0.0952
D(INF(-3))	0.112658	0.102677	1.097200	0.2760
D(INF(-4))	-0.424510	0.103669	-4.094844	0.0001
R-squared	0.445654	Durbin-Watson stat		1.801341

Table A2: Inflation (Resids) - Augmented Dickey Fuller Stationarity Test

The null hypotheses of a unit root can be rejected at a 1% significance level.

A.2 Output Gap Stationarity Test

Null Hypothesis: OUTGAP has a unit root
Exogenous: Constant

		t-Statistic	Prob.
Augmented Dickey-Fuller test statistic		-4.356988	0.0007
Test critical values:	1% level	-3.512290	
	5% level	-2.897223	
	10% level	-2.585861	

Augmented Dickey-Fuller Test Equation
Included observations: 82 after adjustments

Variable	Coefficient	Std. Error	t-Statistic	Prob.
OUTGAP(-1)	-0.379117	0.087013	-4.356988	0.0000
D(OUTGAP(-1))	0.085948	0.100388	0.856153	0.3946
D(OUTGAP(-2))	0.006566	0.087640	0.074918	0.9405
D(OUTGAP(-3))	-0.094169	0.078187	-1.204408	0.2322
D(OUTGAP(-4))	0.752421	0.073349	10.25804	0.0000
C	-0.000260	0.001090	-0.238248	0.8123
R-squared	0.869741	Durbin-Watson stat		2.024005

Table A3: Output Gap-Augmented Dickey Fuller Stationarity Test

The null hypotheses of a unit root can be rejected at a 1% significance level.

A.3 Nominal Interest Rate Stationarity Test

Null Hypothesis: PRIME RATE has a unit root
Exogenous: Constant, Linear Trend

		t-Statistic	Prob.
Augmented Dickey-Fuller test statistic		-3.214919	0.0885
Test critical values:	1% level	-4.069631	
	5% level	-3.463547	
	10% level	-3.158207	

Augmented Dickey-Fuller Test Equation
Included observations: 85 after adjustments

Variable	Coefficient	Std. Error	t-Statistic	Prob.
PRIME_RATE(-1)	-0.119175	0.037069	-3.214919	0.0019
D(PRIME_RATE(-1))	0.551847	0.093752	5.886263	0.0000
C	0.158203	0.049741	3.180535	0.0021
@TREND(1990Q1)	-0.000448	0.000162	-2.761905	0.0071
R-squared	0.324968	Durbin-Watson stat		1.962344

Table A4: Nominal Interest Rate-Augmented Dickey Fuller Stationarity Test

The Prime Interest Rate variable was non-stationary for both cases when an intercept was included and excluded. Thus, the null hypotheses of a unit root could not be rejected at a 5% significance level for these cases. However, the ADF test statistic improved significantly when a linear trend and intercept were included in the test equation, thus indicating that the variable might be trend-stationary. The variable was transformed through a regression against a constant and a linear trend and subsequently extracting the residual series. The results are reported below.

Null Hypothesis: PRIME has a unit root
Exogenous: None

		t-Statistic	Prob.
Augmented Dickey-Fuller test statistic		-3.264491	0.0014
Test critical values:	1% level	-2.592452	
	5% level	-1.944666	
	10% level	-1.614261	

Augmented Dickey-Fuller Test Equation
Included observations: 85 after adjustments

Variable	Coefficient	Std. Error	t-Statistic	Prob.
PRIME(-1)	-0.119486	0.036602	-3.264491	0.0016
D(PRIME(-1))	0.553426	0.092350	5.992702	0.0000
R-squared	0.324592	Durbin-Watson stat		1.963689

Table A5: Nominal Interest Rate (Resids) - Augmented Dickey Fuller Stationarity Test

The null hypotheses of a unit root can be rejected at a 1% significance level.

A.4 Real Exchange Rate Stationarity Test

Null Hypothesis: REAL_EXCHANGE has a unit root
Exogenous: Constant

		t-Statistic	Prob.
Augmented Dickey-Fuller test statistic		-2.087136	0.2504
Test critical values:	1% level	-3.508326	
	5% level	-2.895512	
	10% level	-2.584952	

Augmented Dickey-Fuller Test Equation
Included observations: 86 after adjustments

Variable	Coefficient	Std. Error	t-Statistic	Prob.
REAL EXCHANGE(-1)	-0.094792	0.045417	-2.087136	0.0399
C	0.192630	0.092494	2.082629	0.0403
R-squared	0.049302	Durbin-Watson stat		1.820895

Table A6: Real Exchange Rate - Augmented Dickey Fuller Stationarity Test

The exchange rate variable proved to be non-stationary for all specifications of the test equation. Thus, the null hypotheses of a unit root could not be rejected at a 5% significance level for all cases. On closer examination, it became evident that the variable was stationary around a stochastic trend. To address the issue, the variable was transformed through subtracting a Hodrick-Prescott generated trend. The results are reported below.

Null Hypothesis: REER has a unit root
Exogenous: Constant

		t-Statistic	Prob.
Augmented Dickey-Fuller test statistic		-3.519954	0.0097
Test critical values:	1% level	-3.508326	
	5% level	-2.895512	
	10% level	-2.584952	

Augmented Dickey-Fuller Test Equation
Included observations: 86 after adjustments

Variable	Coefficient	Std. Error	t-Statistic	Prob.
REER(-1)	-0.256867	0.072975	-3.519954	0.0007
C	4.51E-05	0.002094	0.021537	0.9829
R-squared	0.128541	Durbin-Watson stat		1.769437

Table A7: Real Exchange Rate (Resid) - Augmented Dickey Fuller Stationarity Test

The null hypotheses of a unit root can be rejected at a 1% significance level.

A.5 Real Interest Rate Stationarity Test

Null Hypothesis: REAL_PRIME has a unit root
Exogenous: Constant

		t-Statistic	Prob.
Augmented Dickey-Fuller test statistic		-2.086326	0.2507
Test critical values:	1% level	-3.508326	
	5% level	-2.895512	
	10% level	-2.584952	

Augmented Dickey-Fuller Test Equation
Included observations: 86 after adjustments

Variable	Coefficient	Std. Error	t-Statistic	Prob.
REAL_PRIME(-1)	-0.112176	0.053767	-2.086326	0.0400
C	0.088568	0.044334	1.997733	0.0490
R-squared	0.049266	Durbin-Watson stat		1.921098

Table A8: Real Prime Interest Rate - Augmented Dickey Fuller Stationarity Test

The real interest rate variable proved to be non-stationary for all specifications of the test equation. Thus, the null hypotheses of a unit root could not be rejected at a 5% significance level for these cases. On closer examination, it became evident that the variable was stationary around a deterministic trend. The variable was transformed through a regression against a constant and a linear trend and subsequently extracting the residual series. The results are reported below.

