



# Monetary Policy in Low Income Countries: The Case of Uganda

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# Abstract

This thesis addresses interrelated issues that influence the implementation of monetary policy in low-income countries (LICs). These include the role of inflation persistence, financial frictions and the potential impact of regime-changes or large shocks. In this thesis, models that have been applied to address these issues for the purposes of monetary policy analysis and forecasting, using macroeconomic data from Uganda, are developed.

After the introduction, Chapter 2 considers the properties of macroeconomic data that are frequently used in models for monetary policy analysis. These variables are then used in the subsequent chapters of this thesis. Details on data sources, definitions and the transformations that have been applied to the various time series are described. The key findings from research discussed in this chapter are that the computation and coverage of some of the key variables has been subject to several changes. As a result, the base periods and coverage have been affected over time. This may be a source of structural breaks in some of the time series variables. In addition, it is also noted that there is evidence of several large shocks, while the services sector has expanded at the expense of the agricultural sector.

Chapter 3 extends the literature on time-varying unit root tests that are applied with the quantile regression approach to investigate inflation persistence in LICs. The first part of the chapter considers the speed-of-adjustment (i.e. persistence) of the inflation rate in response to various macroeconomic shocks. The results suggest mean-reversion for the whole sample, however, there is evidence of asymmetric mean-reversion within specific quantiles (i.e. while a unit root is found in many of the top quantiles, there is evidence of mean reversion in the bottom quantiles). In addition, it is noted that the level of persistence increases after 2006 and during the inflation-targeting period. The study also suggests that a measure of core inflation that is derived from wavelet techniques appears to provide a useful measure of this variable.

Research covered in chapter 4 considers the role of financial frictions in Uganda. It makes use of a dynamic stochastic general equilibrium (DSGE) model that incorporates several small open-economy features. Financial frictions are introduced through the activities of heterogeneous agents in the household sector (i.e. savers and borrowers). Most of the model parameters are estimated with the aid of Bayesian techniques, using quarterly macroeconomic data from 2000Q1 to 2015Q4. The results suggest that the central

bank currently responds to changes in the interest rate spread. In addition, the analysis also suggests that, to reduce macroeconomic volatility, the central bank should continue to respond to these financial sector frictions, and that it may be possible to derive a more favourable sacrifice ratio by making use of a slightly more aggressive response to macroeconomic developments.

Chapter 5 details our employment of a Markov-switching DSGE model to consider the possibility of regime-switching behaviour. To the best of our knowledge this is the first study to include financial frictions in a Markov regime-switching structural macroeconomic model, in either a developed or developing country setting. Two variants of regime-switching models are considered: One that incorporates regime-switching features in the monetary policy rule only and another that incorporates regime-switching features in both the monetary policy rule and in the volatility of the shock processes. Most of the parameters are again estimated with the aid of Bayesian techniques. The results suggest that the model parameters do not remain constant over the two regimes and the transition probabilities appear to capture important economic events. In addition, the out-of-sample evaluation suggests that the regime-switching models may provide a more accurate description of the data generating processes.

The thesis concludes by discussing possible policy implications of the findings of the three studies for the conduct of monetary policy in Uganda.

# Dedication

In loving memory of my mum, Elizabeth Maturu for her love and inspiration

# Declaration

I declare that this thesis is my original work. Where other people's work is used, acknowledgments have been made. I declare that it has not been previously submitted for the award of a degree at any university.

Francis Leni Anguyo

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*Signature*

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*Date*

# Acknowledgments

This thesis would not be in the current form without the invaluable input of several people and I would like to acknowledge their contributions. First and foremost, I would like to extend my sincere gratitude to my supervisors, Dr. Kevin Kotzé and Prof. Rangan Gupta for their excellent guidance throughout the entire process, right from the conception of the ideas and the many useful extensions along the way. I am forever indebted to Dr. Kotzé for going beyond the call of duty and making his office open to me during the countless consultations. He painfully read through drafts and made insightful suggestions at different stages and his attention to detail tremendously improved this work. In equal measure, I also wish to thank Prof. Rangan Gupta, who was not only enthusiastic, but also provided timely feedback and many useful contributions. The two made a winning team and I have learnt a great deal from both of you during the entire process.

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# List of Acronyms

<b>AIC</b>	Akaike Information Criterion
<b>AfDB</b>	African Development Bank
<b>BIC</b>	Bayesian Information Criterion
<b>BOP</b>	Balance of Payment
<b>BoU</b>	Bank of Uganda
<b>CBR</b>	Central Bank Rate
<b>CPI</b>	Consumer Price Index
<b>GDP</b>	Gross Domestic Product
<b>DSGE</b>	Dynamic Stochastic General Equilibrium
<b>GFC</b>	Global Financial Crisis
<b>GNI</b>	Gross National Income
<b>HLs</b>	Half Lives
<b>IMF</b>	International Monetary Fund
<b>ITL</b>	Inflation Targeting Lite
<b>LICs</b>	low-income Countries
<b>MCMC</b>	Markov chain Monte Carlo
<b>MPC</b>	Monetary Policy Committee
<b>MS-DSGE</b>	Markov-switching Dynamic Stochastic General Equilibrium
<b>NPL</b>	Non-Performing Loans
<b>OECD</b>	Organisation for Economic Co-operation and Development
<b>QAR</b>	Quantile Autoregression
<b>REER</b>	Real Effective Exchange Rate
<b>SARC</b>	Sum of Autoregressive Coefficients
<b>SSA</b>	Sub-Saharan Africa
<b>SUT</b>	Supply and Use Tables
<b>TOT</b>	Terms of Trade
<b>UBOS</b>	Uganda Bureau of Statistics
<b>UNHS</b>	Uganda National Household Survey
<b>VAR</b>	Vector Autoregressive

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# Chapter 1

## Introduction

### 1.1 Introduction and Motivation

Monetary policy plays an important role in the economies of both developed and developing countries. For example, by changing the short-term interest rates, the central bank influences the cost and availability of credit and the level of inflation. In addition, it also affects the balance of payments and other measures of economic activity through various monetary policy transmission mechanisms (c.f. [Bernanke and Blinder, 1988](#); [Kashyap and Stein, 1994](#); [Gertler and Karadi, 2015](#)). To successfully implement monetary policy, most central banks rely on supporting tools, which include quantitative macroeconomic models that can be used to evaluate the effect of monetary policy actions on the rest of the economy. In addition, these tools can also be used to generate forecasts for key macroeconomic variables.

When constructing macroeconomic models that are to be used to describe important aspects of monetary policy in low-income countries (LICs), there are several unique aspects that need to be considered.<sup>1</sup> This is partly due to the fragile macroeconomic environment that exists in LICs, which gives rise to data generating processes that may differ to those of their developed world counterparts. In addition, financial markets, which influence monetary policy transmission, have largely remained underdeveloped in LICs and are mostly dominated by commercial banks. This contributes to the way in which a LIC is able to interact with other economies, which would differ from those of advanced emerging market and developed economies. These features would need to be incorporated into the design of macroeconomic models. As a result, these models may need to incorporate a number of unique features. This thesis considers the construction of macroeconomic models that may be used to describe the Ugandan economy, which is classified as a LIC.

After considering the properties of the macroeconomic variables that may be incorpo-

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<sup>1</sup>According to the World Bank's classification, LICs have a GNI per capita of \$1,025 or less in 2015, where the Atlas method is used to calculate a countries gross nation income (GNI) per capita.

rated into a model, a separate chapter is dedicated to an investigation into the properties of the inflation process. Such information is important, as the inflation rate for most LIC countries is high and volatile, when compared to that of developed or advanced emerging market economies. The focus of this analysis is on the speed of adjustment of inflation rates following a shock to the process. This is in contrast to most of the literature on inflation dynamics in LICs, which mainly concentrates on the causes of inflation (c.f. Laryea and Sumaila, 2001; Loungani and Swagel, 2001; Menji, 2008; Baldini and Poplawski-Ribeiro, 2011; Nguyen et al., 2015). This is also the case for the studies that consider the inflationary process in Uganda, such as those of Kabundi (2012) and Mawejje and Lwanga (2015).

In the first paper of this dissertation - which is contained in chapter 3 we seek to describe the time-varying persistence in Ugandan inflation, using a quantile regression framework. The concept of quantile regressions in time-series analysis was introduced by Koenker and Bassett Jr (1978) and extended to the analysis of inflation persistence by Tsong and Lee (2011). This approach explores the persistence in the inflation rate in a range of conditional quantiles, as opposed to focusing on a single measure that represents the central tendency (c.f. Andrews and Chen, 1994; Marques et al., 2004). These conditional quantiles can be used to determine the degree to which there may be asymmetry in the inflation process. In addition, persistence is also investigated over different time periods, which may provide useful information regarding potential regime changes in inflation persistence, or on whether the level of persistence declined after the Bank of Uganda (BoU) adopted the inflation targeting framework.

The chapter also makes use of the wavelets transformation technique to construct an alternative measure of core inflation, which is compared to measures for the current core and headline inflation produced by the Uganda Bureau of Statistics (UBOS). It is suggested that a more detailed focus on core inflation is necessary in Uganda, since this measure of inflation is the target for monetary policy formulation in the country. The findings suggest that the process is subject to mean reversion for the overall sample, but there does appear to be evidence of unit root in some of the subsamples. In addition, we find evidence of asymmetric mean reversions, as the top quantiles contain a unit root, while the bottom quantiles do not contain a unit root. It is also noted that the level of persistence has increased during the recent period (after 2006) and during the period where inflation targeting was introduced (After July 2011).<sup>2</sup> Lastly, the measure of core inflation obtained from the wavelet transforms is much smoother and more persistent than the core and headline measure from UBOS.

Other considerations that are of interest for the analysis of monetary policy, following the onset of the recent global financial crisis, relate to the inclusion of financial frictions in

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<sup>2</sup>This is also termed the period over which the *inflation targeting lite* (ITL) framework was applied.

models. This aspect is considered in chapter 4, within the context of a theoretical macroeconomic model that incorporates forward-looking economic agents. Such a model seeks to address the major critiques that were levied against the quantitative macroeconomic models that were used during the 1970s, which were popularised by the Cowles commission.<sup>3</sup> These models sought to combine certain aspects of economic theory, statistical methods, and observed data to construct and estimate a system of simultaneous equations that could describe the working of an economy (Christ, 1994). However, the failure of these models to predict the high rates of inflation and unemployment in United States in the late 1970s, and the criticism by Lucas (1976), led to the development of alternative methodologies for macroeconomic analysis.<sup>4</sup> Notably, this process led to the development of theoretical macroeconomic models (which were initially termed real business cycle models) that were based on micro-foundations and incorporated forward-looking rational expectations (Kydland and Prescott, 1982).

Real business cycle models gave rise to the present day New Keynesian models that incorporate several nominal and real rigidities. These models support the original theoretical postulate of Mankiw (1989) and modern variants make use of a relatively rich economic structure. The main features of these dynamic stochastic general equilibrium (DSGE) models are the incorporation of optimizing agents, rational expectations, and market clearing behaviour. The original DSGE models fared reasonably well, despite incorporating so little of what were traditionally thought of as the necessary ingredients of business cycle theories, such as money, nominal rigidities, or non-market clearing forces (Fernández-Villaverde, 2010).

These models are currently being used for monetary policy analysis in many central banks. This is partly because they provide theoretically consistent explanations for the transmission of monetary policy shocks, and, in certain instances, they appear to display superior out-of-sample fit (Christiano et al., 2010). In addition to their superior forecasting performance, DSGE models also provide a solution to the price puzzle, which relates to the effects of monetary policy (Christiano et al., 2010).<sup>5</sup>

The DSGE methodology has been widely adopted for policy analysis and forecasting by central banks in developed economies (such as Riksbank, Norges Bank, the Bank of England, etc.) and in many advanced emerging market economies (such as by the South African Reserve Bank and Banco Central do Brasil). However, most LICs have not yet developed an appropriate framework for the use of these models. Most African LICs con-

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<sup>3</sup>The Cowles Commission type structural simultaneous equation models are largely based on the Keynesian theory.

<sup>4</sup>According to Lucas (1976), Cowles commission type models are not forward-looking hence inappropriate for policy making purposes.

<sup>5</sup>Earlier investigations suggest that most econometric models struggled to explain the slow response of inflation to monetary disturbances, without making use of strong assumptions about price frictions (Mankiw, 2001).

tinue to rely on reduced-form or structural simultaneous equation models to investigate the effects of monetary policy. These models are also used for generating forecasts. This dissertation therefore considers the construction of an appropriate modern macroeconomic model that may be used to describe the behaviour of economic agents in LICs. This is important, since DSGE models have provided an appropriate and theoretically consistent description of the effects of monetary policy in most countries. The aim of the investigations covered in chapters four and five of this thesis is to describe the quantitative implications of monetary policy in Uganda with the aid of small open-economy DSGE models.

At present there are only a few DSGE models that incorporate features of the Ugandan economy. The two most prominent variants are described in [Berg et al. \(2010a\)](#) and [Berg et al. \(2010b\)](#). In their first study, the authors make use of a multi-sector DSGE model to investigate the impact of aid on selected macroeconomic variables, as well as the effect of different policy responses. In their second study, the authors extend the DSGE literature to provide a role for money in two LICs, in a calibrated model. Both models are based on a money targeting policy set-up, which Uganda no longer employs, after the BoU switched to an inflation targeting framework (where an interest rate rule is used for the conduct of monetary policy). Thus, this thesis aims to contribute to the existing literature by constructing models that make use of estimated parameters, after describing the properties of the data that is to be incorporated in these models.

A large part of the current literature on DSGE models considers the role of financial institutions (and the incorporation of financial frictions) in developed and advanced emerging market economies. However, very little is known about the effect of incorporating such financial frictions into the macroeconomic models for LICs.<sup>6</sup> This is despite the fact that commercial banks play a leading role in intermediating financial resources in most LICs. This thesis addresses this aspect of the literature, by considering the design of a mechanism that would appropriately describe the role of financial institutions in a macroeconomic model for a representative LIC in Africa. To achieve this objective, as detailed in chapter 4, we develop a small open-economy DSGE model with financial frictions for Uganda, where there are heterogeneous agents in the household sector. The model also incorporates real and nominal rigidities, habit formation in consumption, financial intermediaries which link savers and borrowers, incomplete asset markets, a continuum of monopolistically competitive firms that produce intermediate goods, perfectly competitive firms that produce final goods, monopolistically competitive foreign good producing firms, and a government sector that incorporates a central bank and a foreign economy sector that is constructed as a trade-weighted average of key trading partners. Quarterly

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<sup>6</sup>Seminal work on the role of financial frictions after the global financial crisis includes the work of [Meeusen \(2009\)](#), [Blanchard et al. \(2010\)](#), [Woodford \(2010\)](#), [Christiano et al. \(2010\)](#), [Curdia and Woodford \(2009\)](#), and [Adrian and Shin \(2011\)](#).

macroeconomic data is used to estimate most of the model parameters with the aid of Bayesian techniques. The key results suggest that, notwithstanding the underdeveloped capital and financial markets in Uganda, the BoU currently responds to changes in the interest rate spread. Furthermore, such a response to financial frictions reduces macroeconomic volatility in Uganda, and also contributes towards a more favourable sacrifice ratio.

This result is important, as one of the challenges that is often faced by those who are responsible for the design of monetary policy models in LICs is the presence of large exogenous shocks that are transmitted through trade and financial flows. Given that the economies of LICs are typically small and open, changes in the terms of trade or export demand are easily transmitted to the domestic economy. In addition, volatile financial flows could also result in large swings in key macroeconomic variables. As the frequency and amplitude of such shocks tend to be higher in LICs, which exacerbates the effect of such shocks. The results shown in this chapter also suggest that theoretical macroeconomic models may provide useful quantitative analytical tools to support the implementation of monetary policy in LICs.

Our analysis in chapter 5 of this thesis makes use of a regime-switching DSGE model to describe structural changes in the data generating process. The various specifications that are taken to the data allow for variations in the parameters that define the monetary policy rule model and the nature of the structural shocks. This is relevant to the design of macroeconomic models in LICs as cross-country studies in the economic growth literature show a negative effect of volatility on long-run (trend) growth, and that this effect tends to be larger in LICs (Ramey and Ramey, 1994). Regime switching behaviour in this model is described by a nonlinear Markov-switching process. The regime-switching model may also allow for asymmetric effects in the exogenous shocks, where monetary policy actions could vary from one period to another, depending on the evolution of such shocks. This chapter therefore seeks to incorporate potential changes in the monetary policy regime and the possible benefits that may be derived from isolating the effect of large shocks (this could have a dramatic effect on economic behaviour in most LICs). The model also incorporates financial frictions and other features of a small open-economy.<sup>7</sup>

To evaluate the relative performance of these models, a selection of in-sample and out-of-sample tests are performed, to compare the fit of models that include regime-switching to those that exclude this feature. The results suggest that the model parameters are somewhat different in the two regimes, although the transition probabilities provide little evidence of a level shift in the central bank rule. Changes in regime seem to be described by pulse effects that relate to important events in Uganda. These include the period of heightened inflationary pressure (between 2011 and 2012), and the shift to an inflation

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<sup>7</sup>Examples of Markov-switching DSGE models include Farmer et al. (2008), Farmer et al. (2009), Farmer et al. (2011), Liu and Mumtaz (2011) and Alstadheim et al. (2013).

targeting framework (during 2011). The results from an evaluation of the models suggest that the regime-switching models provide a comparable in-sample fit to the model that excludes these features. In addition, the out-of-sample evaluation tests suggest that the fit of the regime-switching models is possibly superior to the fit of the model that excludes these features. This suggests that LICs could benefit from the inclusion of non-linear features in the structural macroeconomic models used in these countries for monetary policy analysis and forecasting.

## 1.2 Organisation of the Thesis

This thesis comprises six chapters. Chapter 2 includes an overview of the macroeconomic variables for Uganda that are frequently used to describe key features of the economy. The chapter discusses important features of the data and data preparation for further analysis. It also incorporates a discussion on the key changes that have influenced the data compilation and coverage. Chapter 3 investigates the dynamic features of the measure of inflation in Uganda, using quantile regression techniques and wavelet transformations. It focuses on the identification and estimation of time-varying measures of persistence in the two measures of inflation (headline and core) at both monthly and quarterly frequencies. In addition, the chapter proposes a new approach to create an alternative measure of core inflation using wavelet transformations.

Chapter 4 extends the literature on financial frictions in monetary policy models to consider the use of such models when applied to the data of a LIC. The model includes several features of a small open-economy, and most of the parameters in the model are estimated with the aid of Bayesian techniques. It also includes estimates of optimal monetary policy rule coefficients and sacrifice ratios. Chapter 5 covers an investigation into possible regime switching behaviour by making use of a Markov-switching small open-economy DSGE model that includes financial frictions. It also includes an out-of-sample evaluation that considers the forecasting performance of various models. Lastly, chapter 6 provides a summary of the key findings, and discusses several policy considerations that may be relevant to monetary policy in Uganda.

# Chapter 2

## Ugandan Macroeconomic Data

### 2.1 Introduction

This chapter provides stylized facts on the Ugandan macroeconomic data that will be used in this thesis. It includes details relating to data sources, definitions, and transformations that have been applied to the respective variables. Macroeconomic (financial and economic) time-series data for the Ugandan economy was obtained from the Uganda Bureau of Statistics (UBOS) and the Bank of Uganda (BoU). Both institutions are the primary sources of economic data for Uganda. The two institutions also provide the financial and economic data on Uganda published by international institutions such as the International Monetary Fund (IMF), World Bank, and African Development Bank (AfDB).