Null Hypothesis: RPRIME has a unit root
Exogenous: None

		t-Statistic	Prob.
Augmented Dickey-Fuller test statistic		-2.381265	0.0175
Test critical values:	1% level	-2.592129	
	5% level	-1.944619	
	10% level	-1.614288	

Augmented Dickey-Fuller Test Equation
Included observations: 86 after adjustments

Variable	Coefficient	Std. Error	t-Statistic	Prob.
RPRIME(-1)	-0.129360	0.054324	-2.381265	0.0195
R-squared	0.062489	Durbin-Watson stat		1.915113

Table A9: Real Prime Interest Rate (Resid) - Augmented Dickey Fuller Stationarity Test

The null hypotheses of a unit root can be rejected at a 5% significance level.

A.6 Output Gap Uncertainty Stationarity Test

Null Hypothesis: LVAROUTGAP has a unit root
Exogenous: Constant

		t-Statistic	Prob.
Augmented Dickey-Fuller test statistic		-4.328428	0.0008
Test critical values:	1% level	-3.512290	
	5% level	-2.897223	
	10% level	-2.585861	

Augmented Dickey-Fuller Test Equation
Included observations: 82 after adjustments

Variable	Coefficient	Std. Error	t-Statistic	Prob.
LVAROUTGAP(-1)	-0.381986	0.088251	-4.328428	0.0000
C	-3.306254	0.766073	-4.315849	0.0000
R-squared	0.189753	Durbin-Watson stat		1.698788

Table A10: Output Gap Uncertainty - Augmented Dickey Fuller Stationarity Test

The null hypotheses of a unit root can be rejected at a 1% significance level.

A.7 Inflation Uncertainty Stationarity Test

Null Hypothesis: LVARINF has a unit root
Exogenous: Constant

		t-Statistic	Prob.
Augmented Dickey-Fuller test statistic		-2.573668	0.1024
Test critical values:	1% level	-3.508326	
	5% level	-2.895512	
	10% level	-2.584952	

Augmented Dickey-Fuller Test Equation
Included observations: 86 after adjustments

Variable	Coefficient	Std. Error	t-Statistic	Prob.
LVARINF(-1)	-0.144353	0.056088	-2.573668	0.0118
C	-1.289403	0.506144	-2.547501	0.0127
R-squared	0.073091	Durbin-Watson stat		1.883428

Table A11: Exchange Rate Uncertainty - Augmented Dickey Fuller Stationarity Test

The null hypotheses of a unit root can only be rejected at 10.5% significance level.

A.8 Exchange rate Uncertainty Stationarity Test

Null Hypothesis: LVARREER has a unit root
Exogenous: Constant

		t-Statistic	Prob.
Augmented Dickey-Fuller test statistic		-3.651414	0.0067
Test critical values:	1% level	-3.512290	
	5% level	-2.897223	
	10% level	-2.585861	

Augmented Dickey-Fuller Test Equation
Included observations: 82 after adjustments

Variable	Coefficient	Std. Error	t-Statistic	Prob.
LVARREER(-1)	-0.117899	0.032289	-3.651414	0.0005
C	-0.953307	0.268913	-3.545040	0.0007
R-squared	0.142852	Durbin-Watson stat		1.847234

Table A12: Exchange Rate Uncertainty - Augmented Dickey Fuller Stationarity Test

The null hypotheses of a unit root can be rejected at a 1% significance level.

Appendix B

Serial Correlation Tests

B.1 Output Gap Uncertainty Serial Correlation Test

Heteroskedasticity Test: ARCH

F-statistic	0.005439	Prob. F(3,76)	0.9994
Obs*R-squared	0.017171	Prob. Chi-Square(3)	0.9994

Test Equation:
Included observations: 80 after adjustments

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	0.967227	0.238819	4.050034	0.0001
WGT_RESID^2(-1)	0.012513	0.114350	0.109427	0.9132
WGT_RESID^2(-2)	0.007094	0.114499	0.061954	0.9508
WGT_RESID^2(-3)	0.001893	0.114883	0.016474	0.9869

R-squared	0.000215	Mean dependent var	0.988373
Prob(F-statistic)	0.999443		

Table B1: Output Gap ARCHLM Test

The null hypothesis of no ARCH up to order three in the residuals cannot be rejected.

B.2 Inflation Uncertainty Serial Correlation Test

Heteroskedasticity Test: ARCH

F-statistic	0.953861	Prob. F(3,78)	0.4189
Obs*R-squared	2.901870	Prob. Chi-Square(3)	0.4070

Test Equation:
Included observations: 82 after adjustments

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	1.465925	0.305187	4.803369	0.0000
WGT_RESID^2(-1)	0.055231	0.112593	0.490538	0.6251
WGT_RESID^2(-2)	-0.141654	0.111467	-1.270817	0.2076
WGT_RESID^2(-3)	-0.098600	0.112415	-0.877109	0.3831

R-squared	0.035389	Mean dependent var	1.238357
Prob(F-statistic)	0.418878		

Table B2: Inflation ARCH LM Test

The null hypothesis of no ARCH up to order three in the residuals cannot be rejected.

B.3 Exchange Rate Uncertainty Serial Correlation Test

Heteroskedasticity Test: ARCH

F-statistic	0.840433	Prob. F(3,76)	0.4759
Obs*R-squared	2.568780	Prob. Chi-Square(3)	0.4630

Test Equation:
Included observations: 80 after adjustments

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	0.779571	0.261461	2.981593	0.0039
WGT_RESID^2(-1)	0.052641	0.114008	0.461732	0.6456
WGT_RESID^2(-2)	0.132430	0.113153	1.170359	0.2455
WGT_RESID^2(-3)	0.086705	0.114039	0.760310	0.4494
R-squared	0.032110	Mean dependent var		1.067848
Prob(F-statistic)	0.475912			

Table B3: Exchange Rate ARCH LM Test

The null hypothesis of no ARCH up to order three in the residuals cannot be rejected.