A detailed description of the macroeconomic data is necessary because, to build a quantitative monetary policy model of the Ugandan economy, we require a clear insight into the properties of the main variables, and how these variables should be used. The main observable variables used in Uganda's monetary policy analysis include: Measures of economic output, prices (consumer and producer), exchange rates, interest rates, exports, imports, foreign economic output, foreign nominal interest rates, and foreign prices. Variables related to the foreign economy should provide an accurate representation of Uganda's key trading partners, which are mainly the countries that are included in the calculation of Uganda's real effective exchange rate (REER).

The measure of economic activity that will be employed in the analysis is the real gross domestic product (GDP). This measure is available on a quarterly basis from 2000 onwards. All measures for variables used in our analysis are converted to quarterly measures, as the models do not allow for mixed frequency variables. Because the quarterly economic activity data is only available from 2000Q1, this period forms the starting point for the analysis. In addition, the quarterly GDP data was recently rebased to 2009/10. All other variables, such as the price indices and terms of trade, are rebased to this revised base year, where appropriate.

Descriptions and plots of the main variables are contained in the subsections. Initial inspection of the data reveals that, with the exception of the interest rate variable, the variables display upward trending behaviour. From this data, we need to derive information that relates to the business cycle, to ensure that it is consistent with the model, and the objectives of monetary policy.

## 2.2 Output

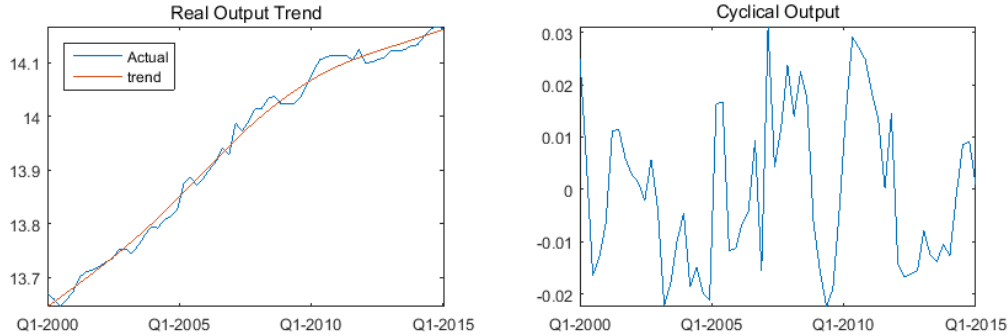
Uganda's economic performance has been impressive since the economic reforms in the early 1990s, when compared to similar LICs. Real GDP has increased on average by about 6.6 percent annually since 2000, and as a result the country has emerged as one of the fastest growing economies in Sub-Saharan Africa. The high growth rate during this period can be attributed to the relatively stable macroeconomic environment, which helped to improve business confidence, and attracted sizable foreign direct investment and aid inflows. This fast growth has been accompanied by an important structural transformation of the economy, in which the services sector (which includes, trade, telecommunications, and financial services) replaced the agricultural sector as the main driver of the economy. The services sector currently contributes roughly half of the total output, while the agricultural and industrial sectors account for the other half.

The output measure utilized in the models in this thesis is the seasonally adjusted GDP at constant (or chained) prices, which represents real GDP. A quick inspection of this variable reveals upward trending behaviour, which is displayed in Figure 2.1. The source of this data is UBOS, which published the first quarterly GDP data for Uganda in 2011. The initial base period for this variable was 2002, and this year was also used as the base period for the annual GDP data at constant prices.

In 2014, UBOS rebased the GDP data to 2009/10. The aim of the revision was to improve the relevance of this measure to reflect increased economic activity in the country, which is described in the 2009/10 Supply and Use Tables (SUT), also compiled by UBOS. This revision also sought to improve the methodology relating to the production of the output estimates, by implementing a number of recommendations relating to the System of National Accounts (UBOS, 2014). Details of the revisions and the methodology currently employed by UBOS are available in the publication for the GDP estimates rebased to 2009/10 (UBOS, 2014). Unfortunately, the published rebased measure of real GDP is only available from 2008/2009 onwards. Therefore, to obtain a consistent measure of this variable for the period prior to 2008/09, we calculate a constant ratio by dividing the GDP over the new base year, relative to the old base year measure. This constant ratio is then applied to the old GDP data to rebase the previous data to the new base period. This approach, which is described in more detail in Stats SA (2014), ensures that previous

growth rates are maintained in the rebased GDP data.

Figure 2.1: Hodrick-Prescott filter for output trend and cycle (2000Q1-2015Q4).



The ITL monetary policy regime recently adopted in Uganda relies on a policy rule that is similar to the Taylor rule (Taylor, 1993) to describe the BoU’s behaviour when setting the short-term monetary policy rate. The original specification of this rule makes use of a measure of the output gap in the monetary policy model. To obtain such a measure, we rely on the widely used filtering technique developed by Hodrick and Prescott (1997).<sup>1</sup> Using the Hodrick-Prescott filter, we can decompose the real GDP data into the trend and cyclical components to generate a measure of the business cycle, by minimizing the following expression;

$$\sum_{t=1}^T (y_t - \bar{y}_t)^2 + \lambda \sum_{t=1}^{T-1} [(\bar{y}_{t+1} - \bar{y}_t) - (\bar{y}_t - \bar{y}_{t-1})]^2 \quad (2.1)$$

In Equation (2.1),  $y_t$  is the natural logarithm of output and  $\bar{y}_t$  is the stochastic trend of output. The constant,  $\lambda$ , represents the penalty for incorporating fluctuations in the trend, such that by increasing the value of  $\lambda$  we assign greater importance to the second difference in the above expression. This would imply that changes in the growth rate of the trend would be kept to a minimum. At the extreme, when  $\lambda \rightarrow \infty$ , the trend level approaches a linear time trend. Similarly, for small values of  $\lambda$ , i.e.  $\lambda \rightarrow 0$ , the trend would be identical to the actual time-series. A key decision when applying this approach is the choice of the value of  $\lambda$  that is to be used in the decomposition. This process is usually influenced by the sampling frequency of the data, and represents a trade-off between smoothness and goodness of fit in the resulting time-series. The literature suggests that,  $\lambda = 1600$  is the value that has traditionally been used for quarterly data. We therefore use the same value to generate the output cycle for Uganda. The result of this decomposition is shown in Figure 2.1.

<sup>1</sup>Hamilton (2017), proposes an alternative approach that relies on a linear projection method to isolate the stationary component in integrated series.

## 2.3 Interest rates

Uganda's financial and capital markets are comprised of a large number of interest rates of different tenures, which reflect the different profiles of risk and maturities within the market. Following the commencement of the ITL monetary policy framework, the Central Bank Rate (CBR) was introduced as the main monetary policy rate. The CBR that is set is aimed at guiding core inflation towards the central bank's policy target of 5 percent over the medium term.

Monetary policy under the ITL is implemented such that the central bank sets the CBR as the operating target to signal its policy stance. The CBR is then used to guide the 7-day interbank interest rate, which is a short-term interbank lending rate, so that it influences the marginal cost of funds for commercial banks. In addition, the central bank regularly intervenes in the money market, with the objective of aligning the 7-day interbank rate to the CBR.

The CBR is set once every two months, and is announced publicly by the BoU governor (the chairperson of monetary policy committee-MPC) at a press briefing, which is held immediately after the interest rate setting meeting of the MPC. This signals the central bank's monetary policy for the ensuing two months. However, the MPC has the prerogative to review the interest rate before its regular scheduled meeting in the case of an unexpected macroeconomic shock to the domestic economy. During the CBR announcement, the chairperson of the MPC also announces the band on the CBR and the margin on the rediscount rate.<sup>2</sup>

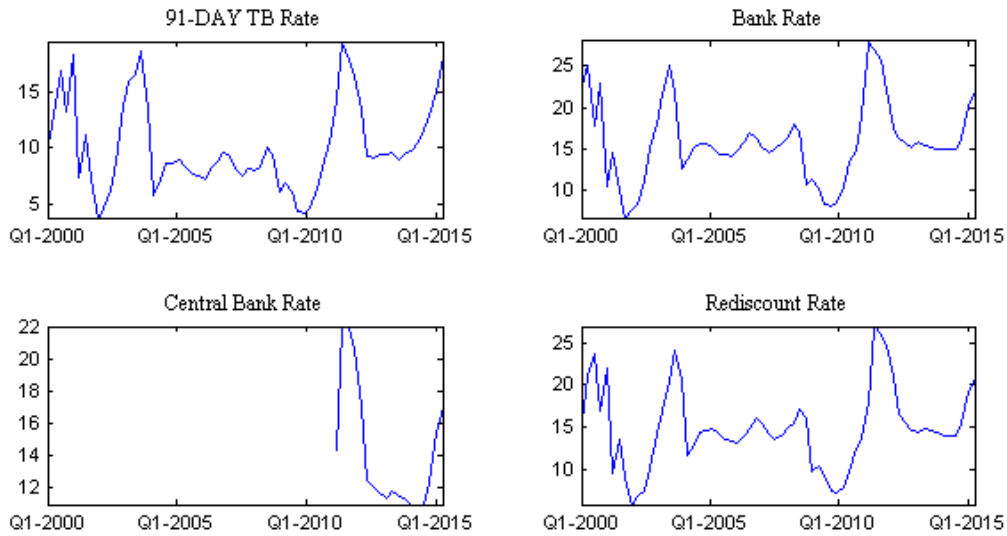
The CBR is thus the main policy instrument, and monetary policy analysis and forecasting models for Uganda would have to incorporate this rate when specifying the policy rule of the monetary authority. However, this interest rate only came into existence in July 2011. We therefore need an alternative short-term interest rate that reflects the monetary policy stance during earlier periods. For this, we select the short-term policy rate that is most highly correlated with the CBR. Since the introduction of ITL, BoU has bench-marked the CBR to the rediscount rate and the bank rate. These two interest rates would thus provide reasonably consistent measures of short-term interest rates in Uganda. The other widely used short-term interest rate in the literature is the 3-month Treasury Bill rate, which, in Uganda's case, is fairly correlated (Figure 2.2) with the other short-term interest rates (bank rate and rediscount rate). In addition, Figure 2.2 shows that there is close co-movement between the bank rate, the rediscount rate, and the CBR, which would imply that the two interest rates could be used in monetary policy models for Uganda. The 3-month Treasury bill rate also closely mimics the bank rate and the rediscount rate. In principle, therefore, any one of the three interest rates could be used

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<sup>2</sup>The band is the limit within which interest rates can change, and the rediscount rate is defined as the rate at which BoU discounts eligible government securities with less than 91 days to maturity.

in a monetary policy model for Uganda.

Figure 2.2: Short-run interest rates in the Ugandan financial market (2000Q1-2015Q4).



Ugandan interest rate data is available on a monthly basis, and quoted as an annual percentage rate. We need to convert these to quarterly interest rates to ensure that they are consistent with the other variables, and the respective characteristics of the models. We convert the data to the respective amount of interest that is earned over the quarter with an annualisation formula which is expressed as:  $R_t = [1 + (\bar{R}_t/100)]^{0.25} - 1$ .

The foreign interest rate employed in the analysis is a trade weighted policy rate for Uganda’s main trading partners, for which there is data available for the period of the study. The trade weighted policy interest rate  $R_t^*$  is also converted into the amount of interest earned over the quarter, using the same annualisation formula above.

## 2.4 Nominal exchange rate

The Ugandan government liberalized foreign exchange controls during the 1990s, dismantling controls on capital accounts, as well as current accounts. Since 1993, the country has largely operated according to a market-based exchange rate regime. Foreign exchange trade takes place in both commercial banks and forex bureaus, where the prevailing exchange rate is determined by the market forces of foreign currency demand and supply. The demand and supply of foreign exchange is in turn largely influenced by the Balance of Payment (BOP). Although market participants exert significant influence over the exchange rate market in Uganda, it is classified by the IMF as a “managed float” de-facto exchange rate regime. The “managed float” exchange rate system allows the central bank to monitor developments in the exchange rate market with the objective of occasionally

intervening to dampen erratic and disruptive fluctuations (or excessive volatility). Moreover, interventions by the central bank are on both the buy and sale sides of the exchange rate market, to ensure that these actions usually have a minimal impact on the country's foreign exchange reserves over a reasonable period of time.

Monthly data on the average exchange rate of the Ugandan currency against the US dollar was sourced from the BoU database. Quarterly exchange rate data is obtained as an average of the exchange rate for the three months in the quarter. To calculate changes in the exchange rate, quarterly exchange rate data is converted to a growth rate, using the following formula,  $\Delta e_t = \log [e_t/e_{t-1}]$ .

Interpretation of movements in the Ugandan currency exchange rate is such that a positive (upward) change in the value of the exchange rate represents a depreciation of the Ugandan currency. A negative (downward) change in the exchange rate would reflect an appreciation in the value of the Ugandan currency. Within this context, preliminary analysis of the exchange rate pattern reveals that the exchange rate is strongly upward trending, which implies that the value of the Ugandan shilling has depreciated over time against the US dollar. The rate of depreciation is represented by the positive percentage change in the value of the Ugandan shilling relative to the US dollar.

## 2.5 Consumer Prices

The price data for goods and services used to calculate the Consumer Price Index (CPI), is collected by UBOS over a two week period each month. The data is collected from the different outlets (for example, markets, shops, saloons, schools, rental houses) in urban centers in the different regions of the country so that the data represents price changes for the country as a whole. After the price data is collected, the CPI is calculated using the "Modified Laspeyres Index" approach.<sup>3</sup>

The list of goods and services for which prices are collected is periodically updated using data from the Uganda National Household Survey (UNHS). This survey collects data on new products in the market, and changes in consumption patterns. In addition, this survey also provides the basis on which to revise weights, so that they are consistent with the changing patterns of consumer preferences. The base period, coverage and weights for the CPI have thus been revised regularly to ensure adequate representation, and such revisions might have caused structural breaks in the CPI data.<sup>4</sup>

For instance, the first post hyper inflation data covered the period between 1989 and July 2000, with 1989 as the base period. The index basket contained prices for

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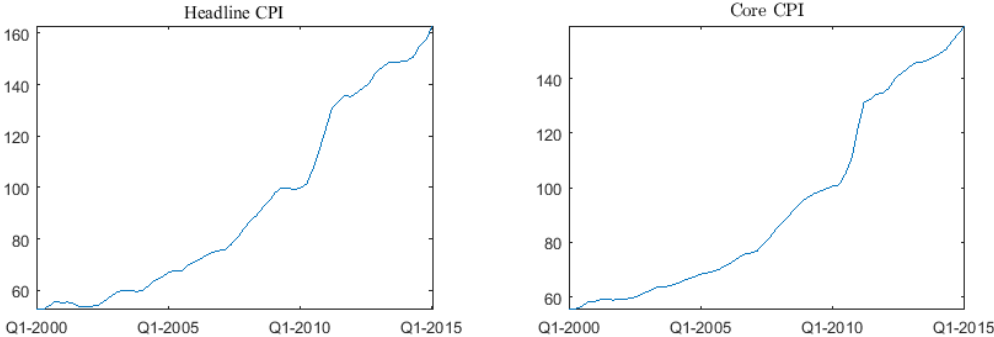
<sup>3</sup>This index is a weighted average of prices of goods and services relative to those prevailing in the base period with the expenditure weights applied in the base period. The "Jevons" geometric average method is used to average prices of comparable items in the expenditure basket.

<sup>4</sup>Structural break points are investigated in chapter 3.

89 items which were collected from 5 urban centres (Kampala/Entebbe, Jinja, Mbale, Masaka and Mbarara). However, in 2000, items in the CPI basket were increased to 125, and the data was collected from 6 urban centres (Gulu was added to the previous 5 centres). In addition, the weights were changed, and the index reconstituted into eight subgroups (Food Crops, Other Foods, Beverages & Tobacco, Clothing & Footwear, Rent, Fuel & Utilities, Household & Personal Goods, Transport & Communication, and Health, Education & Entertainment). These changes were largely informed by the results of the 1997/98 UNHS. Following the results of the 2005/06 UNHS, the CPI was rebased to July 2007, and the re-weighted subgroups increased to nine by separating the Education subgroup from the Health & Entertainment sub-group. In addition, the centres were increased to 8 (Kampala was split into Kampala middle- and low- income, and Kampala high income, and a new centre Arua was added). The number of items was also increased to 276, from 125. In January 2016, the rebased CPI data was released to coincide with the 2009/10 UNHS results, and this is the most recent release.

There are two measures of consumer price data in Uganda. These are the headline index, which measures prices for all goods and services in the consumption basket, and the core index, which is the headline index excluding food crops, electricity, fuel, and metered water. Currently, the core CPI constitutes 82.4 percent of headline CPI.

Figure 2.3: Consumer price index (2000Q1-2015Q4).



The price index which the monetary authority in Uganda targets is the core CPI. This is because the core CPI excludes components that the central bank views as being highly volatile. The central bank does not formulate policy on the basis of a measure that has a lot of noise, as this could give rise to additional volatility in the interest rates. Therefore, the central banks’ reaction function in the multivariate macroeconomic models in this thesis will employ measures for the core inflation rate and the core inflation rate target.<sup>5</sup>

The CPI data is available on a monthly basis, and our theoretical monetary policy models make use of quarterly variables. We therefore first calculate quarterly core CPI data by taking the average of the CPI for the three months in each quarter. The quarterly core inflation rate is then calculated as the quarterly percentage change, using a formula

<sup>5</sup>Currently, the target for core inflation is 5 percent.

that is similar to the one that is applied to the exchange rate. A plot of the quarterly CPI time-series in Figure 2.3 shows a strong upward trend in prices, which implies that prices have generally increased on average in the economy over time.

## 2.6 Exports

Exports play an important role in the economic performance of a small open-economy, such as Uganda's, because they influence developments in the balance of payments, and economic growth. This makes it necessary to briefly discuss this sector, and identify the channels through which shocks to exports are transmitted to the domestic economy. In the early 1980s, 95 percent of Uganda's export revenue was from coffee exports (Dijkstra, 2001). Because exports were concentrated in a single sector, the economy was exposed to external demand and price shocks that affected this commodity. As a result, during the 1990s, the government of Uganda with support from development partners, undertook deliberate policy interventions to reform the export sector. One such intervention focused on widening the export base by promoting non-traditional exports through diversification policies (Atingi-Ego and Sebudde, 2004).<sup>6</sup> As a result of these policies, exports were greatly diversified, and the state of the economy in the early 1990s, in which the country relied mainly on coffee, cotton, tea and tobacco exports, has shifted to include non-traditional products such as fish and horticulture. Available evidence based on the normalized Herfindahl-Hirschman index of export diversification shows that concentration was reduced from 0.5 in 1998 to 0.2 in 2009 (Ofa et al., 2012).

Notwithstanding the observed diversification, the export sector is still dominated by primary and semi-processed products, with prices that fluctuate in the world market. This characteristic of the export sector renders the economy vulnerable to foreign economic developments. For instance, when the global economy is booming, Uganda's exports increase and when there is a global economic slowdown, such as the one experienced during and following the recent financial crisis, Uganda's exports decline. Furthermore, reliance on rainfall patterns for agricultural production also impacts on the country's ability to export. When the country suffers a drought, agricultural output declines, resulting in a decrease in export volumes, and economic growth.

The export data is available as part of the balance of payment (BOP) statistics from the BoU, and it is measured in US dollars. Because the BOP data is quarterly, we only need to convert the data into the Ugandan currency equivalent by multiplying the US dollar export values by the quarterly Ugandan shillings/US dollar exchange rate.

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<sup>6</sup>Non-traditional exports exclude coffee, cotton, tea and tobacco.

## 2.7 Imports

The relatively fast rate of economic growth in Uganda over the last two decades has been accompanied by an increase in demand for foreign goods and services, and as a result, Uganda's import bill has more than quadrupled during this period. In terms of composition, imports to the country include both raw materials, which are used for production, and products that are ready for consumption. About a quarter of the import bill is oil products. Other important products include pharmaceuticals and capital goods.

During this period, growth in the import bill has outstripped the foreign currency inflows from exports, and, as a result, the trade deficit has widened. The exchange rate thus faces significant depreciation pressures. This also contributes towards a rise in inflationary pressures, as the cost of imported goods increases.

Similar to the export data, quarterly data on imports is available as part of the balance of payments statistics from the BoU. We convert the currency value to Ugandan shillings, using the formula used for the export data.

## 2.8 Terms of Trade

The terms of trade (TOT) of the domestic economy is defined as the ratio of an index of the prices of exported goods to an index of the prices of imported goods, both quoted in foreign currency. In this sense, TOT describes the relationship between prices and quantities of goods in the domestic economy relative to the rest of the world. Moreover in small open economies, the price for tradable goods and services is largely determined in an exogenous world market, over which the domestic economy has little or no influence. Therefore, sizable shocks to the TOT, which could be reflected by sudden, large and potentially long lasting changes in either import or export prices, tend to affect domestic economic output. In LICs such as Uganda, which predominantly export primary and semi-processed commodities, TOT shocks tend to occur more frequently. Consequently, the models for macroeconomic analysis in LICs should pay close attention to the behaviour of this variable, and should articulate the manner in which such shocks are transmitted to the domestic economy.

In Uganda, this variable shows tremendous swings in some years, perhaps reflecting the erratic nature of primary commodity prices, but for other periods this variable is fairly stable for extended periods of time. For instance, there were frequent swings in the TOT between the start date of the sample and 2006. However this variable was relatively stable between the years 2006 and 2008, and deteriorated as a result of import prices, which on average rose faster than export prices. In addition, the TOT has improved since 2011, possibly due to the lower prices of key imports (mainly oil) during this period.

## 2.9 Financial sector specific variables

Uganda's financial sector is underdeveloped and dominated by commercial banks. Other key players in the formal financial sector are foreign exchange bureaus, non-bank financial institutions, savings and credit institutions, microfinance deposit-taking institutions, insurance companies, and a securities exchange market. Commercial banks, savings and credit institutions, and microfinance deposit-taking institutions play a dominant role as a source of credit for households and firms. Monetary policy models for Uganda that aim to appropriately capture the role of financial frictions in monetary policy formulation need to incorporate this feature.

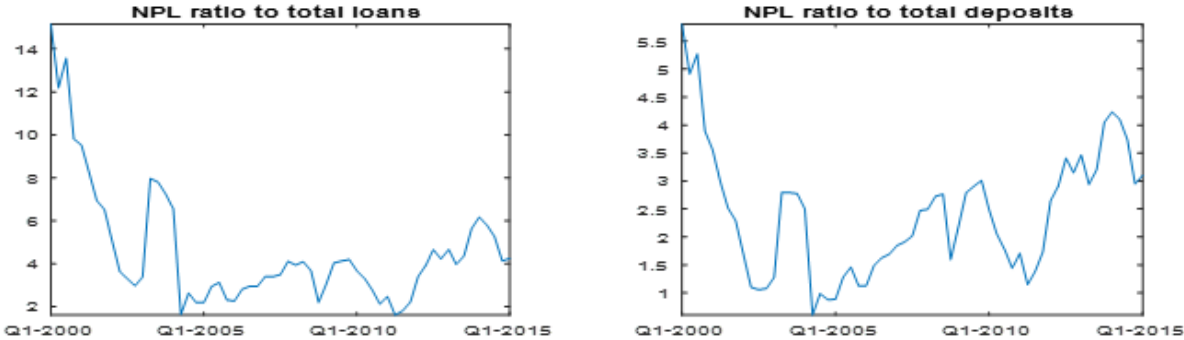
Only 18 to 21 percent of Ugandans have access to formal financial services (BOU, 2014). However, the level of financial inclusion has greatly increased, from 38 percent of the adult population in 2006 to about 85 percent in 2013. This change has to a large extent been aided by mobile money financial services technology.

There is also evidence to suggest that financial intermediation has increased significantly during the last decade, when assessed in terms of both deposit mobilization and the proportion of deposits that are lent out to individuals and businesses. For example, banking sector loans as a share of deposits has expanded from about 38 percent in 2005 to 72.8 percent in June 2015. Similarly, banking sector capital as a share of total assets, which measures the level of capital adequacy in the banking sector, has expanded from 10.25 percent in 2000 to 16.54 percent in 2015. This occurred during a period when the ratio of non-performing loans (NPLs) to total gross loans (Figure 2.4), which is one of the measures of asset quality of the banking sector, declined from 9.82 percent in 2000, to 2.12 percent in 2010. Thereafter, it rose to 5.97 percent in 2013, following monetary policy tightening pursued by the central bank between August 2011 and January 2012. Changes in NPLs translate into changes in bank profitability, which in turn impacts on the commercial banks willingness to lend to households and firms. For instance, the high level of NPLs in 2013 could have led to tighter credit conditions, and this, coupled with increased interest rates, could have led to a reduction in credit extended to households and firms during this period.<sup>7</sup>

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<sup>7</sup>Provisions for NPLs was 64.82 percent in 2013, compared to 45.87 percent in 2012 (BOU, 2014).

Figure 2.4: Non-performing Loan ratios in the Ugandan financial market (2000Q1-2015Q4).



## 2.10 Conclusion

In this chapter we provide an overview of key macroeconomic data for Uganda, which will form the basis of the analysis in the subsequent chapters. We present the sources of the data, the calculations used, and the necessary data conversions to make the variables amenable to our models of business cycles in Uganda. Understanding the key macroeconomic variables that are relevant to monetary policy formulation in Uganda provides an initial insight into the nature of questions that our study must probe. Some of the key findings from this exploration show that the Ugandan economy underwent significant reforms during the early and mid-1990s. In addition, the composition of the economy has undergone a significant structural transformation. This saw the dominance of the agricultural sector reduced, and the expansion of the services sector. Furthermore, coverage and calculation of some of the key variables have gone through several changes. For example, the base period and coverage have changed over time. These changes could mean that there could be structural breaks in some of the time-series.

# Chapter 3

## Inflation dynamics in Uganda

### 3.1 Introduction

High rates of inflation influence the decisions of economic agents, lower real rates of return, are a source of higher expected future rates of inflation, increase the cost of living, affect asset prices, and distort income distribution. Consequently, one of the main objectives of central banks, in both developed and developing countries, is the attainment and maintenance of low and stable rates of inflation. This applies to the Ugandan central bank, where the BoU is tasked with maintaining a rate of core inflation that is less than 5 percent over the medium-term.<sup>1</sup> To satisfy this objective, policymakers at the BoU need to understand the nature of the inflation dynamics over the medium to long term. This include information on the degree of inflation persistence, which is affected by the level of price stickiness.

Measures of inflation are also normally included in multivariate macroeconomic models used by central banks. The features of these models partially depend upon the characteristics of the data generation process for the inflation variable ([Basher and Westerlund, 2008](#)). Therefore, an investigation into whether the inflationary process is stationary or non-stationary plays a vital role in the construction and evaluation of monetary policy rules ([Culver and Papell, 1997](#)). This topic is therefore an active area of macroeconomic research, and it is the main focus of this chapter.

The definition of inflation rate persistence that has been adopted in this analysis relates to the speed at which the inflation rate returns to its starting (or mean) level after a shock (c.f. [De Oliveira and Petrassi, 2010](#); [Wolters and Tillmann, 2015](#)). In this sense, a persistent rate of inflation would potentially increase the cost of monetary policy, because of the output and employment that would need to be sacrificed by the monetary authority to get inflation under control ([Mishkin, 2007](#)). Inflation persistence thus plays an important role in the formulation of monetary policy, since it provides the central bank

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<sup>1</sup>The core inflation measure excludes volatile components such as energy and food prices.

with useful information about how the policy instruments should be employed to achieve their inflation target ([Angeloni et al., 2006](#)).

Uganda provides for an interesting setting for an analysis of the persistence in inflation, as core inflation was kept down to single digits during the early part of the twenty first century. However, between 2008 and 2012, the country experienced two heightened inflationary cycles in quick succession, where inflation rose to double digits. This could have altered the persistence dynamics, since past inflation rates (intrinsic persistence) are regarded as the primary sources of inflation persistence ([Fuhrer, 2009](#)). In addition, such an investigation would be of interest to policymakers in Uganda, who recently adopted an inflation targeting framework for the conduct of monetary policy. Such an analysis would also be of interest to researchers in developing countries and LICs, which have high inflation rates compared to most advanced emerging economy countries.

A large body of literature on inflation persistence has examined the time-series properties of inflation. The early literature mainly focused on investigations into the degree of persistence in the conditional mean of the process. These assessments of inflation persistence involved an analysis of the order of integration in the measures of prices and inflation rates, with the use of standard time-series techniques, such as the [Dickey and Fuller \(1981\)](#) procedure. If the null hypothesis of a unit root could be rejected in favour of the alternative hypothesis of stationarity, it would imply that shocks dissipate and that the inflation rate would return to the equilibrium level after a period of time.

However, the inflation rate could experience structural breaks (either known or unknown) due to a policy shift or other macroeconomic events. For instance, an exogenous policy shift, such as a monetary policy shock (e.g. a shift to inflation targeting, or a change in the intermediate target) or a fiscal policy shock (e.g. change in the tax regime), would result in transitory fluctuations of the inflation rate. For example, an increase in the aggregate tax rate due to a change in fiscal policy may lead to an increase in the prices of goods and services, which would affect inflation. In addition, a monetary policy shift such as the adaptation of an inflation targeting (IT) regime by a central bank may result in a shift in the inflationary regime (i.e. a structural break in the inflationary process). Therefore, failure to account for such changes could yield different estimates of the degree of inflation persistence. Similar observations have been made by those who have considered the effects of structural breaks on parameter estimates in unit root tests.<sup>2</sup>

The impact of such shocks on the dynamic features of inflation may depend on the departure of the inflationary process away from the mean inflation rate. In most emerging economies and LICs, where shocks tend to arise more frequently and may be large, that could give rise to a relatively high degree of persistence. In contrast, smaller shocks would lead to lower deviations from the mean rate of inflation. This could generate a lower degree

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<sup>2</sup>See for example, [Perron, 1990](#), [Perron and Vogelsang \(1992\)](#), [Vogelsang and Perron \(1998\)](#), [Zivot and Andrews \(2002\)](#).

of persistence, as the identification of these isolated shocks may be more accurate. In addition, investigating the persistence in the conditional mean would be less informative in an emerging market or LIC setting as the mean rate of inflation may be volatile. As a result, the conditional quantile should be considered, since it provides information about the level of persistence and the certainty that is associated with parameter estimates around the point estimate. This technique also provides information on the asymmetry arising from the different magnitudes of the shocks that occur over time.

Fortunately, the recent literature provides evidence of persistence based on the conditional distribution of a time-series. For example, one informative framework that has emerged employs the Quantile Regression (QR) technique that was introduced by [Koenker and Xiao \(2004\)](#). The application of this technique has also been used in the analysis of inflation persistence by [Tsong and Lee \(2011\)](#) and [Wolters and Tillmann \(2015\)](#). The quantile regression approach allows us to derive estimates and make inference about the persistence in the inflation rate at different conditional distributions. Such a detailed analysis of the level of persistence would allow us to investigate whether changes in persistence are harmonized across the various quantiles of the inflation rate and whether or not anticipated changes in persistence are useful when seeking to explain changes to the distribution of the inflation rate ([Wolters and Tillmann, 2015](#)).

The literature on inflation dynamics in Uganda has, to date, largely focused on the causes of inflation and very little has been published on the persistence of inflation. For example [Kabundi \(2012\)](#) and [Maweje and Lwanga \(2015\)](#) use time-series analysis techniques to distinguish between the short-run and long-run causes of inflation. These studies suggest that both domestic and external factors are the main drivers of inflation in Uganda, over the short and long-run. Some of these factors that have been identified include, domestic money growth, domestic demand and supply shifts in agricultural sector, as well as developments in world food and energy prices ([Kabundi, 2012](#)). Ugandan inflation may also be driven by structural factors, which have an as-yet unknown effect on the evolution of prices. A study by [Kabundi \(2012\)](#) also finds evidence of inflation inertia in Uganda, which is measured with the aid of a lagged inflation term.

The objective of this chapter is to provide a detailed exploration of the dynamics of the two main measures (headline and core) of inflation in Uganda. This is achieved by analysing inflation persistence. Firstly, we probe the speed of adjustment of the inflation rate in response to various macroeconomic shocks, using the quantile regression framework that was applied to study US inflation by [Wolters and Tillmann \(2015\)](#), and by [Tsong and Lee \(2011\)](#) to study inflation behaviour in 12 OECD countries. This approach allows for the identification and measurement of the mean-reverting properties in various quantiles. The time-varying nature of the measure of persistence is then obtained with the use of a 10 year rolling-window. To investigate structural changes in persistence at the different inflation quantiles, where the structural break-dates are unknown, we em-

ploy the technique developed by [Oka and Qu \(2011\)](#). Persistence is also measured by the sum of the autoregressive coefficients (SARC), which is obtained from the [Hansen \(1999\)](#) grid bootstrap median unbiased estimator that provides a confidence interval that has desirable asymptotic properties. In addition, we also calculate the half-lives (HLs) from the estimated SARC, to consider the robustness of the reported results.

In the second half of the analysis, we extend the framework employed by [Tsong and Lee \(2011\)](#) and [Wolters and Tillmann \(2015\)](#). We first apply a wavelets decomposition to the headline inflation rate to obtain a measure of core inflation, which is different to the core inflation data produced by UBOS (that excludes food and energy prices). This method for calculating core inflation is motivated by a recent study that suggests that a wavelet decomposition of the inflation rate produced a useful measure of core inflation for South Africa ([Du Plessis et al., 2015](#)). We then measure the degree of persistence with the technique used in the first part of the analysis to the wavelet measure of core inflation. This gives us a comparison of the level of persistence in the two alternative measures of core inflation. Such a comparison can be informative for a central bank like the BoU, which targets core inflation. In addition, the comparison will identify any weakness in the current measure of core inflation used by the BoU for monetary policy formulation.

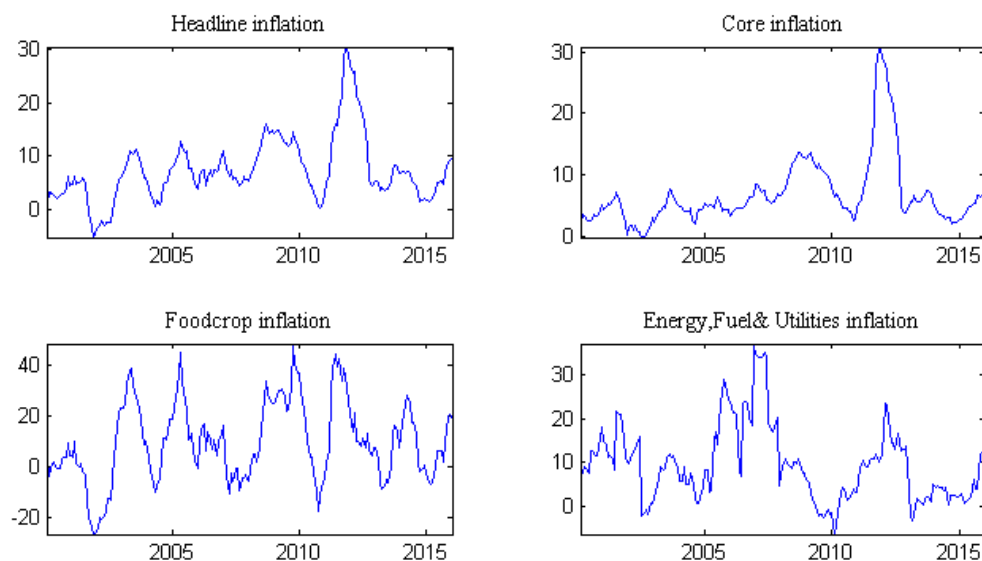
The rest of the chapter is laid out as follows. Section 3.2 briefly discusses the trends in Uganda's inflationary experience in the last two decades. This is followed by section 3.3, which reviews the related literature, that is divided into the theoretical literature and the empirical literature for developed and emerging economies (including African countries). The methodology employed and a description of the data are presented in section 3.4, and section 3.5, respectively. Section 3.6 then discusses the results before the conclusion is presented in the final section.

## 3.2 Stylized facts about Ugandan inflation dynamics

The inflation rate in Uganda was entrenched in the single digit territory for much of the last two decades ([Figure 3.1](#)). Notably, headline and core inflation averaged 7.3 percent and 6.9 percent, respectively between, 2000 and 2015. However, during this period, Uganda experienced two episodes of increased inflationary pressure, in which core and headline inflation reached double digit levels. The first of these spikes was caused by a global food supply shock, that increased international food prices and caused an upsurge in domestic inflation. This lasted from April 2008 to September 2009 for the core measure, and from May 2008 to December 2009 for the headline measure. More recently, inflation spiked again, and price increases were rapid, with inflation peaking at almost 31 percent in October 2011, before taking a downward trajectory. This second upsurge in Ugandan inflation was largely due to the effect of a global commodity price shock, coupled with a

rapid depreciation in the value of the currency, and relatively low interest rates.

Figure 3.1: Ugandan inflation rate January 2000 - December 2015.



Between September 2012 and December 2015, the year-on-year headline and core inflation rates remained at single digit levels. The annual core inflation rate averaged 4.8 percent during this period, which is well within the central bank target rate of 5 percent. Year-on-year headline inflation also averaged 5.0 percent during the same time period.

When the ITL was adopted, inflation was on an upward trajectory, due to a series of supply shocks in agricultural production that resulted in food shortages that pushed domestic food prices upwards. In addition, the sharp rise in the international crude oil price, and a depreciation in the exchange rate, also contributed to rising inflation. However, after the peak in October 2011, inflation has been on a downward trajectory. To a large degree this was driven by exchange rate appreciation over this period, coupled with a contractionary monetary policy phase. Since then, core inflation has remained close to the BoU target rate.

The effectiveness of monetary policy to curb the first episode of heightened inflation was limited. Monetary policy in Uganda at that time was based on targeting monetary aggregates, which could not effectively communicate monetary policy actions to the public. This limited the ability of monetary policy to act as an anchor for domestic price expectations. However, the most recent inflationary phase coincided with the introduction of the ITL monetary policy regime, which perhaps explains why this phase of inflationary pressure was shorter.<sup>3</sup>

Following the introduction of the ITL regime in July 2011, the focus of monetary policy

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<sup>3</sup>Stone (2003), defines ITL as a monetary policy regime where central banks announce a broad inflation objective, however, as a result of their relatively low credibility, they may not be able to maintain an explicit rate of inflation over a period of time.

has shifted explicitly to the containment of inflation to within the set target, over the medium-term. By adopting ITL, the central bank envisaged that the public announcement of the inflation target and the monetary policy actions would enhance transparency in monetary policy, and hence provide a better anchor for inflation expectations (Mugume, 2011).

## 3.3 Literature Review

### 3.3.1 Theoretical Framework

The central bank should be able to design appropriate monetary policy models that help it achieve its objective without exerting an excessive negative effect on output. For this, the central bank needs to understand the inflationary process. This partly explains why macroeconomic models, which are used for purposes of monetary policy analysis, make assumptions about the price formation process. In addition, policymakers recognize that when they pursue a tight monetary policy other important macroeconomic indicators, such as output growth, may be negatively affected over the short term. This is due to the interest rate channel in the monetary policy transmission mechanism. The close relationship between monetary policy actions and output (and unemployment) gives rise to the concept of the sacrifice ratio (Gordon et al., 1982). This ratio is defined as the number of years of elevated unemployment required to reduce inflation by a percentage point.