Appendix C

Full Sample Regression Results: LS & GMM

C.1 Backward-looking regression results: Full sample LS & GMM

Backward-Looking Rule:

$$i_t = \rho_1 + \rho_2 i_{t-1} + \rho_3 e_{t-2} + \rho_{yt} y_{t-1} + \rho_{\pi t} \pi_{t-1} + \rho_{et} e_{t-1} + \mu_t$$

C.2 Present-period regression results: Full sample LS & GMM

Present-Period Rule:

$$i_t = \rho_1 + \rho_2 i_{t-1} + \rho_3 e_{t-1} + \rho_{yt} y_t + \rho_{\pi t} \pi_t + \rho_{et} e_t + \mu_t$$

C.3 Hybrid model regression results: Full sample LS & GMM

Hybrid Rule:

$$i_t = \rho_1 + \rho_2 i_{t-1} + \rho_3 e_{t-1} + \rho_{yt} E(y_{t+1}) + \rho_{\pi t} E(\pi_{t+1}) + \rho_{et} e_t + \mu_t$$

C.4 Forward-looking regression results: Full sample LS & GMM

Forward-Looking:

$$i_t = \rho_1 + \rho_2 i_{t-1} + \rho_3 e_t + \rho_{yt} E(y_{t+1}) + \rho_{\pi t} E(\pi_{t+1}) + \rho_{et} E(e_{t+1}) + \mu_t$$

C.1 Backward-looking regression results: Full sample LS & GMM

	Model A		Model B		Model C		Model D	
Coeff	**LS**	**GMM**	**LS**	**GMM**	**LS**	**GMM**	**LS**	**GMM**
ρ_1	-0.00037 (0.8855)	-0.00183 (0.2848)	-0.00004 (0.9841)	0.00006 (0.5934)	0.000005 (0.9809)	0.000601 (0.6368)	0.000166 (0.9432)	0.001738 (0.3561)
ρ_2	0.8356591 (0.0000)***	0.823959 (0.0000)***	0.859342 (0.0000)***	0.81817 (0.0000)***	0.859729 (0.0000)***	0.822347 (0.0000)***	0.876757 (0.0000)***	0.875466 (0.0000)***
ρ_3	0.34719 (0.0173)**	0.464325 (0.0035)***	-0.23176 (0.0651)***	0.359224 (0.0000)***	0.204608 (0.0954)*	0.2330 (0.0001)***	0.209185 (0.0766)*	0.250407 (0.0100)***
ρ_π	0.342303 (0.032)**	0.339423 (0.0013)***	-0.28496 (0.1233)	-0.27709 (0.0219)**	-0.22628 (0.2125)	-0.23065 (0.0325)**	-0.07146 (0.7020)	-0.20076 (0.2594)
ρ_y	0.1313458 (0.0157)**	0.25641 (0.0023)***	0.138201(0 .2331)	0.156586 (0.0034)***	0.113637 (0.3156)	0.116942 (0.0513)**	0.084525 (0.4466)	0.066288 (0.4378)
ρ_e	-0.30214 (0.0288)**	-0.53344 (0.0020)***	-0.075 (0.5516)	-0.31052 (0.0021)***	0.132197 (0.2893)	0.119351 (0.3383)	0.305765 (0.0512)*	0.278961 (0.0798)*
ρ_π^π			-0.09296 (0.0000)***	-0.09782 (0.0000)***	-0.08335 (0.08335)*	-0.08742 (0.0000)***	-0.16944 (0.3556)	-0.54387 (0.0328)**
ρ_y^y			-0.02607 (0.0521)*	-0.02564 (0.0003)***	-0.02462 (0.0597)*	-0.02312 (0.0092)***	0.115538(0 .4208)	0.088692 (0.4618)
ρ_e^e					0.033874 (0.0267)**	0.049091 (0.0006)***	0.718203 (0.0019)***	-0.21976 (0.2821)
ρ_π^y							-0.2185 (0.2162)	0.27642 (0.0505)*
ρ_π^e							0.333501 (0.0674)*	0.189537 (0.4198)
ρ_y^π							-0.08704 (0.6464)	0.357518 (0.0502)
ρ_y^e							-0.05722 (0.7486)	-0.50312 (0.0005)***
ρ_e^π							-0.36962 (0.0254)**	-0.36048 (0.0099)***
ρ_e^y							-0.24801 (0.1979)	0.624774 (0.0024)***
Adj. R-Squared	0.87335	0.867299	0.909866	0.906783	0.914549	0.913552	0.922786	0.892568
Σe^2	0.04376	0.04568	0.030286	0.031106	0.028330	0.028436	0.023523	0.032265
F-StatProb	0.000000		0.000000		0.000000		0.000000	
J-StatProb		0.523702		0.864791		0.920151		0.836493
Parameter Stab	0.0022	0.0000	0.0902	0.0000	0.0012	0.0000	0.0035	0.0000
PP Prob.	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

Numbers in parentheses are the probability values of the standard errors. For the LS estimation, the parameter stability test values are the F-statistic probability values of a Chow Breakpoint test with date specified as 1999. With regards to the GMM estimation, the instruments are a constant and five lags of the variables in the estimated rule. The J-statistic is a test of over-identifying moment conditions. The parameter stability test values are the probabilities of a Chi Square statistic generated through the Andrews-Fair-Wald Breakpoint test. PP refers to Phillips-Peron unit root tests.
***, **, * represent coefficient significance at 1%, 5% and 10% respectively.

Table C1: Backward-looking regression results: Full sample LS & GMM

C.2 Present-period regression results: Full sample LS & GMM

	Model A		Model B		Model C		Model D	
Coefficient	**LS**	**GMM**	**LS**	**GMM**	**LS**	**GMM**	**LS**	**GMM**
$\boldsymbol{\rho_1}$	-0.0005 (0.8152)	-0.00107 (0.5710)	-0.001242 (0.5847)	-0.00253 (0.0812)*	-0.00006 (0.9769)	-0.00011 (0.9402)	-0.000198 (0.9476)	0.001875 (0.5575)
$\boldsymbol{\rho_2}$	0.831641 (0.0000)***	0.802604 (0.0000)***	0.848072 (0.0000)***	0.846242 (0.0000)***	0.840879 (0.0000)***	0.823292 (0.0000)***	0.856618 (0.0000)***	0.853334 (0.0000)***
$\boldsymbol{\rho_3}$	0.3194 (0.0100)***	0.66787 (0.0006)***	0.308373 (0.0137)**	0.536572(0 .0013)***	0.398208 (0.0036)***	0.554715 (0.0000)***	0.47329 (0.0766)*	0.602979 (0.0094)***
$\boldsymbol{\rho_\pi}$	0.621776 (0.0000)***	0.667356 (0.0000)***	2.748869 (0.0276)**	3.106668 (0.0014)***	2.664417 (0.0309)**	1.138601 (0.0478)**	2.992247 (0.1097)	5.457214 (0.1626)
$\boldsymbol{\rho_y}$	0.1267468 (0.0121)**	0.153109 (0.1079)	2.284264 (0.0612)*	1.740109 (0.0851)*	2.286513 (0.0582)*	1.666356 (0.0480)**	0.590482 (0.8283)	-5.79912 (0.1294)
$\boldsymbol{\rho_e}$	-0.32265 (0.0055)***	-0.80544 (0.0000)***	-0.322288 (0.0058)***	-0.53654 (0.0002)***	2.305859 (0.1500)	2.281242 (0.1353)	0.924807 (0.4864)	3.77872 (0.1936)
$\boldsymbol{\rho_\pi^\pi}$			0.240938 (0.0828)*	0.27159 (0.0101)**	0.233319 (0.0893)*	0.051874(0 .4401)	-0.000001 (1.0000)	-0.18023 (0.4266)
$\boldsymbol{\rho_y^y}$			0.233565 (0.1006)	0.182756 (0.1279)	0.23281 (0.0979)*	0.173891 (0.0756)*	0.188161 (0.1341)	-0.1437 (0.6654)
$\boldsymbol{\rho_e^e}$					0.338585 (0.1007)	0.345393 (0.0745)*	0.668218 (0.0207)**	0.347743 (0.4315)
$\boldsymbol{\rho_\pi^y}$							-0.103233 (0.5260)	0.27272 (0.3083)
$\boldsymbol{\rho_\pi^e}$							0.397697 (0.0106)**	0.477973 (0.2818)
$\boldsymbol{\rho_y^\pi}$							-0.109846 (0.6170)	0.446804 (0.2364)
$\boldsymbol{\rho_y^e}$							-0.039467 (0.7835)	-1.06318 (0.0322)**
$\boldsymbol{\rho_e^\pi}$							-0.292924 (0.1109)	-0.27066 (0.2643)
$\boldsymbol{\rho_e^y}$							-0.166957 (0.4360)	0.452282 (0.1745)
Adj. R-Squared	0.911139	0.889772	0.914345	0.910201	0.916311	0.914046	0.918751	0.887018
Σe^2	0.030729	0.037944	0.028781	0.029966	0.027746	0.028273	0.024753	0.033932
F-Stat Prob	0.00000		0.00000		0.00000		0.000000	
J-Stat Prob		0.845456		0.806788		0.879147		0.776422
Parameter Stab	0.0000	0.0000	0.0001	0.0000	0.0004	0.0000	0.0005	0.0000
PP Prob.	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

Numbers in parentheses are the probability values of the standard errors. For the LS estimation, the parameter stability test values are the F-statistic probability values of a Chow Breakpoint test with date specified as 1999. With regards to the GMM estimation, the instruments are a constant and five lags of the variables in the estimated rule. The J-statistic is a test of over-identifying moment conditions. The parameter stability test values are the probabilities of a Chi Square statistic generated through the Andrews-Fair-Wald Breakpoint test. PP refers to Phillips-Peron unit root tests.

***, **, * represent coefficient significance at 1%, 5% and 10% respectively.

Table C2: Present-period regression results: Full sample LS & GMM

C.3 Hybrid model regression results: Full sample LS & GMM

	Model A		Model B		Model C		Model D	
Coefficient	**LS**	**GMM**	**LS**	**GMM**	**LS**	**GMM**	**LS**	**GMM**
$\boldsymbol{\rho_1}$	-0.00053 (0.8069)	-0.000008 (0.9686)	-0.000008 (0.9681)	0.00009 (0.4874)	0.000834 (0.7430)	0.001543 (0.2417)	-0.00012 (0.9625)	0.005939 (0.0674)
$\boldsymbol{\rho_2}$	0.888289 (0.0000)***	0.885209 (0.0000)***	0.845985 (0.0000)***	0.82748 (0.0000)***	0.837946 (0.0000)***	0.807404 (0.0000)***	0.869585 (0.0000)***	0.849929 (0.0000)***
$\boldsymbol{\rho_3}$	0.234445 (0.0500)**	0.270414 (0.1895)	0.286912 (0.0241)**	0.429462 (0.0003)***	0.361333 (0.1779)	0.465131 (0.0002)***	0.43406 (0.0025)***	0.610732 (0.0002)***
$\boldsymbol{\rho_\pi}$	0.604556 (0.0000)***	0.676142 (0.0000)***	0.297744 (0.0751)*	0.347572 (0.0003)***	0.270105 (0.0109)**	0.304016 (0.0007)***	0.238065 (0.1527)	0.252375 (0.0851)
$\boldsymbol{\rho_y}$	0.214759 (0.0450)**	0.261518 (0.0009)***	0.209395 (0.0564)*	0.265024 (0.0000)***	0.189231 (0.0335)**	0.194826 (0.0000)***	0.135897 (0.2165)	0.101419 (0.1808)
$\boldsymbol{\rho_e}$	-0.22298 (0.0684)*	-0.27202 (0.3130)	-0.2542 (0.0375)**	-0.45899 (0.0003)***	1.77552 (0.1104)	3.155095 (0.0217)**	-0.4897 (0.7803)	7.103803 (0.0233)**
$\boldsymbol{\rho_\pi^\pi}$			-0.04237 (0.0241)**	-0.04159 (0.000)***	-0.04366 (0.0071)***	-0.04459 (0.0000)***	-0.07095 (0.7050)	-0.25745 (0.2618)
$\boldsymbol{\rho_y^y}$			-0.01955 (0.1427)	-0.0157 (0.0702)***	-0.02147 (0.0464)**	-0.02291 (0.0039)***	0.153978 (0.2723)	0.36105 (0.0386)**
$\boldsymbol{\rho_e^e}$					0.262525 (0.0690)*	0.449676 (0.0131)**	0.670425 (0.0101)**	0.528497 (0.1164)
$\boldsymbol{\rho_\pi^y}$							-0.25472 (0.1543)	0.082664 (0.5480)
$\boldsymbol{\rho_\pi^e}$							0.294045 (0.1155)	0.143021 (0.5553)
$\boldsymbol{\rho_y^\pi}$							-0.16686 (0.3839)	0.19418 (0.2942)
$\boldsymbol{\rho_y^e}$							-0.00633 (0.9724)	-0.61256 (0.0117)*
$\boldsymbol{\rho_e^\pi}$							-0.30864 (0.0634)*	-0.61256 (0.3251)
$\boldsymbol{\rho_e^y}$							-0.32519 (0.1037)	0.588735 (0.0103)**
Adj. R-Squared	0.909494	0.910841	0.915755	0.914731	0.916391	0.917780	0.922260	0.877287
Σe^2	0.03087	0.030264	0.027907	0.028044	0.027322	0.026649	0.023316	0.036264
F-Statistic Prob.	0.000000		0.000000		0.000000		0.000000	
J-Statistic Prob.		0.933164		0.871154		0.914112		0.902942
Parameter Stab	0.0005	0.0000	0.0008	0.0000	0.0026	0.0000	0.0006	0.0000
PP Prob.	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