The sacrifice ratio has emerged as one of the key policy considerations in macroeconomics, because it serves as an acknowledgment of assumed persistence in the inflation variable. That is, more persistence may result in a higher sacrifice ratio, since the central bank would need to raise interest rates for a longer period or by a larger amount, when inflation is above the target rate. Similarly, less persistence may result in a smaller sacrifice ratio, since a small increase in the interest rate, or a monetary contraction for a shorter period of time would get inflation back to the target rate.

Techniques used to measure persistence have evolved over time, following the development of a number of important time-series methods. In the early literature, many authors used univariate models to measure persistence. Specifically, persistence was measured through scalar indicators in univariate models such as the SARC, the largest AR root, the half-life, and spectral density at the zero frequency (c.f. Andrews and Chen, 1994; Marques et al., 2004).<sup>4</sup> The use of such scalar measures of persistence was justified by the intuitive relationship between persistence and impulse response functions (IRFs).<sup>5</sup>

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<sup>4</sup>Half lives measure the number of periods in which inflation rate remains above half of its initial level following a unit shock to the inflation rate.

<sup>5</sup>Persistence is defined in the literature as the speed with which inflation converges to equilibrium level, which makes it synonymous to the concept of an IRF for a AR(p) process.

Despite this relationship, IRFs could not be used as alternative measures of persistence, since IRFs are infinite-length vectors, which makes it difficult to arrive at a single value to measure the degree of persistence.

The use of univariate models to measure inflation persistence was also challenged on the grounds that the mean (or equilibrium) inflation rate is presumed to be constant over time. This contradicts a large body of evidence which suggests that the dynamics of the inflation process change over time (c.f. [Dossche and Everaert, 2005](#); [Gadzinski and Orlandi, 2004](#); [Levin et al., 2004](#)). Moreover, some of the specific measures of persistence that are based on the univariate approach have also been criticised on the grounds that they ignore potentially important information. For example, the measurement of persistence that uses the largest AR root has been challenged on the basis that it provides a very poor summary measure of the impulse response functions, because the shape of such a function would in fact depend on all the AR roots, and not just the largest root (c.f. [Andrews and Chen, 1994](#); [Pivetta and Reis, 2007](#)). By ignoring additional roots, one would obtain scalar measures of persistence that are less precise. The measurement of persistence based on HLs has also been criticised on the grounds that it does not identify changes in persistence over time, and the half-life for highly persistent process is normally reported to be very large ([Pivetta and Reis, 2007](#)).

Furthermore, the literature on inflation persistence has suggested that it may be more appropriate to use multivariate models, because univariate models suffer from omitted variable bias, as some of the potential drivers of inflation (such as output gap) are excluded. According to this theory, the observed persistence in the inflation rate may be attributed to the evolution of the output gap, and omitting such important information may result in biased and inconsistent estimates of persistence. To address such concerns in the measurement of inflation persistence, some studies suggest the use of multivariate models such as the classical vector autoregressive (VAR) models and Bayesian VAR methods (c.f. [Cogley and Sargent, 2001](#); [Pivetta and Reis, 2007](#)).

Some studies have also investigated the issue of measuring persistence in inflation with the use of structural Dynamic Stochastic General Equilibrium (DSGE) models. These studies, which include [Schorfheide \(2008\)](#), [Caraianni \(2009\)](#), and [Dixon and Kara \(2010\)](#), consider the possibility of shifts in the inflation mean (or equilibrium) while also considering the degree of inflation persistence. Presently, new Keynesian macroeconomic models explain inflation dynamics using the New-Keynesian Phillips Curve (NKPC), in which nominal and real rigidities give rise to sticky prices that may generate a greater degree of inflation persistence. This can be attributed to three sources. First, persistence in inflation may result from nominal rigidities in wages or prices. Second, nominal wage and price rigidities could give rise to real rigidities in wages and prices. Third, marginal costs of firms could then rise, due to the real rigidities. Consequently, as the percentage of firms that adjust prices increases, the optimal price level in the economy would be expected to

rise. In addition, the existence of a positive output gap, where the actual level of output exceeds the potential level of output, would be expected to increase wages and prices, and thus inflation could rise.

Recent advances in inflation persistence analysis have sought to model the time-varying nature of inflation persistence. Such studies argue that mean inflation rates may have decreased worldwide, because of changes in the credibility of central banks over time. This could also happen because of the emergence of more formal new monetary policy frameworks (such as IT) in several countries. This decrease in mean inflation rates could have altered the persistence in the inflation variable. For example, [Lansing \(2009\)](#), argues that IT resulted in lower rates of inflation, and this in turn distorts standard measures of persistence and volatility. Therefore, the time varying persistence literature (c.f. [Taylor, 1998](#); [Sargent, 1999](#)) posits that such changes imply that the lead and lag terms in the NKPC may need to be adjusted, when such a model is applied to different samples of data and where the model makes use of calibrated parameters.

### 3.3.2 Empirical Literature

Most empirical studies of measures of inflation persistence have concentrated on case studies of developed and advanced emerging market economies. This research provides mixed results, particularly concerning the dynamics of persistence after the mid-1980s. Early studies had generally shown a decrease in the level of persistence between 1960s and mid-1980s for both the United States and several advanced countries. Some studies find evidence of a decline in inflation persistence after the mid-1980s, while others do not find such evidence. There is general consensus, more recently, that inflation persistence has declined, particularly in those countries that have adopted IT, either formally (several European and emerging countries) or informally (the United States).

Different estimation procedures have been employed in the literature. For example [Williams \(2006\)](#) utilizes a Phillips curve model to investigate whether or not inflation persistence has declined in the United States. In this model, the inflation rate is influenced by past levels of inflation and the unemployment rate from the previous period. The measure of persistence he employs is the sum of the coefficients on lagged inflation. This model is estimated over different samples, and the results reveal that the SARC (four lags) on inflation appears to have declined significantly, from a level that is close to unity in the period 1980Q2 to 2006, to levels ranging from 0.6 for core personal consumption expenditure (PCE) inflation, and 0.4 for core CPI inflation, during the period 1999Q4 to 2006Q2. The author attributes the observed decline in persistence to changes in monetary policy framework, which helped to anchor inflation expectations.

In a study which focuses on developed countries, [De Oliveira and Petrassi \(2010\)](#), makes use of univariate and multivariate reduced-form models. These are models that

include lags of inflation with and without GDP gap; NKPC with foreign exchange rates; and models that are reduced-form inflation dynamics of structural models that incorporate some form of wage rigidity. They use these models to compare the dynamics in quarterly headline inflation persistence in 23 industrialized countries and 17 emerging economies. They find a low and stable level of inflation persistence for both developed and emerging economies. The level of persistence for the developed countries is found to be lower than in emerging economies. Similar results can be found in studies by [Dossche and Everaert \(2005\)](#) and [Altissimo et al. \(2006\)](#). For instance, [Dossche and Everaert \(2005\)](#), argue that failure to account for shifts in mean inflation may result in a biased estimate of inflation persistence. To account for shifts in the level of mean inflation, they employ a structural time-series approach, in both a univariate and multivariate setup, to model the data-generating process of inflation in countries of the European Union and the United States. In addition, they use Kalman filtering and smoothing techniques to estimate unobserved time-varying inflation dynamics. In their setup, output is decomposed into potential output and a business cycle component, which helps to disentangle intrinsic and extrinsic persistence in response to the business cycle. Based on this categorization, their results reveal that intrinsic inflation persistence is less than that of a random walk, with the SARC at 0.45 for the euro area and 0.8 percent for the United States.

In a further study, [Benati \(2008\)](#), investigates persistence for different periods in a number of European countries (pre and post-Monetary Union), the United Kingdom, Canada, Australia (pre and post- IT), and the United States (pre and post-Volcker disinflation period). He uses a structural model, which is based on the medium unbiased estimation technique, where the confidence intervals are derived from a grid bootstrap method. The results suggest that inflation persistence decreased in all countries in the sample that adopted an IT monetary policy regime, including the United States, which has an informal IT regime. A similar approach is employed by [Levin et al. \(2004\)](#) to investigate inflation inertia in the core and headline inflation of advanced economies. Their findings suggest that inflation persistence is lower among IT countries. They report that for the countries that do not use IT, the level of persistence in headline and core measures are identical.

[Clark \(2006\)](#), investigate the level of inflation persistence in the United States by comparing persistence in the disaggregated and aggregated measures of consumer price inflation. He also examines whether inflation persistence has changed based on a rolling window estimation procedure, similar to the approach employed by [Stock and Watson \(2001\)](#) and [Pivetta and Reis \(2007\)](#). The procedure he followed is also similar to the one used by [Andrews and Chen \(1994\)](#), where persistence is measured by the SARC that measures the cumulative long-run response of inflation to a shock (where the spectral density is close to zero). To obtain confidence intervals for the persistence estimates and the median unbiased estimates of persistence, Clark employs the grid bootstrap ap-

proach developed by Hansen (1999). The results from Clark’s paper reveal that, when mean inflation is assumed to remain unchanged within samples, the average persistence in disaggregated inflation is consistently below aggregate persistence. Furthermore, the aggregated measure of persistence was reduced, marginally. The model for disaggregate data showed that inflation persistence declined during the same period. This suggests that there has been a mean shift in inflation persistence for both the aggregate and disaggregate measure of inflation. These results continue to hold after accounting for changes in the mean rates of inflation.

A related approach that investigates time varying persistence, and which will be followed in this chapter, can be found in Tsong and Lee (2011) and Wolters and Tillmann (2015). This approach uses a quantile regression technique proposed by Koenker and Xiao (2004), to assess the time variation in inflation rate persistence at different quantiles. Tsong and Lee (2011), apply this framework to investigate the dynamics of inflation in 12 OECD countries, and find that inflation rates are not only mean-reverting but also asymmetric. Wolters and Tillmann (2015), apply the same technique on post-war US inflation data, and identify a number of break points at various quantiles during 1980s. These are due to the time-varying nature of the mean rate of inflation.

Gadzinski and Orlandi (2004), investigate inflation persistence in the GDP deflator, CPI inflation, core inflation, HICP inflation, private consumption inflation, and services inflation, for the EU countries. They also compare persistence in the euro area and the US, using quarterly time-series data that span the period 1970-2003. The framework they follow assumes that inflation may be modelled as an AR process that allows for structural breaks, and a time varying mean. The inclusion of an endogenous structural break ensures that the degree of inflation persistence in the time-series is not overestimated (c.f. Perron, 1990; Levin and Piger, 2002). They examine the level of persistence through the SARC, and the half-life, and conclude that inflation persistence decreased across all measures from the beginning of 1984, albeit at varying magnitudes. They also show that the hypothesis that there is an absence of persistence in GDP inflation cannot be rejected in many cases. Lastly, the degree of persistence in the euro area was found to be comparable to that of the United States.

Studies that have considered the degree of inflation persistence in African countries include, Rangasamy (2009) and Balcilar et al. (2016a), which make use of South African data. While, Cuestas et al. (2009), makes use of data from selected African countries and Belbute et al. (2015) consider inflation persistence in Angola. These studies use different methodologies to explore inflation persistence for the different African countries. For example, Rangasamy (2009), uses a univariate AR model to obtain measures of persistence in both aggregate as well as disaggregated inflation data. In his approach, persistence (which is given by the SARC,  $\rho = \sum_{i=1}^n \alpha_i$ ) is measured as the time it takes for inflation

to return to a time-varying inflation mean following a shock. Rangasamy’s results show that inflation in South Africa was persistent ( $\rho = 0.98$ ) up until the adaptation of IT in 2000, but decreased during the post IT period ( $\rho = 0.83$ ). He concludes that IT provides a useful anchor of inflationary expectations, and the results are robust, as the disaggregated inflation data produces similar results. However, Rangasamy notes that these results could be sensitive to structural breaks.

Similarly, in a recent paper, [Balcilar et al. \(2016a\)](#), makes use of a Markov-Switching AR fractionally integrated moving average model, to test for the presence of a long memory amidst changes in inflationary regimes. Their findings suggest that volatility and persistence in South African inflation increase during periods of high inflation. Notably, a shock to inflation required approximately 70 months to shed half the shock during regimes for high mean rates of inflation. During a low inflation regime, it took 10 months to shed a shock of the same magnitude.

[Cuestas et al. \(2009\)](#), apply a logistic smooth transition AR (LSTAR) model to analyse inflation persistence in selected African countries. Their findings suggest that there is an absence of persistence in most countries sampled, which means that shocks to the inflation rate tend to be short-lived. In addition, they find that the estimated models are stable, suggesting that in the absence of exogenous shocks, inflation would possibly stay within a single regime.

[Belbute et al. \(2015\)](#), examine inflation persistence in Angola using five inflation indicators (headline, food, energy, underlying core, and 10% trimmed mean core) using a non-parametric approach. This measure of persistence is based on the degree of mean reversion. Where the time-varying mean is extracted, after applying a Hodrick-Prescott filter to the data. The results suggest that, when structural breaks are incorporated in the analysis, all five measures of inflation are stationary. In addition they find that the level of inflation persistence is low, and that it is similar for all five measures, throughout the sample.

## 3.4 Empirical methodology

### 3.4.1 Univariate AR model

One of the early approaches used to measure persistence in a time-series was the use of univariate AR models. The model specification for the standard univariate AR(q) process for inflation, could be expressed as:

$$\pi_t = \alpha + \sum_{j=1}^q \beta_j \pi_{t-j} + \varepsilon_t, \quad (3.1)$$

where  $\pi_t$  is the monthly or quarterly seasonally adjusted inflation measure (core or

headline),  $\alpha$  is the intercept term and  $\varepsilon_t$  is an independent and identically distributed (i.i.d) innovation to the inflation rate with mean zero and a constant variance,  $\sigma^2$ . The persistence in the inflation rate is then measured using the scalar measure of the SARC ( $\rho = \sum_{j=1}^q \beta_j$ ) in Equation (3.1). The justification for this scalar measure of persistence is discussed in [Andrews and Chen \(1994\)](#), who argue that the long-run persistence property in a time-series can be displayed with the aid of an impulse response function. Consequently, [Andrews and Chen \(1994\)](#), suggest that it is appropriate to use the SARC to capture persistence, because there is a monotonic relationship between  $\rho$  and the cumulative impulse response function of future values of inflation ( $\pi_{t+j}$ ) due to a shock to the inflation rate process ( $\varepsilon_t$ ). To capture the sum of the autocorrelation coefficients for the inflation rate, Equation (3.1) can be rewritten as:

$$\pi_t = \alpha + \rho\pi_{t-1} + \sum_{j=1}^{q-1} \delta_j \Delta\pi_{t-j} + \varepsilon_t. \quad (3.2)$$

Equation (3.2) corresponds to the popular Augmented Dickey Fuller (ADF) regression by [Dickey and Fuller \(1979, 1981\)](#), which is used to determine whether a time-series process is stationary, where the change in the inflation rate between two periods is expressed as,  $\Delta\pi_t = \pi_t - \pi_{t-1}$ . The value of  $\rho$  from Equation (3.2) plays an important role in determining the form of time-series process (i.e persistent or not), such that when  $|\rho| = 1$ , the inflation rate would contain a unit root (i.e. it is a random walk process). A variable with such a characteristic is said to display infinite persistence. In contrast, when  $|\rho| < 1$ , the inflation rate is said to be stationary, as it would exhibit mean reverting characteristics following a shock.

When the AR process has a unit root, which occurs when the true value of  $\rho$  is unity, then the estimate obtained for this coefficient in Equation (3.2) suffers from a downward bias problem when classical techniques are used. To resolve this problem, [Andrews and Chen \(1994\)](#) and [Hansen \(1999\)](#) suggest that the median unbiased estimate of  $\rho$ , which is derived from a bootstrap procedure, should be used. This bootstrap procedure could be used to calculate the estimated coefficient, for persistence as well as its confidence intervals. The procedure that will be adopted to report the estimates from the conditional quantiles in this analysis is one proposed by [Koenker and Xiao \(2004\)](#) and which is also found in [Tsong and Lee \(2011\)](#) and [Wolters and Tillmann \(2015\)](#). This approach has a greater power over the ADF test, when the shock exhibits heavy-tailed behaviour.

### 3.4.2 Quantile Autoregression

Quantile autoregression (QAR henceforth) models are derived from univariate AR models, and they may be used to investigate persistence when the time-series has an asymmetric distribution. The application of the QAR method in unit root tests was introduced by

Koenker and Xiao (2004). This literature was later extended to the analysis of inflation persistence by Tsong and Lee (2011), and recently by Wolters and Tillmann (2015).

This framework makes use of quantiles to describe the distributions of the parameters according to the proportion of observations that fall below the respective quantile. Within this context, this approach allows us to explore unit root characteristics across the different quantiles, and also to measure the speed of adjustment of the time-series back to its mean level, following shocks of different magnitudes and signs. Moreover, since the unit root test in the QAR framework is performed at individual quantiles, we avoid making the strong assumption that the time-series is normally distributed, which is the case in other standard unit root tests, such as Dickey and Fuller (1979, 1981).

Therefore, to obtain the QAR(q) from Equation (3.2), we define the  $\tau^{th}$  quantile as  $q_\tau(\pi_t|\pi_{t-1}, \dots, \pi_{t-q})$  and the probability that the conditional inflation rate will lie above or below the  $\tau^{th}$  quantile is given as  $\tau$  and  $1 - \tau$ , respectively. The resulting QAR(q) can then be expressed as:

$$q_\tau(\pi_t|\pi_{t-1}, \dots, \pi_{t-q}) = \alpha(\tau) + \rho(\tau)\pi_{t-1} + \sum_{j=1}^{q-1} \delta_j \Delta\pi_{t-j}. \quad (3.3)$$

where,  $\rho(\tau)$  is the measure of the degree of persistence in the inflation rate, conditional on all the lagged inflation rates  $(\pi_{t-1}, \dots, \pi_{t-q})$ . This procedure requires that the  $\tau^{th}$  quantile be suitably identified.

A second measure of persistence, which we will also investigate, may be derived from the measures of HLs in each quantile. The HLs measure the number of periods in which the inflation rate remains above half of its initial level, following a unit shock to the inflation rate. After  $\hat{\rho}(\tau)$  is obtained, we calculate the HLs using the formula  $\log(0.5)/\log(\hat{\rho}(\tau))$ .

To estimate Equation (3.3), we must choose the order of the autoregression (i.e. the lag length,  $q$  in the QAR). This may be achieved with the use of information criterion, either the Akaike Information Criterion (AIC) or the Bayesian Information Criterion (BIC). Because of the nature of the data utilized in this chapter, we assume a lag length of 4 for the quarterly data and a lag length of 12 for the monthly data, as this would correspond to a lag of one year.<sup>6</sup>

### 3.4.3 Persistence with breaks

Structural breaks are known to alter the degree of inflation rate persistence (Perron, 1990). The main causes of breaks in macroeconomic time-series identified in the literature are regime changes and revisions to methodologies for data calculation. Uganda has implemented a number of macroeconomic management reforms since the late 1980s, and recently adopted an IT monetary policy regime. In addition, the coverage and metho-

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<sup>6</sup>The lag order is chosen to eliminate serial correlation from the residuals.

dology for calculating the consumer price index in Uganda have changed over the years. Inflation rate data in Uganda may therefore include structural breaks, which may affect the measure of inflation rate persistence.