Numbers in parentheses are the probability values of the standard errors. For the LS estimation, the parameter stability test values are the F-statistic probability values of a Chow Breakpoint test with date specified as 1999. With regards to the GMM estimation, the instruments are a constant and five lags of the variables in the estimated rule. The J-statistic is a test of over-identifying moment conditions. The parameter stability test values are the probabilities of a Chi Square statistic generated through the Andrews-Fair-Wald Breakpoint test. PP refers to Phillips-Peron unit root tests.
***, **, * represent coefficient significance at 1%, 5% and 10% respectively.

Table C3: Hybrid model regression results: Full sample LS & GMM

C.4 Forward-looking regression results: Full sample LS & GMM

	Model A		**Model B**		**Model C**		**Model D**	
Coefficient	**LS**	**GMM**	**LS**	**GMM**	**LS**	**GMM**	**LS**	**GMM**
$\boldsymbol{\rho_1}$	-0.00053 (0.8079)	0.000108 (0.9489)	-0.00005 (0.9819)	0.000421 (0.7308)	-0.00016 (0.9510)	-0.00032 (0.7386)	-0.00091 (0.7266)	0.0034 (0.0673)
$\boldsymbol{\rho_2}$	0.864963 (0.0000)***	0.86986 (0.0000)***	0.829582 (0.0000)***	0.816867 (0.0000)***	0.830968 (0.0000)***	0.827967 (0.0000)***	0.852732 (0.0000)***	0.844985 (0.0000)***
$\boldsymbol{\rho_3}$	-0.16019 (0.1974)	0.130828 (0.2343)	-0.16948 (0.1857)	0.07350 (0.3980)	-0.40111 (0.8236)	-1.94458 (0.1130)	-2.2428 (0.3262)	0.6748 (0.7555)
$\boldsymbol{\rho_\pi}$	0.602037 (0.0000)***	0.721908 (0.0000)***	0.360108 (0.0406)**	0.421965 (0.0000)***	0.363512 (0.0242)**	0.468513 (0.0000)***	0.344825 (0.0263)***	0.519768 (0.0000)***
$\boldsymbol{\rho_y}$	0.24499 (0.0249)**	0.231777 (0.0019)***	0.234159 (0.0384)**	0.246769 (0.0000)***	0.236113 (0.0040)***	0.286989 (0.0000)***	0.193477 (0.0511)*	0.217106 (0.0057)***
$\boldsymbol{\rho_e}$	0.129668 (0.2662)	-0.16498 (0.3165)	0.125828 (0.2873)	-0.12747 (0.2359)	0.129483 (0.2335)	-0.04364 (0.6496)	0.076325 (0.2863)	-0.12156 (0.3794)
$\boldsymbol{\rho_\pi^\pi}$			-0.02761 (0.1383)	-0.0338 (0.0000)***	-0.02772 (0.0274)**	-0.03248 (0.0000)***	0.068287 (0.5527)	0.154377 (0.4245)
$\boldsymbol{\rho_y^y}$			-0.02564 (0.0611)*	-0.01703 (0.0031)***	-0.02534 (0.0083)***	-0.01726 (0.0017)***	0.187724 (0.1797)	0.309012 (0.0289)**
$\boldsymbol{\rho_e^e}$					-0.0290 (0.8962)	-0.24808 (0.1067)	0.297547 (0.1844)	-0.45634 (0.0748)*
$\boldsymbol{\rho_\pi^y}$							-0.29816 (0.0405)**	0.001945 (0.9910)
$\boldsymbol{\rho_\pi^e}$							0.212331 (0.1952)	-0.1946 (0.3563)
$\boldsymbol{\rho_y^\pi}$							-0.23758 (0.1269)	-0.0480 (0.7786)
$\boldsymbol{\rho_y^e}$							0.032595 (0.8051)	-0.28636 (0.1241)
$\boldsymbol{\rho_e^\pi}$							-0.15628 (0.1513)	0.197035 (0.3103)
$\boldsymbol{\rho_e^y}$							-0.36408 (0.1926)	0.287481 (0.0926)*
Adj. R-Squared	0.90644	0.89892	0.910845	0.908217	0.909649	0.908197	0.911258	0.885230
Σe^2	0.031911	0.034311	0.029533	0.030186	0.029525	0.029755	0.026616	0.033917
F-Statistic Prob.	0.000000		0.000000		0.000000		0.000000	
J-Statistic Prob.		0.978174		0.855737		0.880032		0.737293
Parameter Stab	0.0044	0.0000	0.0027	0.0000	0.0047	0.0000	0.0040	0.0000
PP Prob.	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

Numbers in parentheses are the probability values of the standard errors. For the LS estimation, the parameter stability test values are the F-statistic probability values of a Chow Breakpoint test with date specified as 1999. With regards to the GMM estimation, the instruments are a constant and five lags of the variables in the estimated rule. The J-statistic is a test of over-identifying moment conditions. The parameter stability test values are the probabilities of a Chi Square statistic generated through the Andrews-Fair-Wald Breakpoint test. PP refers to Phillips-Peron unit root tests.
***, **, * represent coefficient significance at 1%, 5% and 10% respectively.

Table C4: Forward-looking regression results: Full sample LS & GMM

Appendix D

Parameter Stability Tests

Quandt-Andrews unknown breakpoint test
Null Hypothesis: No breakpoints within trimmed data
Number of breaks compared: 60

Statistic	Value	Prob.
Maximum LR F-statistic (1999Q1)	5.888209	0.9899
Maximum Wald F-statistic (1999Q1)	5.888209	0.9899

Table D1: Model A Quandt-Andrews Tests for LS Specification

Quandt-Andrews unknown breakpoint test
Null Hypothesis: No breakpoints within trimmed data
Number of breaks compared: 57

Statistic	Value	Prob.
Maximum LR F-statistic (1999Q1)	5.016407	1.0000
Maximum Wald F-statistic (1999Q1)	5.016407	1.0000

Table D2: Model B Quandt-Andrews Tests for LS Specification

Quandt-Andrews unknown breakpoint test
Null Hypothesis: No breakpoints within trimmed data
Number of breaks compared: 57

Statistic	Value	Prob.
Maximum LR F-statistic (1999Q1)	4.050589	1.0000
Maximum Wald F-statistic (1999Q1)	4.050589	1.0000

Table D3: Model C Quandt-Andrews Tests for LS Specification

Quandt-Andrews unknown breakpoint test
Null Hypothesis: No breakpoints within trimmed data
Number of breaks compared: 49

Statistic	Value	Prob.
Maximum LR F-statistic (1999Q1)	3.399028	1.0000

Table D4: Model D Quandt-Andrews Tests for LS Specification

Appendix E

Split Sample Regression Results: LS & GMM

E.1 Backward-looking regression results: Split sample LS & GMM

Backward-Looking Rule:

$$i_t = \rho_1 + \rho_2 i_{t-1} + \rho_3 e_{t-2} + \rho_{yt} y_{t-1} + \rho_{\pi t} \pi_{t-1} + \rho_{et} e_{t-1} + \mu_t$$

E.2 Present-period regression results: Split sample LS & GMM

Present-Period Rule:

$$i_t = \rho_1 + \rho_2 i_{t-1} + \rho_3 e_{t-1} + \rho_{yt} y_t + \rho_{\pi t} \pi_t + \rho_{et} e_t + \mu_t$$

E.3 Hybrid model regression results: Split sample LS & GMM

Hybrid Rule:

$$i_t = \rho_1 + \rho_2 i_{t-1} + \rho_3 e_{t-1} + \rho_{yt} E(y_{t+1}) + \rho_{\pi t} E(\pi_{t+1}) + \rho_{et} e_t + \mu_t$$

E.4 Forward-looking regression results: Split sample LS & GMM

Forward-Looking:

$$i_t = \rho_1 + \rho_2 i_{t-1} + \rho_3 e_t + \rho_{yt} E(y_{t+1}) + \rho_{\pi t} E(\pi_{t+1}) + \rho_{et} E(e_{t+1}) + \mu_t$$

E.1 Backward-looking regression results: Split sample LS & GMM

	Sample: 1990Q1 - 1999Q4			**Sample: 2000Q1 - 2011Q3**		
	Model A	**Model B**	**Model C**	**Model A**	**Model B**	**Model C**
Coefficient		**GMM**			**GMM**	
ρ_1	-0.00052 (0.7916)	-0.003408 (0.0001)***	0.005037 (0.0000)***	-0.00361 (0.0252)**	-0.00360 (0.0001)***	-0.00342 (0.0003)***
ρ_2	0.885942 (0.0000)***	0.857109 (0.0000)***	0.844079 (0.0000)***	0.616909 (0.0000)***	0.811449 (0.0000)***	0.710823 (0.0000)***
ρ_3	0.667536 (0.0000)***	0.376547 (0.0000)***	0.294257 (0.0000)***	0.369701 (0.0045)***	0.161185 (0.0031)***	0.1300 (0.0069)***
ρ_π	0.215478 (0.0761)*	-0.25154 (0.0330)**	0.068458 (0.0789)*	0.567315 (0.0000)***	-0.12498 (0.1033)	-0.08674 (0.3229)
ρ_y	0.31621 (0.0019)***	0.150025 (0.0104)**	0.35492 (0.0000)***	0.239089 (0.0026)***	0.16381 (0.0060)***	0.142946 (0.0050)***
ρ_e	-0.16894 (0.1895)	0.250199 (0.0000)***	0.671458 (0.0000)***	-0.61477 (0.0000)***	0.24457 (0.0000)***	-0.12309 (0.1724)
ρ_π^π		-0.09804 (0.0000)***	-0.06464 (0.0000)***		-0.08591 (0.0000)***	-0.08312 (0.0000)***
ρ_y^y		-0.04097 (0.0000)***	-0.03207 (0.0000)***		-0.01669 (0.0061)***	-0.08312 (0.0012)***
ρ_e^e			0.092652 (0.0000)***			0.012194 (0.1528)
Adj. R-Squared	0.849103	0.884769	0.904133	0.904469	0.939665	0.939746
Σe^2	0.021981	0.015081	0.012001	0.015724	0.009446	0.009192
F-Statistic Prob.	0.909973	0.997908	0.99603	0.81516	0.982018	0.996763
J-Statistic Prob.	0.0007	0.0002	0.0001	0.0042	0.0007	0.0018

Numbers in parentheses are the probability values of the standard errors. The instruments are a constant and five lags of the variables in the estimated rule. The J-statistic is a test of over-identifying moment conditions. The parameter stability test values are the probabilities of a Chi Square statistic generated through the Andrews-Fair-Wald Breakpoint test. PP refers to Phillips-Peron unit root tests.
***, **, * represent coefficient significance at 1%, 5% and 10% respectively.