Fortunately, the starting period in this analysis corresponds to the period after the main reforms (such as the currency devaluations between 1981-1988) that had a substantial impact on measures of inflation. Nevertheless, following [Oka and Qu \(2011\)](#), we investigate changes in inflation persistence by assuming that any break points in the inflation rate are unknown in the quantile regression. As suggested by [Oka and Qu \(2011\)](#), the implementation of this test is based on a two stage procedure. In the first stage, we consider whether there are any break points in the various quantiles, using the dynamic quantile (DQ) test. During this stage, we examine the changes in the conditional distribution of the inflation rate for the entire sample, and also for all possible quantiles, since at this point, the test assumes we lack prior information about the exact break points. To formulate the DQ-test hypothesis, we assume that  $\vartheta(\tau) = (\alpha(\tau), \rho(\tau), \delta_1(\tau), \dots, \delta_{q-1}(\tau))$  represents the vector of parameters in Equation (3.3) at quantile  $\tau$ , such that:

$$H_0^* : \vartheta_i(\tau) = \vartheta_0(\tau) \forall_i \text{ and } \forall_\tau \in \{0.20, 0.25, \dots, 0.80\}$$

$$H_1^* : \vartheta_i(\tau) = \begin{cases} \vartheta_1(\tau) & \text{for } i = 1, 2, \dots, t \\ \vartheta_2(\tau) & \text{for } i = t + 1, \dots, T \end{cases} \text{ for some } \tau \in \{0.20, 0.25, \dots, 0.80\}$$

The final stage involves testing for structural change in the inflation rate at pre-specified quantiles using the  $SQ_\tau$ -test. This test is only performed once we reject the null hypothesis of no structural break in the DQ-test. This is because the DQ-test could reject the null hypothesis of an absence of break points. However, when the  $SQ_\tau$ -test is performed, the results could still show the presence of break points in the time-series ([Wolters and Tillmann, 2015](#)). When performing the  $SQ_\tau$ -test, we make the assumption that structural changes in the inflation rate are known *a priori*, and therefore the quantile to be investigated can be specified during the testing process. This test is then used to investigate breaks in the time-series with the aid of the following hypothesis:

$$H_0^* : \vartheta_i(\tau) = \vartheta_0(\tau) \forall_i \text{ and for a given } \tau \in \{0.20, 0.25, \dots, 0.80\}$$

$$H_1^* : \vartheta_i(\tau) = \begin{cases} \vartheta_1(\tau) & \text{for } i = 1, 2, \dots, t \\ \vartheta_2(\tau) & \text{for } i = t + 1, \dots, T \end{cases} \text{ for a given } \tau \in \{0.20, 0.25, \dots, 0.80\}$$

If the null hypothesis of no break points is rejected in the above formulation, then the testing procedure continues in sequential steps. The starting point for the subsequent test

assumes the null hypothesis of 1 break against 2 breaks, using  $DQ(l+1|l)$  and  $SQ_\tau(l+1|l)$ . If we establish evidence in support of 2 breaks in the time-series we proceed to examine the proposition of 2 breaks against the counter proposition of 3 breaks. This process continues until we are unable to reject the null hypothesis of further structural breaks. The critical values for this test can be found in [Qu \(2008\)](#).

### 3.4.4 QAR unit root test

In order to test the time-series properties of  $\pi_t$  (i.e  $H_0 : \rho(\tau)=1$ ) within the  $\tau$ -th quantile, [Koenker and Xiao \(2004\)](#), suggests a testing statistic that is based on the following  $t$  ratio statistics:

$$t_n(\tau) = \frac{\hat{g}(G^{-1}(\tau))}{\sqrt{\tau(1-\tau)}} \left( \pi'_{-1} M_X \pi_{-1} \right)^{1/2} (\hat{\rho}(\tau) - 1) \quad (3.4)$$

where the function  $\hat{g}(G^{-1}(\tau))$  corresponds to the consistent estimator of  $g(G^{-1}(\tau))$ , while  $g$  and  $G$  denote the density and distribution function of  $\varepsilon_t$  in Equation (3.2). The vector of past inflation rates is denoted by  $\pi_{-1}$ , and  $M_X$  denotes the projection matrix onto the space orthogonal to  $X = (1, \Delta\pi_{t-1}, \dots, \Delta\pi_{t-k+1})$ .

This test statistic allows us to explore the unit root behaviour of the inflation rate in the different quantiles, to capture the dynamics of the shocks that affect the inflation rate at different quantiles of its distribution.

Another approach involves assessing the unit root property over a range of quantiles. To achieve this, [Koenker and Xiao \(2004\)](#) recommends the use of the quantile Kolmogorov-Smirnov (QKS) test, which is expressed as:

$$QKS = \sup |t_n(\tau)| \quad (3.5)$$

In this setting,  $t_n(\tau)$  represents the  $t$  ratio statistics as defined in Equation (3.4). The implementation of this test involves first calculating  $t_n(\tau)$  at  $\tau \in \Gamma$ , which is used to compute the QKS test, by calculating the maximum over  $\Gamma$ .

The limiting distribution of the  $t_n(\tau)$  and QKS tests are nonstandard, and depend on nuisance parameters. One approach used to estimate nuisance parameters involves applying a re-sampling procedure [Koenker and Xiao \(2004\)](#). As an alternative, [Galvao \(2009\)](#) proposes the use of a simulation strategy to derive these nuisance parameters.

### 3.4.5 Wavelets Estimate of Core Inflation

In this sub-section we briefly discuss the wavelets technique which is employed in the second part of the analysis to decompose headline inflation. [Graps \(1995\)](#) describes wavelets as mathematical functions that are used to decompose data into different frequency

components, which can then be used to study the behaviour of each component in a resolution that is matched to its scale. The early literature on decomposition of economic time-series data, used methodologies developed by [Hodrick and Prescott \(1997\)](#), [Baxter and King \(1999\)](#), [Christiano and Fitzgerald \(2003\)](#), that focus on either the time or frequency domain. Wavelet transforms were developed to simultaneously capture information that relates to time and frequency domains. An additional advantage of wavelet transforms is that, unlike the Fourier transforms, which have good properties in series that are known to be stationary, wavelets have superior properties in time-series that have varying degrees of integration.

The wavelets are comprised of both father wavelets,  $\phi$ , and mother wavelets  $\psi$  (as seen in Equation (3.6)). The father wavelets, which are also referred to as scaling functions, integrate to one, and are used to represent the smooth baseline trend. The mother wavelets integrate to zero and are used to represent the deviation from the trending component. Therefore, a time-series  $\pi(t)$ , which in our case is a data series on the headline inflation rate, can be transformed with the aid of multi-resolution techniques that comprise both father and mother wavelets, using the expression;

$$\pi(t) = \sum_{k=1}^{N_J} v_{J,k} \phi_{J,k} + \sum_{j=1}^J \sum_{k=1}^{N_j} w_{j,k} \psi_{j,k}(t). \quad (3.6)$$

where  $v_{J,k}$  and  $w_{j,k}$  are the coefficients and  $N_j$  are the number of coefficients in the  $j$ -th scale. In this analysis, we make use of the Daubechies wavelets filters, which are a collection of wavelet functions that are most commonly used ([Daubechies et al., 1992](#)).

### 3.5 Data

The analysis discussed in this chapter relies on year-on-year monthly and quarterly data on changes in the headline Consumer Price Index (CPI) and core CPI. The core CPI is the component of headline CPI that excludes prices related to food crops, electricity, fuel, and metered water. Core CPI currently constitutes 82.4 percent of headline CPI. The analysis time-span is July 1993 to December 2015, for the headline inflation (270 observations), and July 1998 to December 2015, for core inflation (210 observations). The start and end dates are determined by data availability. This data sample corresponds to quarterly data periods 1993Q3 to 2015Q4 (90 observations) and 1998Q3 to 2015Q4 (70 observations) for the headline and core inflation rates, respectively. The year-on-year monthly headline and core inflation rates are computed by taking the natural logarithmic difference of the CPI for a given month in the current year and the same month in the previous year. The year-on-year quarterly inflation rates are calculated as the natural logarithmic difference of the CPI for a given quarter in the current year and the same quarter in the previous

year. The monthly time-series data are obtained from the UBOS website. The quarterly time-series are obtained by taking the average index value for the three months in a quarter.

As an initial step to explore the properties of these time-series, Table 3.1 presents the key descriptive statistics for the two measures of inflation. The statistics presented are the first four sample moments and the Jarque-Bera (JB) normality test of inflation rates. In addition, since our interest relates to time varying persistence, the summary statistics are also reported for two subsamples, after splitting the entire data in 2007. The results of the first moment show that the mean inflation rate for both headline and core inflation have increased in the recent period. Specifically, the mean inflation rate for the subsample 2007-2015 increased to 9.27% and 9.03% for the quarterly and monthly measures, respectively. This is off a relatively low base, as the respective mean quarterly and monthly rates were 5.31% and 4.06% for the subsample prior to 2007. Inflation remained high in the period following the global financial crisis, on account of domestic currency depreciation and a monetary expansion.

Table 3.1: Summary Statistics for headline and core inflation rates.

Variable	Sample	Mean	Std.Dev.	Skewness	Kurtosis	JB Stat.(P-Value)
Headline(q)	1993-2015	6.89	5.70	1.04	5.39	37.96**(0.000)
Headline(m)		6.89	5.74	1.08	5.69	133.21**(0.000)
Core(q)	1998-2015	6.61	5.41	2.40	9.57	193.40**(0.000)
Core(m)		6.62	5.48	2.42	9.72	600.71**(0.000)
Headline(q)	1993-2006	5.31	4.41	-0.25	2.63	0.85(0.652)
Headline(m)		5.31	4.37	-0.33	2.73	3.46(0.177)
Core(q)	1998-2006	4.06	1.85	-0.36	2.45	1.17(0.556)
Core(m)		4.06	1.92	-0.33	2.67	2.36(0.307)
Headline(q)	2007-2015	9.27	6.59	1.21	4.04	10.45**(0.005)
Headline(m)		9.27	6.67	1.23	4.20	33.67**(0.000)
Core(q)	2007-2015	9.03	6.49	1.74	5.61	28.31**(0.000)
Core(m)		9.03	6.56	1.76	5.71	88.77**(0.000)

Notes: JB stat. refers to the Jarque-Bera normality test and this test is  $\chi^2$  distributed asymptotically. m & q refers to monthly and quarterly series respectively.

\*\*denotes significance at the 5% level.

Within each of the subsamples, it is also worth noting that the mean of the headline inflation rate is higher than the mean of the core inflation rate. In addition, the standard deviations in each subsample suggest that core inflation has successfully removed those components that are considered to be more volatile.

The correlation coefficients between headline and core inflation for the two subsamples are lower for the earlier subsample at 0.84 and 0.85, for the monthly and quarterly rates. These measures of correlation increased to 0.97 and 0.96, for the second subsample.

Moreover, when the mean inflation rate and the inflation rate standard deviations (Table 3.1) increase in the second subsample, the correlation follows suit. This behaviour is consistent with the literature for this field, where Okun (1971), Davis and Kanago (1998), Daal et al. (2005), and Tsong and Lee (2011), suggest that in most cases a high inflation rate and high inflation uncertainty move hand-in-hand.

Lastly, it is necessary to investigate persistence in the Ugandan inflation rate using a quantile regression approach. This is supported by the overwhelming evidence that the data has fat tails. The JB test for the full sample and the subsample after 2006 strongly rejects the null hypothesis of normality, given the extremely small  $p$ -values. This implies that the inflation rate in Uganda has asymmetric properties, and therefore cannot be described as a constant coefficient unit root process.

## 3.6 Results

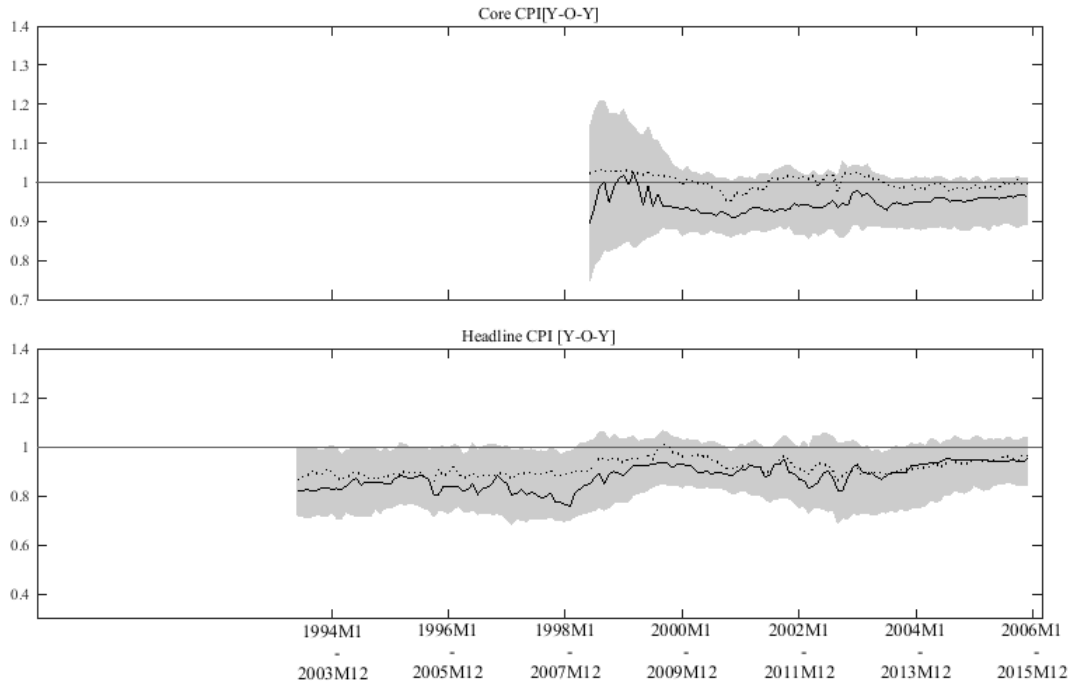
### 3.6.1 Quantile regression

The preliminary exploration in the previous section was based on summary statistics and correlation coefficients. We now consider persistence based on, a quantile regression, since the normality test established asymmetry in the inflation rates in Uganda. Our analysis is based on the pioneering work of Koenker and Xiao (2004), who proposed that, when there is a significant evidence of non-normality in an economic time-series, a quantile regression approach provides superior estimates of the level of persistence in such time-series. The QAR procedure we employ is based on a 10 year rolling-window to estimate the persistence in the conditional mean and median of the two inflation rates.

Figures (3.2) and (3.3), plot the measures of persistence for the estimated inflation rate, along with the bootstrap confidence bands at the 95% confidence level. In the persistence plots, the dotted line represents the estimates of the conditional mean, and the solid line represents the estimated conditional median (devoid of confidence bands). These graphs relate to the results of the model that were estimated for the entire sample of data.

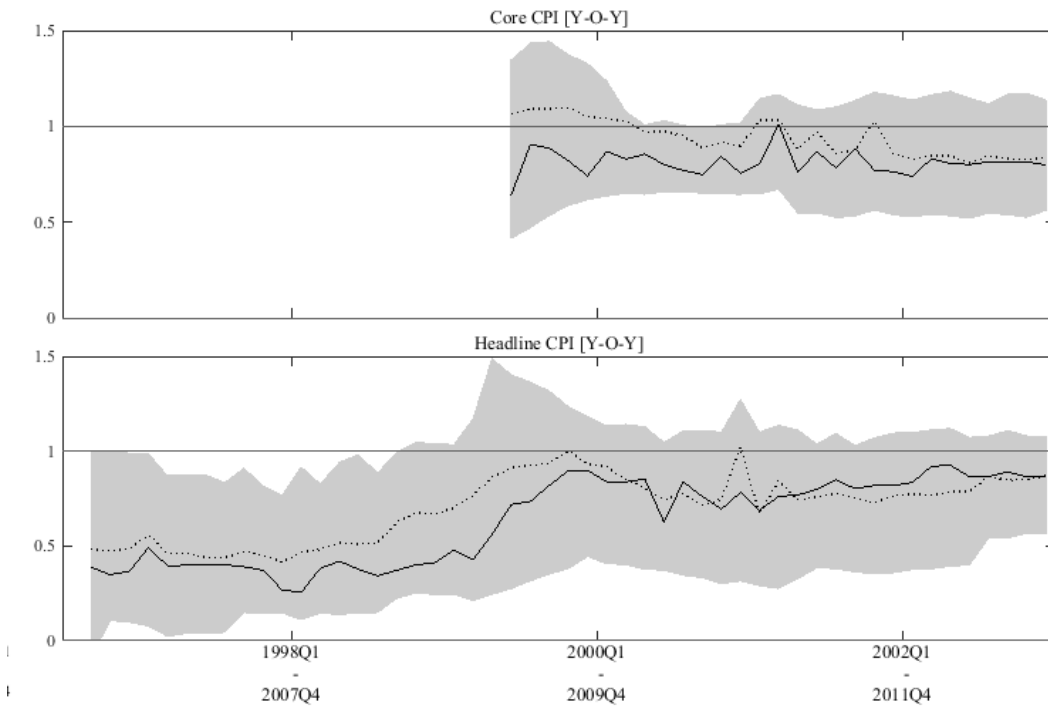
The results reveal that the headline inflation rate was largely stationary for the bulk of the sample, implying that the headline inflation rate reverted to the equilibrium inflation rate following a shock. However, this reversion took place at varying speeds over the sample. Furthermore, the level of persistence in the headline inflation rate was lower at the start of the study period, and this behaviour is more pronounced in the quarterly inflation rate. Specifically, the persistence in the monthly headline inflation rate increased from about 0.8 at the start of the study period to about 0.95 in the end of the study period. Similarly, the persistence in the quarterly headline inflation rate also increased during the same period, from about 0.5 to 0.9.

Figure 3.2: Monthly inflation rate persistence.



Notes: The graphs plot the estimates of  $\rho$  in the 10-year rolling window where the conditional mean and median are represented by the dotted and solid lines, respectively. The gray area represents the 95% bootstrap confidence bands.

Figure 3.3: Quarterly inflation rate persistence.



Notes: The graphs plot the estimates of  $\rho$  in the 10-year rolling window where the conditional mean and median are represented by the dotted and solid lines, respectively. The gray area represents the 95% bootstrap confidence bands.

Results for the core inflation rate suggest that the persistence in monthly and quarterly core inflation rates was lower at the end of the study period. Once again, this trajectory was more pronounced in the quarterly measure. Notwithstanding the observed decrease in the level of persistence, both monthly and quarterly core inflation rates exhibited a few signs of instability between 2007 and 2009. In some quantiles, the conditional mean and median measures of persistence may be described by a unit root (see Figure 3.3). In addition, persistence of the monthly core inflation rate, which was relatively low at the start of the sample, increased somewhat from 2007 onwards. Notably, persistence in the monthly core inflation rate (Figure 3.2 top panel), as measured by the conditional mean estimate, remained close to unitary after 2007.

The observed behaviour in the persistence of the two inflation rates is contrary to findings in the literature from most advanced and middle income countries. These find declining levels of inflation persistence during the more recent period. Explanations for the increased persistence in inflation levels could be the global commodity price boom that started in 2007, and the sharp rise in domestic food and energy prices in Uganda, during this period. In addition, the high inflationary environment during this time could have anchored inflation expectations. Moreover, the observed trajectory of the inflation rate persistence after 2007 is consistent with Oliveira and Petrassi (2014), who also discover increased inflation rate persistence in a number of emerging countries during the same period.

### 3.6.2 Quantile structural break tests

In Table 3.2, we present the results of the DQ-test used to investigate the presence of structural breaks in persistence at the different quantiles. The main feature of this test is that it does not make assumptions about the specific break dates, and the testing procedure helps us identify such dates. While, the testing procedure estimates the break points for  $\tau \in \{0.20, 0.25, \dots, 0.80\}$ , we only report on the results for  $\tau \in \{0.20, 0.30, 0.40, 0.50, 0.6, 0.7, 0.8\}$  for clarity of presentation.

Table 3.2: DQ-test for break points in QAR.

Variable	1st break point	2nd break point	3rd break point	4th break point
Headline(m)	-	-	-	-
Core(m)	-	-	-	-
Headline(q)	2004Q3*	-	-	-
Core(q)	-	-	-	-

Notes: \*refers to the 10% level of significance.

The results suggest that there is a single break in the quarterly headline inflation rate data, and this break occurred in the third quarter of 2004, perhaps reflecting the surge in prices during this period. This upsurge in prices was caused by changes to the

tax structure, as noted in [Aron et al. \(2015\)](#). For the monthly headline inflation rate, there is no evidence of a structural break in the time-series. There is also no evidence of a break in the core inflation rate data (for both the monthly and quarterly measures). These findings are contrary to our initial expectations of several structural breaks in the Ugandan inflation time-series data, which we thought could have been caused by changes in the monetary and fiscal policy regime and data collection and data calculation methods.

### 3.6.3 Quantile regression results

We now investigate if the respective inflation rates contain a unit root. For this we rely on analysis of the QAR unit root tests and the related QKS-tests. These tests are performed for the sample as a whole and for subsamples, which are based on the results of the JB normality tests and the start date of the ITL regime. We choose these subsamples because the formal structural break tests could not identify the dates of the breaks and we need to investigate if these results are robust. The first subsample for the monthly inflation series we consider runs from the respective start dates to December 2006. The choice for this subsample is because of the differences in the summary statistics in the two subsamples that were reported earlier. The second subsample starts from January 2007 and ends in June 2011. The end point corresponds to the start of the ITL regime of the central bank. The final subsample runs from July 2011 to the end of the full sample (December 2015). This corresponds to the period when the central bank implemented ITL. We split the quarterly series into two subsamples because this series has few data points.<sup>7</sup>

The results of the QAR unit root tests for the individual quantiles and the QKS tests are reported in [Table 3.3](#) and [Table 3.4](#) for the quarterly, and monthly series, respectively. These tables summarize the regression results for the different quantiles, the SARC, the unit root determination, the test statistics, and the critical values at the 5% confidence level. The penultimate row of each sample contains the HLs, and the last row shows results of the KS-test (where QKS denotes the test statistics, together with the corresponding critical values at the 5% level of significance). The results reveal that, in some quantiles, the inflation rates contain unit root. However, in other quantiles, shocks to the time-series are short-lived, and the inflation rates would return to the mean inflation rate relatively quickly. More specifically, the SARC measures vary significantly from the bottom to the top quantiles, which suggests that there are asymmetric patterns in inflation persistence. Moreover, in the bottom quantiles, the estimated values of  $\hat{\rho}(\tau)$  fall far below unity with small  $t$ -values, which rejects the unit root null at the 5% significance level. For the top quantiles (especially,  $\tau = 0.7$  &  $0.8$ ), the estimated values of the SARC are close to or slightly larger than unity and the  $t$ -values do not reject the unit root null at the 5%

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<sup>7</sup>First subsample is before December 2006, and second subsample from January 2007 to the end of sample.

significance level.

Table 3.3: Quantile unit root tests for quarterly inflation rate.

Variable	Period	$\tau$	0.20	0.30	0.40	0.50	0.60	0.70	0.80	
Headline	1993Q3-2015Q4	$\hat{\rho}(\tau)$	0.63	0.67	0.68	0.67	0.67	0.69	0.75	
		Unit root	no	no	no	no	no	no	yes	
		t-stat	-3.33	-3.25	-3.51	-3.67	-3.72	-2.79	-1.92	
		critical value	-2.46	-2.56	-2.72	-2.58	-2.67	-2.72	-2.57	
		Half-lives	1.50	1.73	1.81	1.73	1.73	1.84	2.47	
	KS-test	unit root: no	QKS=4.20		cv=2.90					
	1993Q3-2006Q4	$\hat{\rho}(\tau)$	0.60	0.35	0.41	0.40	0.54	0.64	0.60	
		Unit root	yes	yes	yes	no	yes	yes	yes	
		t-stat	-1.32	-2.16	-2.66	-3.14	-2.52	-2.21	-1.85	
		critical value	-2.60	-2.68	-2.73	-2.70	-2.57	-2.59	-2.45	
Half-lives		1.36	0.67	0.79	0.77	1.11	1.54	1.35		
KS-test	unit root: no	QKS=3.28		cv=2.88						
2007Q1-2015Q4	2007Q1-2015Q4	$\hat{\rho}(\tau)$	0.68	0.72	0.90	0.86	0.89	0.90	0.97	
		Unit root	no	yes	yes	yes	yes	yes	yes	
		t-stat	-3.85	-1.95	-0.85	-1.23	-0.93	-1.80	-0.28	
		critical value	-2.53	-2.66	-2.66	-2.64	-2.38	-2.53	-2.12	
		Half-lives	1.82	2.07	6.49	4.77	5.93	6.41	19.89	
	KS-test	unit root: no	QKS=3.85		cv=2.91					
	Core	1998Q3-2015Q4	$\hat{\rho}(\tau)$	0.66	0.64	0.79	0.79	0.90	0.92	1.05
			Unit root	no	no	no	no	yes	yes	yes
			t-stat	-3.84	-5.35	-3.34	-2.81	-1.45	-1.00	0.44
			critical value	-2.20	-2.44	-2.40	-2.43	-2.56	-2.52	-2.39
Half-lives			1.69	1.55	3.01	2.89	6.36	8.08	$\infty$	
KS-test	unit root: no	QKS=5.35		cv=2.89						
1993Q3-2006Q4	1993Q3-2006Q4	$\hat{\rho}(\tau)$	0.24	0.35	0.41	0.46	0.53	0.43	0.71	
		Unit root	yes	yes	yes	yes	yes	no	yes	
		t-stat	-2.15	-1.77	-1.51	-2.09	-2.10	-2.55	-1.52	
		critical value	-2.70	-2.80	-2.76	-2.55	-2.41	-2.15	-2.12	
		Half-lives	0.48	0.66	0.77	0.88	1.09	0.81	2.02	
	KS-test	unit root: yes	QKS=2.55		cv=2.86					
	2007Q1-2015Q4	2007Q1-2015Q4	$\hat{\rho}(\tau)$	0.61	0.61	0.74	0.81	0.88	1.03	1.07
			Unit root	no	no	yes	yes	yes	yes	yes
			t-stat	-4.36	-4.85	-2.26	-1.61	-0.73	0.15	0.45
			critical value	-2.61	-2.54	-2.47	-2.57	-2.70	-2.56	-2.77
Half-lives			1.41	1.40	2.35	3.38	5.67	$\infty$	$\infty$	
KS-test	unit root: no	QKS=4.85		cv=2.89						

Notes: Critical value (cv) at the 5% significance level. QKS statistics are calculated for the entire sample. We reject the null when the calculated test statistics is less than the critical value. Infinity HLs mean  $\hat{\rho}(\tau)$  is larger than unity.

The dispersion in the measures of persistence in the inflation rates is large, since the rates are not all that persistent at the bottom quantiles but become highly persistent (to the extent that they approximate unit root behaviour) at the top quantiles. This could be because of inflation expectations that influence the behaviour of the observed inflation rate. For example, such expectations may be incorporated in the price formation process. That is, when the companies and wholesalers expect the inflation rate to increase, they respond by rising their prices, which in turn leads to higher inflation. However, as prices are sticky to downward movements, this process would not be expected to work in the opposite direction, when there is pressure on prices to decrease and the expectation of a change in future prices is low.

Table 3.4: Quantile unit root tests for monthly inflation rate.

Variable	Period	$\tau$	0.20	0.30	0.40	0.50	0.60	0.70	0.80
Headline	1993M7-2015M12	$\hat{\rho}(\tau)$	0.90	0.92	0.89	0.92	0.92	0.94	0.94
		Unit root	no	yes	no	no	no	yes	yes
		t-stat	-2.91	-2.57	-3.56	-2.80	-3.17	-2.32	-1.81
		critical value	-2.52	-2.57	-2.56	-2.59	-2.62	-2.55	-2.59
		Half-lives	6.55	8.01	6.19	7.97	7.81	10.42	12.05
	KS-test	unit root: no	QKS=3.56		cv=2.93				
	1993M7-2006M12	$\hat{\rho}(\tau)$	0.82	0.82	0.78	0.81	0.88	0.91	0.98
		Unit root	yes	yes	no	no	yes	yes	yes
		t-stat	-2.69	-2.64	-3.78	-3.07	-2.11	-1.24	-0.29
		critical value	-2.74	-2.68	-2.59	-2.53	-2.39	-2.48	-2.44
Half-lives		3.57	3.47	2.80	3.38	5.22	7.15	35.67	
KS-test	unit root: no	QKS=3.78		cv=2.90					
2007M1-2011M6	$\hat{\rho}(\tau)$	0.64	0.73	0.77	0.73	0.82	0.87	0.88	
	Unit root	no	no	yes	yes	yes	yes	yes	
	t-stat	-8.18	-2.72	-2.18	-2.16	-1.20	-0.78	-0.93	
	critical value	-2.17	-2.40	-2.38	-2.26	-2.71	-2.53	-2.25	
	Half-lives	1.54	2.24	2.63	2.24	3.51	5.07	5.28	
KS-test	unit root: no	QKS=8.18		cv=2.90					
2011M7-2015M12	$\hat{\rho}(\tau)$	0.77	0.90	0.93	0.90	0.96	0.96	0.97	
	Unit root	no	yes	yes	yes	yes	yes	yes	
	t-stat	-2.92	-1.21	-0.80	-1.11	-0.53	-0.46	-0.47	
	critical value	-2.12	-2.14	-2.12	-2.35	-2.24	-2.46	-2.54	
	Half-lives	2.70	6.73	9.75	6.69	16.15	18.79	20.86	
KS-test	unit root: no	QKS=2.92		cv=2.89					
Core	1998M7-2015M12	$\hat{\rho}(\tau)$	0.93	0.95	0.93	0.94	0.94	0.96	0.98
		Unit root	yes	no	no	no	no	yes	yes
		t-stat	-2.28	-2.67	-3.85	-3.28	-2.80	-1.82	-0.69
		critical value	-2.43	-2.51	-2.55	-2.59	-2.63	-2.71	-2.62
		Half-lives	10.31	12.37	9.72	11.18	12.16	16.80	39.27
	KS-test	unit root: no	QKS=3.85		cv=2.90				
	1998M7-2006M12	$\hat{\rho}(\tau)$	0.64	0.69	0.79	0.79	0.81	0.82	0.77
		Unit root	yes	yes	yes	yes	yes	yes	yes
		t-stat	-2.37	-1.78	-1.74	-1.70	-1.75	-1.54	-1.99
		critical value	-2.75	-2.78	-2.78	-2.73	-2.61	-2.47	-2.26
Half-lives		1.56	1.89	2.99	2.96	3.25	3.50	2.72	
KS-test	unit root: yes	QKS=2.37		cv=2.83					
2007M1-2011M6	$\hat{\rho}(\tau)$	0.76	0.77	0.84	0.82	0.82	0.78	0.83	
	Unit root	no	no	yes	yes	yes	yes	yes	
	t-stat	-2.92	-2.68	-1.64	-1.64	-1.88	-2.13	-1.57	
	critical value	-2.14	-2.37	-2.41	-2.68	-2.60	-2.47	-2.18	
	Half-lives	2.55	2.63	3.96	3.59	3.41	2.75	3.81	
KS-test	unit root: no	QKS=3.02		cv=2.90					
2011M7-2015M12	$\hat{\rho}(\tau)$	0.91	0.94	0.97	0.96	0.96	0.97	1.01	
	Unit root	no	yes	yes	yes	yes	yes	yes	
	t-stat	-2.88	-1.80	-1.05	-1.11	-1.14	-0.70	0.27	
	critical value	-2.12	-2.28	-2.45	-2.30	-2.54	-2.30	-2.34	
	Half-lives	7.52	11.45	21.90	18.22	19.40	23.25	$\infty$	
KS-test	unit root: yes	QKS=2.88		cv=2.88					

Notes: See notes in Table 3.3.

For the subsample after 2006, persistence for both the quarterly and monthly measures of both inflation rates increased. The increase in the level of persistence is more noticeable in the core inflation rate. Recall that this period corresponds to the two inflationary spikes. This is also consistent with the descriptive statistics that were discussed earlier, which

suggest that periods of low inflation tend to be associated with low inflation variability and periods of high inflation tend to be associated with high inflation variability.

From the estimated values of  $\hat{\rho}(\tau)$ , we calculate the HLs in each quantile for the two inflation series for the different subsamples. The results reveal that, at the bottom quantiles, the HLs are smaller. They become larger in the top quantiles, which again reinforces the suggestion that there is asymmetry in the measures of persistence in the inflation rates. When inflation is hit by a large shock, the inflation rates for the bottom quantiles return to the long-run level fairly quickly. However, at the top quantiles, the inflation rate may not return to the long-run equilibrium after a large shock, as the HLs for those quantiles are infinite. The infinite HLs in this case imply that the effect of shocks on the measures of inflation take too long to disappear.

### 3.6.4 Quantile regression results under possible structural breaks

It has been suggested that inflation persistence decreased after the implementation of an IT monetary policy regime (c.f. [Bratsiotis et al., 2002](#); [Levin et al., 2004](#); [Benati, 2008](#); [Rangasamy, 2009](#); [Gerlach and Tillmann, 2012](#)). In this section, we investigate evidence to support such a claim for Uganda. We analyse inflation persistence during the IT period ( July 2011 to December 2015) using monthly inflation rates. The QKS test for the headline inflation rate reveals that the inflation rate is mean reverting, as we strongly reject the null hypothesis of unit root at the 5% significance level. However, the core inflation rate contains evidence of unit root behaviour, as the QKS test cannot reject the null hypothesis of a unit root over the whole conditional distribution.

In addition, the results for  $\hat{\rho}(\tau)$  are somewhat different to those of the period prior to the implementation of ITL. However, the earlier asymmetry is still evident, especially in the top quantiles. The measures of HLs have also slightly increased, particularly at the top quantiles, which contradicts findings in the literature. When considering these results, it is important to bear in mind that the IT period in the study includes periods when the highest inflation rates in Uganda were recorded and that these could be attributed to large shocks that had very little to do with the implementation of the IT regime (i.e. there is no counterfactual against which to measure the effect of this policy change).

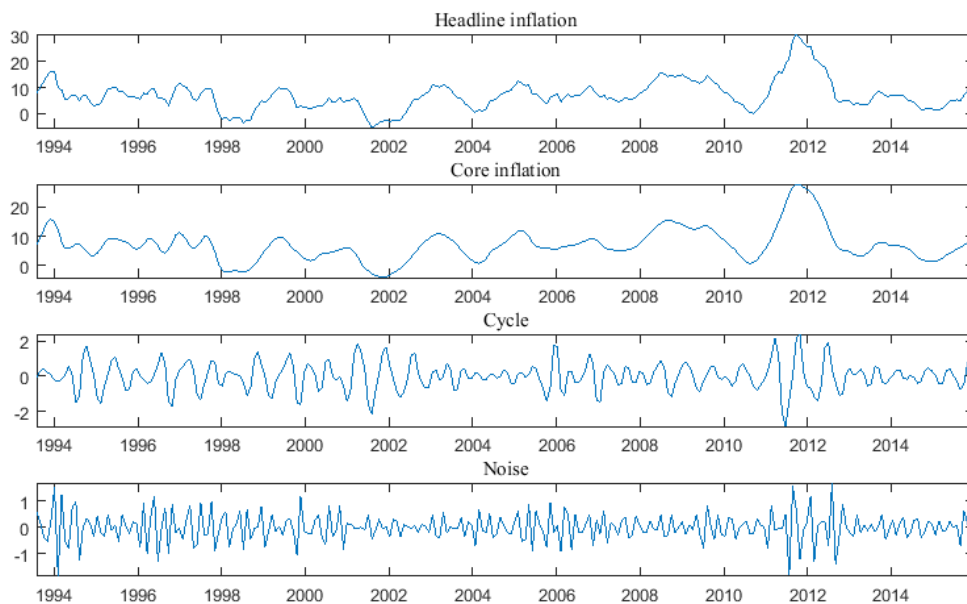
In summary, the tests suggest that inflation rate persistence in Uganda increased slightly after 2007. This trajectory is more pronounced in the core inflation rate than in the headline inflation rate. Additionally, there is a difference in the level of persistence between the bottom and top quantiles, suggesting asymmetry in persistence. These findings should be of concern to the central bank and other policymakers because it implies that higher inflation rates could be feeding higher inflation rate expectations. These results are relevant for core inflation rate targeting, because they suggest higher sacrifice ratios du-

ring periods of heightened inflationary pressure. Higher inflation expectations by agents might reflect greater degrees of persistence in the inflation rate.

### 3.6.5 Wavelet decomposition

Figure 3.4 presents the original headline inflation rate (top panel), the smoothed stochastic trend (father wavelet) and the two corresponding wavelet details (mother wavelets). These wavelet functions may be interpreted in much the same way as the results from a [Baxter and King \(1999\)](#) filter, which provides estimates of the stochastic trend, cycle, and noise. In addition, given the nature of this data, the smoothed stochastic trend could be used as an estimate of the core inflation rate (Core-Wavelet). The wavelet details would then represent the cyclical features and noise in the rate of headline inflation.

Figure 3.4: Daublet (4) wavelet decomposition of headline year-on-year inflation.



After inspecting the results, it is worth noting that, when the inflation rate increases, the cycle plots widen and the level of noise increases. Similarly, when the inflation rate reduces, these two components contract. For example, when the inflation rate increased between 2011 and 2012, the noise in the headline inflation rate increased along with the cyclical component in inflation. From late 2012, when the inflation rate decelerated, the cyclical component decreased and the level of noise reduced. These results could suggest that the high frequency components in the Ugandan inflation rate are more volatile during periods of high inflation.

Figure 3.5 plots the headline inflation rate (dotted line) and the Core-Wavelet inflation rate (solid line). It shows that the two measures closely track each other (as should be the

case), where the Core-Wavelet appears to be more persistent than the headline inflation rate.

Figure 3.5: Headline inflation rate and Core-Wavelet inflation rate (year-on-year).