Table E1: Backward-looking regression results: Split sample LS & GMM

E.2 Present-period regression results: Split sample LS & GMM

	Sample: 1990Q1 - 1999Q4			Sample: 2000Q1 - 2011Q3		
	Model A	**Model B**	**Model C**	**Model A**	**Model B**	**Model C**
Coefficient		**GMM**			**GMM**	
$\boldsymbol{\rho_1}$	0.00171 (0.4837)	0.003399 (0.0180)**	0.003388 (0.1001)	-0.00472 (0.0008)***	0.00757 (0.0000)***	-0.00729 (0.0000)***
$\boldsymbol{\rho_2}$	0.886846 (0.0000)***	0.922691 (0.0000)***	0.92325 (0.0000)***	0.690629 (0.0000)***	0.707628 (0.0000)***	0.705852 (0.0000)***
$\boldsymbol{\rho_3}$	0.900442 (0.0000)***	0.55868 (0.0036)***	0.541125 (0.0280)**	0.253106 (0.0126)**	0.070527 (0.2270)	0.050806 (0.2958)
$\boldsymbol{\rho_\pi}$	0.712497 (0.0000)***	10.01401 (0.0041)***	10.17733 (0.0035)***	0.812761 (0.0000)***	3.698081 (0.0000)***	3.449524 (0.0000)***
$\boldsymbol{\rho_y}$	0.1229625 (0.1456)	5.14528 (0.0000)***	5.23586 (0.0000)***	0.044353 (0.4767)	3.434595 (0.0000)***	3.072194 (0.0000)***
$\boldsymbol{\rho_e}$	-0.95509 (0.0000)***	-0.28555 (0.0223)***	-0.77036 (0.8536)	-0.39654 (0.0000)***	-0.19179 (0.0006)***	-0.30076 (0.5863)
$\boldsymbol{\rho_\pi^\pi}$		1.108033 (0.0067)***	1.12785 (0.0057)***		0.324894 (0.0000)***	0.29894 (0.0000)***
$\boldsymbol{\rho_y^y}$		0.570584 (0.0000)***	0.580812 (0.0000)***		0.373657 (0.0000)***	0.329631 (0.0000)***
$\boldsymbol{\rho_e^e}$			0.06245 (0.9031)			-0.01512 (0.8261)
Adj. R-Squared	0.891527	0.902953	0.898957	0.933145	0.946550	0.945704
Σe^2	0.015801	0.012837	0.012809	0.011004	0.008368	0.008283
F-Statistic Prob.	0.721267	0.964384	0.946275	0.888149	0.963049	0.992020
J-Statistic Prob.	0.0016	0.0004	0.0005	0.0010	0.0005	0.0004

Numbers in parentheses are the probability values of the standard errors. The instruments are a constant and five lags of the variables in the estimated rule. The J-statistic is a test of over-identifying moment conditions. The parameter stability test values are the probabilities of a Chi Square statistic generated through the Andrews-Fair-Wald Breakpoint test. PP refers to Phillips-Peron unit root tests.
***, **, * represent coefficient significance at 1%, 5% and 10% respectively.

Table E2: Present-period regression results: Split sample LS & GMM

E.3 Present-period regression results: Split sample LS & GMM

	Sample: 1990Q1 - 1999Q4			Sample: 2000Q1 - 2011Q3		
	Model A	**Model B**	**Model C**	**Model A**	**Model B**	**Model C**
Coefficient		**GMM**			**GMM**	
$\boldsymbol{\rho_1}$	0.003275 (0.0455)**	0.005366 (0.0000)***	0.004445 (0.0018)***	-0.00428 (0.0051)***	-0.00324 (0.0005)***	-0.0033 (0.0000)***
$\boldsymbol{\rho_2}$	0.921979 (0.0000)***	0.872371 (0.0000)***	0.889872 (0.0000)***	0.794861 (0.0000)***	0.706533 (0.0000)***	0.703962 (0.0000)***
$\boldsymbol{\rho_3}$	0.512287 (0.0002)***	0.661276 (0.0000)***	0.5915589 (0.0000)***	-0.01896 (0.8484)	-0.01413 (0.6901)	0.009499 (0.7463)
$\boldsymbol{\rho_\pi}$	0.802709 (0.0000)***	0.399335 (0.0000)***	0.456202 (0.0000)***	0.696807 (0.0000)***	0.3162013 (0.0219)**	0.160582 (0.0106)**
$\boldsymbol{\rho_y}$	0.197435 (0.0143)**	0.197968 (0.0000)***	0.24982 (0.0000)***	0.24044 (0.0012)***	0.23176 (0.0000)***	0.240823 (0.0000)***
$\boldsymbol{\rho_e}$	-0.41414 (0.0049)***	-0.55155 (0.0000)***	-5.91316 (0.0035)***	-0.04908 (0.6754)	-0.0612 (0.3558)	-0.14067 (0.6683)
$\boldsymbol{\rho_\pi^\pi}$		-0.0189 (0.0000)***	-0.04493 (0.0000)***		-0.06656 (0.0000)***	-0.06505 (0.0000)***
$\boldsymbol{\rho_y^y}$		-0.03048 (0.0001)***	-0.03108 (0.0017)***		-0.0160 (0.0003)***	-0.01581 (0.0002)***
$\boldsymbol{\rho_e^e}$			-0.6857 (0.0063)***			-0.00467 (0.9121)
Adj. R-Squared	0.890822	0.904385	0.903481	0.931166	0.945074	0.944027
Σe^2	0.015904	0.012513	0.012082	0.011081	0.008400	0.008335
F-Statistic Prob.	0.899609	0.998243	0.997035	0.857381	0.978568	0.995004
J-Statistic Prob.	0.0001	0.0002	0.0004	0.0007	0.0008	0.0008

Numbers in parentheses are the probability values of the standard errors. The instruments are a constant and five lags of the variables in the estimated rule. The J-statistic is a test of over-identifying moment conditions. The parameter stability test values are the probabilities of a Chi Square statistic generated through the Andrews-Fair-Wald Breakpoint test. PP refers to Phillips-Peron unit root tests.
***, **, * represent coefficient significance at 1%, 5% and 10% respectively.

Table E3: Hybrid model regression results: Split sample LS & GMM

E.4 Present-period regression results: Split sample LS & GMM

	Sample: 1990Q1 - 1999Q4			Sample: 2000Q1 - 2011Q3		
	Model A	**Model B**	**Model C**	**Model A**	**Model B**	**Model C**
Coefficient		**GMM**			**GMM**	
$\boldsymbol{\rho_1}$	0.004181	0.007143	0.00537	-0.00394	-0.00303	-0.00347
	(0.0194)**	(0.0000)***	(0.0000)***	(0.0116)**	(0.0001)***	(0.0000)***
$\boldsymbol{\rho_2}$	0.910125	0.865204	0.891573	0.806842	0.712298	0.70723
	(0.0000)***	(0.0000)***	(0.0000)***	(0.0000)***	(0.0000)***	(0.0000)***
$\boldsymbol{\rho_3}$	0.010252	-0.26982	-10.3394	0.039421	-0.23613	-0.81342
	(0.9380)	(0.0000)***	(0.0000)***	(0.5967)	(0.0000)***	(0.0685)***
$\boldsymbol{\rho_\pi}$	0.789034	0.572188	0.623211	0.765294	0.162596	0.195215
	(0.0000)	(0.0000)***	(0.0000)***	(0.0000)***	(0.0229)**	(0.0007)***
$\boldsymbol{\rho_y}$	0.16376	0.257699	0.35849	0.150335	0.268219	0.274407
	(0.0118)**	(0.0000)***	(0.0000)***	(0.0558)*	(0.0000)***	(0.0000)***
$\boldsymbol{\rho_e}$	-0.4236	0.257699	0.048961	-0.05384	0.176789	0.168571
	(0.0045)***	(0.0313)**	(0.1667)	(0.6082)	(0.0003)***	(0.0000)***
$\boldsymbol{\rho_\pi^\pi}$		-0.02965	-0.02208		-0.06120	-0.06157
		(0.0003)***	(0.0106)**		(0.0003)***	(0.0000)**
$\boldsymbol{\rho_y^y}$		-0.02745	-0.03087		-0.02602	-0.02266
		(0.0000)***	(0.0000)***		(0.0000)***	(0.0000)***
$\boldsymbol{\rho_e^e}$			-1.27996			-0.07382
			(0.0000)***			(0.1749)
Adj. R-Squared	0.850975	0.879212	0.884999	0.929456	0.946790	0.944935
Σe^2	0.021709	0.015808	0.014396	0.011357	0.008138	0.008200
F-Statistic Prob.	0.930854	0.997869	0.996227	0.768175	0.982389	0.994957
J-Statistic Prob.	0.0000	0.0009	0.0017	0.0007	0.0002	0.0002