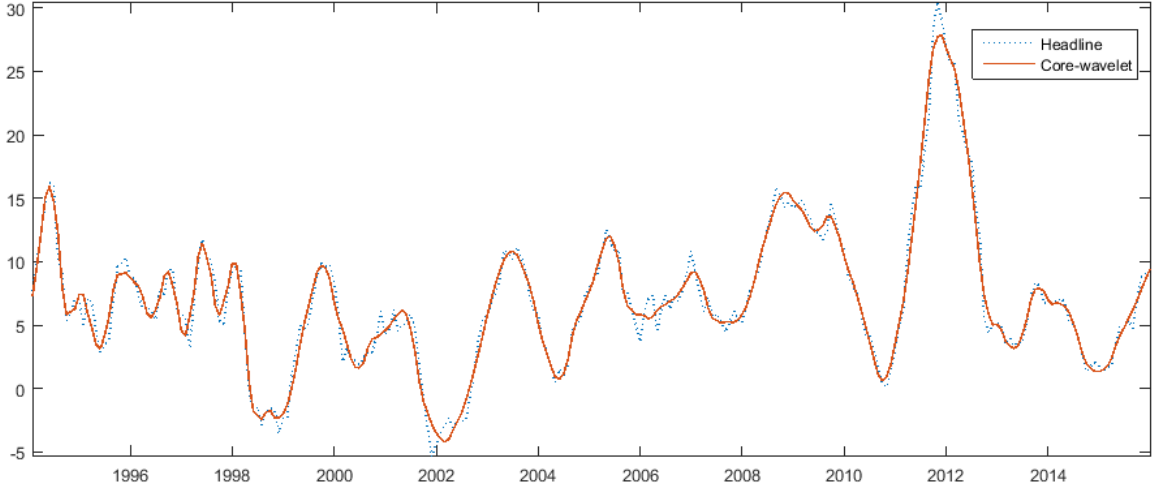
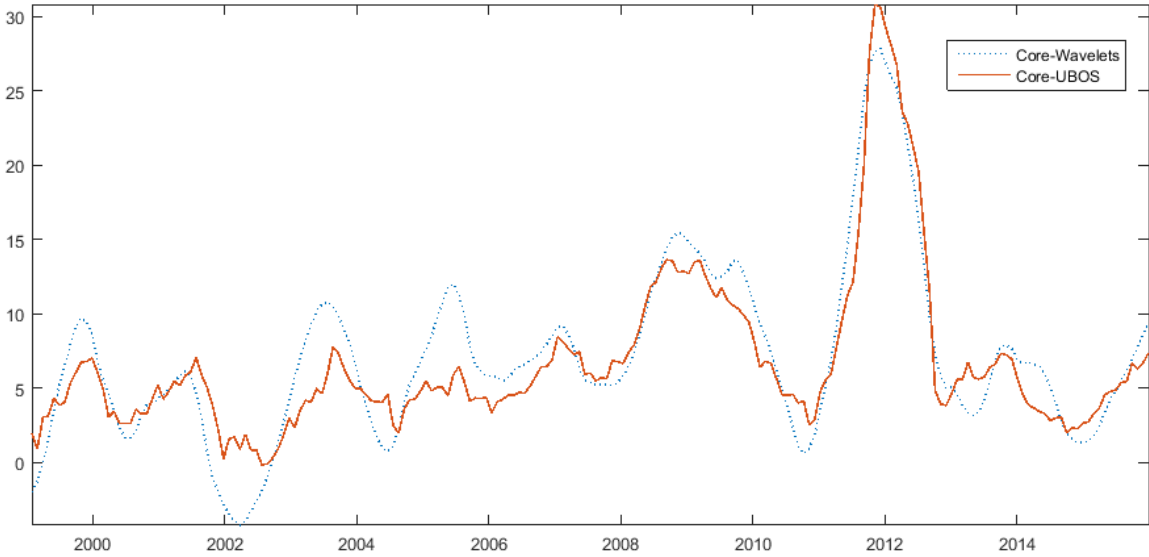


Figure 3.6 plots the current core inflation rate measure (Core-UBOS, represented by the solid line) and the Core-Wavelet (dotted line). The graph suggests that the Core-UBOS is more volatile and less persistent than the Core-Wavelet. This could have important implications for monetary policy. That is, a more volatile measure of core inflation might result in more frequent changes in monetary policy. This would in turn affect inflation expectations, as more frequent monetary policy changes may promote higher levels of uncertainty.

Figure 3.6: Core-UBOS inflation rate and Core-Wavelet inflation rate (year-on-year).



These findings are supported by the results in Table 3.5, which considers volatility and correlation of the key measures of inflation. They confirm that the Core-UBOS measure of inflation is volatile and has low correlation with both current and future headline inflation. This measure also has a low correlation with the measure of core inflation that is provided by the wavelet decomposition. The results in the table also show that the volatility of the wavelet measure is lower, while the measure is highly correlated with both current and future headline inflation. This suggests that the core wavelet based measure could be a useful target for monetary policy, as it could provide a more stable base on which to anchor inflation expectations.

Table 3.5: Volatility and Correlation.

	Standard Deviation	Correlations		
		Headline ( $t$ )	Headline ( $t + 1$ )	Core-UBOS
Headline	6.4028	1.0000	0.9664	0.9607
Core-UBOS	6.3516	0.9607	0.9240	1.0000
Core-Wavelet	6.3410	0.9889	0.9732	0.9576

Notes:  $t$  refers to the current period,  $t+1$  refers to future period.

### 3.6.6 Quantile regression results for core inflation obtained from wavelets

Table 3.6 provides the results of the quantile regression unit root tests for the Core-Wavelet. These results are compared with the unit root test results from the Core-UBOS measure. The results suggest that the quantiles in which the core inflation rate contains a unit root are more when using the Core-Wavelet measure. This suggests that Core-Wavelet inflation rate measure is more persistent than the Core-UBOS measure.

In addition, the level of persistence increases as we move from the bottom quantiles to the top quantiles, which suggests asymmetry in the Core-Wavelet measure of persistence. This supports the QAR approach adopted to investigate this issue.

Furthermore, the persistence results based on the HLs show a significant increase in the HLs, when using the Core-Wavelet measure. These are more pronounced in the top quantiles than in the bottom quantiles, which re-confirms the asymmetry in persistence.

A comparison of the two measures of core inflation for the subsample from July 2011 to December 2015, during which the central bank implemented ITL, reveals higher persistence in Core-Wavelet measured by the SARC and HLs. The two persistence indicators increased in value during the ITL in comparison to the Core-UBOS measure. However, the QKS test shows that the Core-Wavelet is mean reverting as it rejects the null hypothesis of a unit root. In contrast, the QKS test for the Core-UBOS suggests that during this period this measure was not mean reverting, as the test fails to reject the null of a unit root. This would suggest that, despite the high rate of inflation before the introduction

of the ITL, the new monetary policy framework may have contributed to the observed decrease in inflation and mean reversion in the Core-Wavelet inflation rate. Findings from this measure of core inflation supports the current monetary policy regime. The measure would seem to provide a better anchor of inflation expectations than the current core inflation measure produced by UBOS.

Table 3.6: Quantile unit root tests for monthly Core-Wavelet inflation rate.

Variable	Period	$\tau$	0.20	0.30	0.40	0.50	0.60	0.70	0.80
Core-Wavelet	1993M7-2015M12	$\hat{\rho}(\tau)$	0.99	1.00	0.89	1.00	1.00	1.00	0.99
		Unit root	yes	yes	yes	yes	yes	yes	yes
		t-stat	-5.58	-0.12	0.29	1.05	0.42	0.02	-0.99
		critical value	-2.42	-2.51	-2.60	-2.61	-2.51	-2.57	-2.57
		Half-lives	60.30	$\infty$	$\infty$	$\infty$	$\infty$	$\infty$	$\infty$
		KS-test	unit root: yes		QKS=1.05		cv=2.93		
	1993M7-2006M12	$\hat{\rho}(\tau)$	0.99	1.01	1.00	1.00	1.00	0.99	0.97
		Unit root	yes	yes	yes	yes	yes	yes	yes
		t-stat	-0.44	0.58	0.31	0.29	-0.23	-1.24	-0.29
		critical value	-2.54	-2.68	-2.74	-2.61	-2.54	-2.40	-2.37
Half-lives		60.30	$\infty$	$\infty$	$\infty$	$\infty$	70.00	20.56	
KS-test		unit root: yes		QKS=1.63		cv=2.89			
2007M1-2011M6	$\hat{\rho}(\tau)$	0.96	0.97	1.00	0.99	0.98	0.98	0.99	
	Unit root	yes	yes	yes	yes	yes	yes	yes	
	t-stat	-0.76	-0.89	-0.01	-0.29	-0.55	-0.46	-0.31	
	critical value	-2.51	-2.77	-2.31	-2.45	-2.14	-2.29	-2.18	
	Half-lives	24.06	21.01	$\infty$	87.47	33.63	42.75	63.22	
	KS-test	unit root: no		QKS=1.02		cv=2.90			
2011M7-2015M12	$\hat{\rho}(\tau)$	0.96	0.97	0.97	0.99	0.98	0.98	0.98	
	Unit root	no	yes	yes	yes	yes	yes	yes	
	t-stat	-5.01	-1.66	-1.65	-0.46	-0.81	-1.19	-2.58	
	critical value	-2.30	-2.34	-2.53	-2.44	-2.51	-2.31	-2.58	
	Half-lives	15.65	23.00	20.31	74.66	41.35	34.19	29.12	
	KS-test	unit root: no		QKS=5.01		cv=2.91			
Core-UBOS	1998M7-2015M12	$\hat{\rho}(\tau)$	0.93	0.95	0.93	0.94	0.94	0.96	0.98
		Unit root	yes	no	no	no	no	yes	yes
		t-stat	-2.28	-2.67	-3.85	-3.28	-2.80	-1.82	-0.69
		critical value	-2.43	-2.51	-2.55	-2.59	-2.63	-2.71	-2.62
		Half-lives	10.31	12.37	9.72	11.18	12.16	16.80	39.27
		KS-test	unit root: no		QKS=3.85		cv=2.90		
	1998M7-2006M12	$\hat{\rho}(\tau)$	0.64	0.69	0.79	0.79	0.81	0.82	0.77
		Unit root	yes	yes	yes	yes	yes	yes	yes
		t-stat	-2.37	-1.78	-1.74	-1.70	-1.75	-1.54	-1.99
		critical value	-2.75	-2.78	-2.78	-2.73	-2.61	-2.47	-2.26
Half-lives		1.56	1.89	2.99	2.96	3.25	3.50	2.72	
KS-test		unit root: yes		QKS=2.37		cv=2.83			
2007M1-2011M6	$\hat{\rho}(\tau)$	0.76	0.77	0.84	0.82	0.82	0.78	0.83	
	Unit root	no	no	yes	yes	yes	yes	yes	
	t-stat	-2.92	-2.68	-1.64	-1.64	-1.88	-2.13	-1.57	
	critical value	-2.14	-2.37	-2.41	-2.68	-2.60	-2.47	-2.18	
	Half-lives	2.55	2.63	3.96	3.59	3.41	2.75	3.81	
	KS-test	unit root: no		QKS=3.02		cv=2.90			
2011M7-2015M12	$\hat{\rho}(\tau)$	0.91	0.94	0.97	0.96	0.96	0.97	1.01	
	Unit root	no	yes	yes	yes	yes	yes	yes	
	t-stat	-2.88	-1.80	-1.05	-1.11	-1.14	-0.70	0.27	
	critical value	-2.12	-2.28	-2.45	-2.30	-2.54	-2.30	-2.34	
	Half-lives	7.52	11.45	21.90	18.22	19.40	23.25	$\infty$	
	KS-test	unit root: yes		QKS=2.88		cv=2.88			

Notes: See notes in Table 3.3.

### 3.7 Conclusion

Price stability has become a key macroeconomic management objective for central banks in both advanced and developing countries. An investigation into the inflationary process is thus important, particularly in those countries that have recently adopted IT.

To investigate inflation persistence in Uganda, we make use of the quantile regression technique, that is based on a 10-year rolling-window, together with the 95% bootstrapped confidence intervals. This framework was influenced by the results of our normality tests, which suggested that the headline and core inflation measures have heavy-tails. The QAR framework allowed us to explore persistence in the inflation rate in a range of conditional quantiles, rather than focus on a single measure that represents the central tendency. We find that, for the sample as a whole, the inflation rate in Uganda cannot be described as a unit root process, as the QKS test rejects the null hypothesis of unit root, which implies evidence of mean reversion. However, for some subsamples, the core inflation rate shows evidence of unit root, which suggest absences of mean reversion in these subsamples.

Furthermore, when specific quantiles are assessed, the results suggest that there may be evidence of a unit root in the top quantiles, as the test failed to reject the null hypothesis of unit root for these quantiles. However, no evidence of a unit root is evident in the bottom quantiles. The results also reveal asymmetric mean reversion to the equilibrium of the inflation rate. This suggests that inflation in Uganda does not follow a constant unit root process for the different quantiles, rather the persistence in the top quantiles is consistently higher than that in the bottom quantiles. The level of persistence increased after 2006, and following the implementation of inflation targeting. One possible reason for this is that inflationary expectations in Uganda have become more stable recently.

As an alternative measure of core inflation, wavelet decomposition provides a measure that is smoother and more persistent than the headline inflation rate and the Core-UBOS measure. The QAR persistence results suggest that the Core-Wavelet measure is also asymmetric, as persistence varies across the different quantiles (being generally lower in the bottom quantiles). Furthermore, in the Core-Wavelet measure, there are significantly more quantiles in which the null hypothesis of a unit root cannot be rejected. However, the results are somewhat mixed for the period after inflation targeting.

These findings have important implications for the formulation of monetary policy in Uganda, as the behaviour of the inflation target used for monetary policy is asymmetric, and the persistence in headline inflation is high in recent samples. In addition, the results show that the current measure of core inflation (Core-UBOS) might not be the most appropriate inflation rate to target. This is because this measure shows more volatility, and when monetary policy responds to such volatility, these actions could weaken the effectiveness of the ITL monetary policy regime as a tool to anchor inflation expectations. The wavelet-generated measures of core inflation (Core-Wavelet) could be an alternative

measure, since it tracks the headline inflation rate with greater precision, and is less volatile.

Lastly, to control inflation, policymakers in the central bank would need to constantly monitor the build-up of inflation pressures, and proactively employ monetary policy tools to anchor inflation expectations, as the persistence in the measures of inflation are currently high.

# Chapter 4

## Monetary policy and Financial Frictions in a Small Open-Economy model for Uganda

### 4.1 Introduction

The financial sector plays an important role in a modern economy. It acts as a vehicle to mobilise savings, and channels them to other productive sectors of the economy through credit extensions. Disruptions to the financial system may be transmitted to other sectors of the economy and cause macroeconomic instability.<sup>1</sup> It is worth noting that the 1980 Latin American crisis, the 1997 Asian crisis, and the Great recession that started in 2007, were mainly triggered by financial sector weaknesses.

Financial instability also has important implications for the formulation of monetary policy (c.f. [Patinkin, 1956](#); [Tobin, 1969](#)).<sup>2</sup> In addition, [Mishkin \(1996\)](#), argues that instability in the financial sector may partially be attributed to monetary policy actions, such as excessive monetary policy tightening (increasing the interest rate), that are aimed at reducing inflationary pressures. This could explain why central banks in several countries, including LICs such as Uganda, include financial sector stability in their goals.<sup>3</sup>

Prior to the onset of the global financial crisis (GFC), most DSGE models did not fully incorporate financial sector frictions in their design. Initial designs that introduced financial sector frictions into DSGE models by [Kiyotaki et al. \(1997\)](#) and [Bernanke et al. \(1999\)](#) were not adopted by central banks or other policy institutions ([Quadrini, 2011](#)). The general view at the time was that the realisation of price stability would automatically

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<sup>1</sup>[Gray et al. \(2011\)](#) describes how various economic factors (including changes to interest rates) affect financial sector credit risks. They also describe how the financial sector affects measures of economic activity.

<sup>2</sup>According to [Svensson \(2012\)](#), financial stability implies a financial system that is able to fulfill the key role of facilitating payments, extending credit, and managing risks without undue interruptions.

<sup>3</sup>This objective is pursued in tandem with the primary aim of price stability.

stabilize macroeconomic features of the economy, those affected by financial markets. However, the events of the global financial crisis have clearly shown that crises may occur during periods of fairly low inflation. Therefore, financial sector frictions need to feature more prominently in monetary policy models.

Pre-GFC DSGE models largely relied on a simplistic assumption of frictionless financial markets originally characterized in [Modigliani and Miller \(1958\)](#). This assumed that developments in the financial and credit markets would have no bearing on the real economy. As a consequence, the bank lending channel of monetary policy transmission would play no role in the economy, as businesses could source funds directly from firms; and not via banks. These pre-GFC DSGE models therefore did not allow for credit market imperfections, in which some borrowers (who qualify for credit) may be rationed out of the market at the prevailing interest rate ([Stiglitz and Weiss, 1981](#)).

The problem of financial frictions tends to be magnified in LICs such as Uganda, as their financial sectors are underdeveloped, and often dominated by commercial banks. Many of their other financial markets, such as those for fixed-income securities and equities, do not function effectively. This suggests that the bank lending channel for monetary policy transmission in LICs would work through the effect of central bank actions on short-term interest rates charged by banks on loans, and paid on deposits ([Mishra et al., 2010](#)). In addition, commercial banks in LICs operate in an environment with limited creditor information. This is because of underdeveloped credit reference bureaus, where these exist, there are problems with providing physical addresses, and weaknesses in national identification systems.

Furthermore, the GFC showed that loose monetary policies (such as very low or even negative interest rates) and large-scale asset purchases can destabilize the financial system and render financial intermediation futile. Similarly, extremely tight monetary policy may increase borrowing rates and cause non-performing loans to rise, which would also have a destabilizing effect, by weakening the balance sheet of commercial banks ([Mishkin, 1996](#)). Moreover, instability in the financial sector could further derail the real economy, if commercial banks respond to increases in non-performing loans by implementing stringent credit screening processes and reducing credit extensions. For example, during four months of heightened inflationary pressure in Uganda in 2011, the central bank increased its policy rate (central bank rate) by 1000 basis points. Following this, the percentage of non-performing loans (measured as a share of gross loans) rose from 1.81% in September 2011 to 4.65% in September 2012. The annual growth rate of private sector credit fell to 3.9% from 46.4%, during the same period.

After the GFC, the inclusion of financial sector frictions have taken centre stage in the monetary policy models of most developed and some emerging market economies. In many LICs including Uganda, however, these discussions are yet to find a place in monetary policy research. Presently, financial sector stability models of the BoU are not

linked to their monetary policy models. [Vlcek and Roger \(2012\)](#) argue that these limited macro-financial linkages partly reflect institutional arrangements in central banks.<sup>4</sup>

This chapter seeks to extend the DSGE framework to the analysis of monetary policy in Uganda under the inflation-targeting (IT) regime. This aim is motivated by [Baldini et al. \(2015\)](#), who suggest that DSGE models can improve the quality of quantitative macroeconomic policy analysis in LICs. Importantly, the research covered in this chapter extends the literature on the inclusion of financial frictions in DSGE models to the analysis of a LIC economy with a nominal interest rate rule similar to that discussed by [Taylor \(1993\)](#). Our research combines financial friction discussed in [Curdia and Woodford \(2010\)](#) with the small open-economy model in [Justiniano and Preston \(2010\)](#). To the best of our knowledge, this is the first attempt to estimate a DSGE model that incorporates financial frictions for a LIC that targets inflation and pursues a flexible exchange rate regime. Such an exercise is important as LICs have underdeveloped financial and capital markets, which is often reflected in high commercial bank lending rates.

The rest of the chapter is organized as follows. The related literature is discussed in section 4.2. Section 4.3 describes the model, which takes the form of a small open-economy model with financial frictions. Section 4.4 describes the data used, as well as techniques that have been employed for the estimation and the calibration of model parameters. The posterior distributions, the optimal policy rule investigation, the sacrifice ratio estimates, and other results are discussed in section 4.5, and the conclusion is contained in section 4.6. The full log-linear model equations, and additional figures related to the estimation, are contained in the appendix.

## 4.2 Selected literature review

This section contains the literature review for the present study. We initially consider studies that apply structural macroeconomic models to low-income countries (LICs) in Sub-Saharan Africa (SSA). Thereafter, we discuss the literature on inclusion of financial frictions in structural macroeconomic models.

### 4.2.1 Structural macroeconomic models for LICs in SSA

The literature on the application of structural macroeconomic models to LICs in SSA is limited, and shrinks further when we focus our attention on studies that involve monetary policy investigations.

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<sup>4</sup>In most countries, macroeconomic models used for forecasting and policy analysis are developed by monetary/economic policy analysis divisions in central banks, while financial system analysis models are used by Bank supervision/financial stability divisions.