Numbers in parentheses are the probability values of the standard errors. The instruments are a constant and five lags of the variables in the estimated rule. The J-statistic is a test of over-identifying moment conditions. The parameter stability test values are the probabilities of a Chi Square statistic generated through the Andrews-Fair-Wald Breakpoint test. PP refers to Phillips-Peron unit root tests.
***, **, * represent coefficient significance at 1%, 5% and 10% respectively.

Table E4: Forward-looking regression results: Split sample LS & GMM

Appendix F

Combined Uncertainty Regression Results: LS & GMM

F.1 Combined uncertainty regression results: 1990 – 1999

F.2 Combined uncertainty regression results: 2000 – 2011

F.1 Combined uncertainty regression results: 1990 - 1999

GMM	Sample: 1990Q1 - 1999Q4			
	Backward	**Present**	**Hybrid**	**Future**
ρ_1	0.32119	0.58214	0.515518	0.584611
	(0.0000)***	(0.0000)***	(0.0000)***	(0.0000)***
ρ_2	0.711622	0.717218	0.725973	0.703265
	(0.0000)***	(0.0000)***	(0.0000)***	(0.0000)***
ρ_3	0.382704	0.26191	0.33277	-16.548
	(0.0004)***	(0.0031)***	(0.0001)***	(0.0000)***
ρ_π	0.603943	9.877642	0.281506	0.348933
	(0.0000)***	(0.0000)***	(0.0000)***	(0.0000)***
ρ_y	0.150073	3.017859	-0.05918	-0.02935
	(0.0630)*	(0.0000)***	(0.1059)	(0.2123)
ρ_e	0.495776	-14.6936	-13.974	0.017797
	(0.0000)***	(0.0000)***	(0.0000)***	(0.7894)
ρ_π^*	-0.01227	0.02222	-0.010158	0.014988
	(0.0100)*	(0.0000)***	(0.0025)***	(0.0001)***
ρ_y^*	0.008243	0.005785	-0.004899	0.005392
	(0.0001)***	(0.0001)***	(0.0000)***	(0.0001)***
ρ_e^*	0.042791	0.040889	0.046363	0.049083
	(0.0000)***	(0.0000)***	(0.0000)***	(0.0000)***
ρ_π^π	-0.04905	1.081886	-0.06398	-0.05355
	(0.0001)***	(0.0000)***	(0.0000)***	(0.0000)***
ρ_y^y	-0.01099	0.335706	-0.01007	-0.00858
	(0.0020)***	(0.0000)***	(0.1218)	(0.0569)*
ρ_e^e	0.076914	-1.82633	-1.72598	-2.07145
	(0.0000)***	(0.0000)***	(0.0000)***	(0.0000)***
Adj. R^2	0.935269	0.954623	0.944218	0.938173
Σe^2	0.006998	0.004906	0.006031	0.006684
J-Stat Prob.	0.985214	0.982711	0.98521	0.987047
PP Prob.	0.0001	0.0000	0.0000	0.0004

Table F1: Combined uncertainty regression results: 1990 – 1999

F.2 Combined uncertainty regression results: 2000 - 2011

GMM	Sample: 1990Q1 - 1999Q4			
	Backward	**Present**	**Hybrid**	**Future**
ρ_1	-0.11187	-0.04995	-0.07284	-0.04263
	(0.0000)***	(0.0613)*	(0.0002)***	(0.0426)**
ρ_2	0.670729	0.704384	0.707398	0.716685
	(0.0000)***	(0.0000)***	(0.0000)***	(0.0000)***
ρ_3	-0.01694	-0.06317	-0.07638	-0.56887
	(0.7129)	(0.3859)	(0.1012)	(0.1224)
ρ_π	-0.01876	2.417814	0.185598	0.180742
	(0.7998)	(0.0007)***	(0.0006)***	(0.0012)***
ρ_y	0.08435	1.988917	0.187357	0.187492
	(0.0886)*	(0.0053)***	(0.0001)***	(0.0000)***
ρ_e	-0.11875	-0.42119	-0.59165	0.141555
	(0.1891)	(0.3482)	(0.0618)*	(0.0021)***
ρ_π^*	-0.01554	-0.00966	-0.0109	-0.0088
	(0.0000)***	(0.0001)***	(0.0000)***	(0.0000)***
ρ_y^*	-0.0061	-0.00414	-0.00355	-0.00312
	(0.0000)***	(0.0000)***	(0.0011)***	(0.0000)***
ρ_e^*	0.010872	0.010006	0.007651	0.008492
	(0.0000)***	(0.0000)***	(0.0006)***	(0.0001)***
ρ_π^π	-0.08183	0.186405	-0.06702	-0.06712
	(0.0000)***	(0.0103)**	(0.0000)***	(0.0000)***
ρ_y^y	-0.1599	0.210736	-0.01481	-0.01848
	(0.0003)***	(0.0081)***	(0.0006)***	(0.0002)***
ρ_e^e	0.025647	-0.03074	-0.05818	-0.03894
	(0.0000)***	(0.5876)	(0.1442)	(0.3904)
Adj. R^2	0.943229	0.947489	0.947082	0.947327
Σe^2	0.007977	0.007378	0.007241	0.007208
J-Stat Prob.	0.98992	0.977317	0.983808	0.984602
PP Prob.	0.0017	0.0005	0.0000	0.0000

Table F2: Combined uncertainty regression results: 2000 – 2011