Peiris and Saxegaard (2007) was one of the first to estimate a DSGE model for monetary policy analysis in an African LIC, using data for the Mozambican economy. They include a response function that allows for the monetary policy authority to influence the supply of money, through foreign exchange and government bond transactions. They also recognised a role for credit frictions that are faced by firms, and suggest that the central bank should focus on maintaining the internal value of the currency (rather than the external value), when seeking to stabilise real economic variables. However, unlike our model they do not explicitly model financial frictions as a mechanism for influencing monetary policy.<sup>5</sup>

In a study that focuses on the application of fiscal policy, Berg et al. (2010a), makes use of a multi-sector calibrated DSGE model to investigate the impact of aid on selected macroeconomic variables. This model is applied to economic data from Uganda to evaluate the implications of different policy responses to an inflow of aid. Some of the LIC features that are captured in this model include: Varying degrees of public investment efficiency, realistic monetary and fiscal policy rules, and a household sector with dynamic optimization and rule-of-thumb agents. Their results are mixed. For instance, they find a temporary demand increase and a real exchange rate appreciation results in an increase in public capital spending and aid absorption. In addition, they also find that real gross domestic product (GDP) increases over the medium term, when there is high public capital spending. Conversely, they find that high levels of public capital spending with partial absorption reduces exchange rate appreciation pressures, and decreases real GDP growth over the medium term (as it crowds out private sector spending). Unlike their model, which is designed for fiscal policy analysis, our model discussed in this chapter is used for an investigation into the monetary policy. Another important feature of research by Berg et al. (2010a) is the introduction of heterogeneity, using optimizing and non-optimizing households, in which only the optimizing households have access to financial services. This is contrary to what has been proposed in this chapter, where we assume that households have access to financial services, and only differ in their marginal utility of consumption. In addition, unlike the model in their paper, which is fully calibrated, the model parameters in this paper are mostly estimated with the aid of Bayesian techniques that combine prior information and observed data.

Further research by Berg et al. (2010b) employs Bayesian techniques to estimate the parameters in a new-Keynesian DSGE model for monetary policy analysis in three LICs (Ghana, Tanzania, and Uganda). They account for the differences in monetary policy frameworks in the three countries by assuming monetary aggregate rules for Tanzania and Uganda, and an interest rate rule for Ghana, which had an IT regime. Contrary to

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<sup>5</sup>Peiris and Saxegaard (2007) utilise a pegged exchange rate regime for Mozambique, while the model in this chapter makes use of a flexible exchange rate mechanism to ensure that it is consistent with the current Ugandan exchange rate policy regime.

the assumption of a monetary aggregate rule, the model in this paper incorporates details of the new monetary policy regime that has recently been introduced in Uganda. The Bank of Uganda follows a nominal interest rate rule, that may be modelled according to the general framework of [Taylor \(1993\)](#). They also do not allow for the inclusion of financial frictions in their model (through heterogeneity in the household sector).

[Senbeta \(2011\)](#) introduces foreign exchange availability constraints as an additional friction in their DSGE model for LICs, to capture the conditions faced by domestic firms.<sup>6</sup> Foreign exchange is introduced into the model with the aid of uncovered interest rate parity (UIP) and complete risk-sharing conditions. The results from this study suggest that the introduction of foreign exchange constraints increases the variability in the selected macroeconomic variables, following domestic and external shocks. In addition, the impulse responses are theoretically consistent, and match stylised facts, as they suggest that foreign exchange availability plays an important role in the macroeconomic performance of LICs.

In a recent paper, [Baldini et al. \(2015\)](#) make use of a DSGE model to analyse the impact of the GFC and monetary policy in the Zambian economy. They include the banking sector in their model, to assess the role of monetary policy in the transmission of the financial crisis. Their results suggest that the model broadly matches the path of most of the variables considered. Specifically, they suggest that shocks to the terms of trade, external risk premium, and changes in the bank's appetite for risk help to explain the macroeconomic changes in Zambia during the crisis. This model captures important LICs features, such as the use of monetary aggregate targets for monetary policy formulation, and the dominant role of banks in the financial system. However they do not incorporate explicit financial frictions or heterogeneity in the household sector in their model.

#### 4.2.2 Financial frictions in structural macroeconomic models

Financial sector frictions were introduced into the macroeconomic models by [Kiyotaki et al. \(1997\)](#) and [Bernanke et al. \(1999\)](#). [Kiyotaki et al. \(1997\)](#) introduces financial sector frictions by including collateral constraints. This framework assumes that output in the economy is produced by two sectors, whereby one sector is assumed to be more productive than the other. This heterogeneity gives rise to a dual role for durable assets, in which one form of collateral may be used for borrowing and another for production. Financial sector frictions result from the differences in collateral usage by the two sectors. The second approach for incorporating financial frictions, which is followed by [Bernanke et al. \(1999\)](#), makes use of the financial accelerator mechanism. This framework assumes that there is a degree of information asymmetry between lenders and entrepreneurs, which results in financial market inefficiencies. This allows for an increase in credit premiums

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<sup>6</sup>The model is calibrated but not to any specific LIC.

when the degree of leverage rises. As a result, the supply of credit in the market gets distorted, and this amplifies business cycle fluctuations. As noted in [Curdia and Woodford \(2009\)](#), an important aspect of both of these approaches is that they focus on the demand side of credit, while omitting factors that may affect the supply of credit (which was one of the main causes of the GFC).

Most of the post-GFC literature that incorporates financial sector frictions into structural macroeconomic models may be categorised into one of two groups. The first are studies that state that the standard Taylor rule should include an interest rate spread (c.f. [McCulley and Toloui, 2008](#); [Taylor, 2009](#)). According to this view, the intercept term in the Taylor rule should be adjusted downwards by the magnitude of the observed increase in spreads, in a way that would allow for a one-to-one relationship. The second strand of the literature states that the Taylor rule should be modified to include a measure of credit ([Christiano et al., 2010](#)).

[Curdia and Woodford \(2009\)](#) consider these two modifications. They introduce features of heterogeneity, to separate the participation of agents in the financial markets, and show that an adjustment to the spread marginally improves using the standard Taylor rule. However, these are less robust when considering adjustments in credit volumes. [Curdia and Woodford \(2010\)](#) extend the new- Keynesian model for the monetary policy transmission mechanism to allow for a spread between the interest rate available to savers and borrowers. They suggest that the inclusion of a positive average spread in the model does not substantially alter the effect of policies (relative to the baseline model). It is worth noting that both of these studies use data from a developed economy, and also assume a closed-economy setting. In addition, they make use of calibrated parameter estimates.

[Gray et al. \(2011\)](#) make use of economic data from Chile for a monetary policy model that is influenced by financial sector vulnerability, after incorporating a distance-to-default (DTD) measure to capture credit risks in the banking sector. The results from this model suggest that including this measure in the central bank's reaction function reduces volatility in both inflation and output.

[Steinbach et al. \(2014\)](#), extend the [Curdia and Woodford \(2010\)](#) model and apply it to the South African economy. Unlike the [Curdia and Woodford \(2010\)](#) model which was calibrated to the United States economy, their model parameters are estimated with the aid of Bayesian techniques. They investigate the benefits of the optimal response to rising credit spreads in a small open-economy that is subjected to a financial disturbance. They find that the optimal reaction coefficient that minimises the central bank's loss function is less than unity. They find that the optimal reaction to a change in inflation declines by about 0.2 percentage points, compared to that in a closed economy. They attribute this

to the effect of the exchange rate on the evolution of inflation.<sup>7</sup>

Another novel approach to the introduction of financial sector frictions into a model for African economies is provided in Babilla (2014). He makes use of a small open-economy DSGE model to explore the bank lending channel of the monetary policy transmission mechanism in the West African Monetary Union (WAEMU). The financial system in this model is characterised by an oligopolistic banking sector, and a central bank that follows a fixed exchange rate regime. Similar to some of the findings for advanced and emerging market economies, the authors suggest that adding financial sector frictions improve the model's ability to explain the behaviour of real macroeconomic variables. Furthermore, he finds that the bank lending channel ensures that the monetary policy transmission in WAEMU is more effective, as it strengthens the monetary policy's influence on real economic variables.<sup>8</sup>

Ezezew (2015) applies the financial accelerator mechanism of Bernanke et al. (1999) to a new-Keynesian DSGE model with a banking sector calibrated to the Ethiopian economy. Some of the LIC specific features that the author captures include: The existence of high investment adjustment costs, strong fiscal dominance, and underdeveloped financial and/or capital markets, in which monetary policy targets monetary aggregates. The impulse response functions that follow a monetary policy shock suggest that credit market imperfections amplify the propagation of these shocks in Ethiopia. In addition, a comparison of the results from monetary growth and interest rate rules, suggests that the former generates higher volatility in output and inflation. This setup is somewhat different to our model discussed in this chapter. In our model, the central bank's monetary policy is focused on inflation-targeting, using an explicit interest rate rule.

### 4.3 The model

This section describes the structure of our model for a small open-economy. The domestic economy is that of Uganda, and the foreign economy is represented by the weighted average of the key variables of its trading partners. The open-economy features are based on Justiniano and Preston (2010), which is in turn based on Gali and Monacelli (2005). Financial sector frictions are introduced with the aid of heterogeneous household agents, which is consistent with the approach of Curdia and Woodford (2010). The small open-economy model consists of representatives for final goods producing firms, intermediate goods producing firms, households, financial markets, and fiscal and monetary authorities.

As in the framework of Curdia and Woodford (2010), the households are grouped into

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<sup>7</sup>The model in this chapter is a smaller version of the one in Steinbach et al. (2014) except for differences in the small open-economy features.

<sup>8</sup>The model in Babilla (2014) assumes a fixed exchange rate regime and homogeneous households, which is contrary to assumptions in our model.

two. One group of households are classified as savers, and another group classified as borrowers. It is assumed that the saver households have excess financial resources, which they save and invest with domestic and foreign financial intermediaries. In contrast, the borrowing households have resource deficiencies, which they meet by borrowing from financial intermediaries. Households derive utility from consuming a composite good, that is either produced domestically or imported, while exhibiting habit formation in consumption. In addition, they supply differentiated labour to firms. We impose nominal rigidities in the model, by assuming monopolistic competition in the import and export goods markets. This in turn implies that there is incomplete exchange rate pass-through to both import and export goods prices. Moreover, the domestic and imported goods sectors are assumed to face staggered price setting, and partial indexation of current prices to past inflation. The assumptions on price rigidities, and habit formation are used to increase persistence in the model, following a cost-push or monetary policy shock.

Monetary policy is formulated using a generalized open-economy rule that follows [Taylor \(1993\)](#). Therefore, it is assumed that the short term nominal interest rate is adjusted in response to the evolution of inflation, output, and nominal exchange rate depreciation. Interest rate spreads are also included in the monetary policy reaction function, to promote financial stability in the financial sector. Lastly, the model includes a fiscal sector, to account for government spending behaviour. In the following subsections, we describe the features for the respective sectors of the economy in our model.

### 4.3.1 Heterogeneous households

Following [Curdia and Woodford \(2010\)](#), the representative households are grouped into savers, denoted by  $s$ , and borrowers, denoted by  $b$ . This categorization is assumed to be influenced by differences in the levels of marginal utility of consumption, where the borrowing households have a higher rate of marginal utility for current period consumption. This feature allows a role for financial intermediation, where savers either deposit excess income with financial intermediaries, or invest in risk-free bonds. These instruments pay the prevailing gross policy rate,  $R_t$  for domestic bonds, or  $R_t^*$  in the case of foreign bonds. The borrowing households may then consume in excess of their income during the current period, after they obtain credit from financial intermediaries that is associated with an interest rate that is equivalent to the gross lending rate,  $R_t^b$ . The presence of households that have different objectives establishes a relationship between the gross policy rate and the lending rate, where  $R_t^b > R_t$ .

It is assumed that it would take a special event for households to change from being borrowers to savers (and vice versa). Such events are described by an independent two-state Markov chain process, where it is assumed that in each period there is a transition probability of  $1 - \Omega$ . In terms of the initial state probabilities, it is assumed that the

proportion of saving households is represented by the probability  $\pi_s$ , and the proportion of borrowing households is represented by the probability  $\pi_b$ , where, after superimposing the laws of probabilities,  $\pi_s + \pi_b = 1$ . Furthermore, for simplicity, it is assumed that the number of saver and borrower households are equal (i.e.  $\pi_s = \pi_b = 0.5$ ), and the probability that a transition will arise is 0.025 (which corresponds to  $\Omega = 0.975$ ). This implies that it takes about 10 years for a household to change from one type to another. Each household type seeks to maximize the following expected discounted utility:

$$E_o \sum_{t=0}^{\infty} \beta^t \left[ u^{\tau_t(i)} (C_t(i); \varsigma_t^{gc}) - v^{\tau_t(i)} (n_t(i); \varsigma_t^{gc}) \right], \quad (4.1)$$

where  $\tau_t(i) \in \{s, b\}$  denotes the household's type in period  $t$ ,  $\beta$  is the rate of time preference (discount factor) and  $\varsigma_t^{gc}$  represents preference shocks. The utility and disutility from consumption and labour supply, respectively are assumed to take the following forms:

$$u^{\tau_t(i)} (C_t(i); \varsigma_t^{gc}) \equiv \varsigma_t^{gc} \frac{(C_t(i) - h_{\tau} C_{t-1}^{\tau})^{1-\sigma_{\tau}}}{1-\sigma_{\tau}},$$

and

$$v^{\tau_t(i)} (n_t(i); \varsigma_t^{gc}) \equiv \varsigma_t^{gc} \Lambda_L \frac{n_t(i)^{1+\sigma_L}}{1+\sigma_L}. \quad (4.2)$$

where  $\sigma_{\tau}$  is the inverse elasticity of intertemporal substitution,  $\sigma_L$  is the inverse elasticity of labour supply, and  $h_{\tau}$  captures the degree of habit formation in consumption. The parameter,  $\Lambda_L$  denotes the steady state of labour supply, and  $n_t(i)$ , represents the hours of labour supply that are provided by each household type. Equation (4.1) implies that household utility depends positively on the difference between the current level of consumption,  $C_t(i)$ , that is chosen by each household type, and the average level of consumption that was chosen by all households in the previous period,  $C_{t-1}^{\tau}$ . This equation also suggests that the utility depends negatively on labour supply. Moreover, the equilibrium marginal utility of consumption of savers is less than that of the borrowers. Consequently, the expenditure of savers is less sensitive to interest rate changes, than the expenditure of borrowers, and this is expressed as,  $\sigma_s > \sigma_b$  and  $b_s > b_b$ . Lastly, both types of households are affected by preference shocks  $\varsigma_t^{gc}$ , which are represented by a first order autoregressive process:  $\varsigma_t^{gc} = \rho_{gc} \varsigma_{t-1}^{gc} + \eta_t^{gc}$ .

The average level of household consumption for the two household types is assumed to be a composite index consisting of domestically produced and foreign goods, expressed as:

$$C_t = \left[ (1 - \alpha)^{\frac{1}{\eta}} C_{H,t}^{\frac{\eta-1}{\eta}} + \alpha^{\frac{1}{\eta}} C_{F,t}^{\frac{\eta-1}{\eta}} \right]^{\frac{\eta}{\eta-1}} \quad (4.3)$$

where  $C_{H,t}$  and  $C_{F,t}$  denote the consumption of domestically produced and foreign goods, respectively, and the parameter  $\alpha \in [0, 1]$ , denotes the degree of openness, as measured by the fraction of imported goods in households' consumption. The parameter,  $\eta$ , denotes the elasticity of substitution between domestic and imported goods. The consumption of these goods would then evolve as a constant elasticity of substitution (CES) function, given by:

$$C_{H,t} = \left[ \int_0^1 C_{H,j,t}^{\frac{\varepsilon-1}{\varepsilon}} dj \right]^{\frac{\varepsilon}{\varepsilon-1}} \quad (4.4)$$

and

$$C_{F,t} = \left[ \int_0^1 C_{F,j,t}^{\frac{\varepsilon-1}{\varepsilon}} dj \right]^{\frac{\varepsilon}{\varepsilon-1}} \quad (4.5)$$

where  $\varepsilon$  represents the elasticity of substitution between domestically produced and foreign goods.

Furthermore, it is assumed that the random draws that the households are subjected to could generate idiosyncratic risks, and this, combined with the aggregate risk, could cause instability within the model setup. Accordingly, to guard against such anticipated instabilities, it is assumed that households insure each other and the insurance transfers are paid in the period that occurs prior to revealing the household types. Once the households receive the insurance transfers and know their new types, they decide how much to spend, save, and borrow, in every period, while taking into account their net wealth after the insurance transfer.

Let us assume that each household's net domestic financial wealth,  $A_t(i)$  at the start of the period takes the following form:

$$A_t(i) = [B_{t-1}(i)]^+ R_{t-1} + [B_{t-1}(i)]^- R_{t-1}^b + D_t^{int} \quad (4.6)$$

where  $B_{t-1}(i)$ , represents the net domestic financial wealth of the household in the previous period. Whereby  $[B]^+ \equiv \max(B, 0)$  denotes the households with positive balances, and  $[B]^- \equiv \min(B, 0)$  denotes the households with negative balances. The households with positive balances could then deposit such balances with a financial intermediary, and be remunerated at the gross policy rate,  $R_t$ . While the households with negative balances would have to borrow from financial intermediaries at the gross lending rate,  $R_t^b$  to finance their consumption. In addition, it is assumed that the household's own financial intermediaries, and the profits of the financial intermediaries, are equally distributed, and denoted by  $D_t^{int}$ . Suppose,  $B_t^g$  denotes risk-free government bonds at the end of each

period  $t$ ,  $D_t$  represents aggregate household deposits with financial intermediaries, and  $L_t$  denotes aggregate household borrowing from financial intermediaries. The equation describing the evolution of households' net domestic wealth may then be expressed as:

$$D_t + B_t^g = \int_{\mathcal{S}_t} A_t(i) di, \quad L_t = - \int_{\mathcal{B}_t} A_t(i) di \quad (4.7)$$

where  $\mathcal{B}_t$  denotes the set of households' for whom,  $A_t(i) < 0$  and  $\mathcal{S}_t$  denotes the set of households' for whom  $A_t(i) \geq 0$ .

In order to obtain the budget constraint for households, recall that the saving households have access to both domestic bonds ( $B$ ) and foreign bonds ( $B^*$ ). Using the small open-economy literature, we assume that the nominal interest rate on foreign bonds is subject to a risk premium, which increases with the stock of foreign bonds in domestic currency (Schmitt-Grohé and Uribe, 2003). The remuneration of foreign bonds would have to be adjusted by such a risk premium, and may be expressed as  $R_t^* \phi_{t-1}$ . Where  $\phi_t$  is the risk premium factor. The households' stock of foreign asset holdings can then be expressed in terms of domestic currency as,  $e_t B^*$ , where the nominal exchange rate ( $e_t$ ) is used as the conversion factor (i.e. the domestic currency price of a unit of foreign currency). Given these assumptions, the household's total bond holdings could then be expressed as  $B_t + e_t B^* \leq R_{t-1} B_{t-1} + R_{t-1}^* \phi_{t-1} e_t B_{t-1}^*$ .

The household's budget constraint may thus be expressed by:

$$P_t C_t + B_t + e_t B^* = R_{t-1} B_{t-1} + R_{t-1}^* \phi_{t-1} e_t B_{t-1}^* (a_t) + W_t n_t + T_t \quad (4.8)$$

where,  $a_t$  represents the net asset position of the domestic economy,  $W_t$  denotes the nominal wage rate,  $T_t$  denotes lump-sum taxes and transfers. The term  $P_t$  represents the domestic CPI, so that  $P_t C_t$  is total domestic consumption expenditure. In Equation (4.8), the left hand side represents household expenditure (consumption and investment in bonds), while the right hand side represents household income. The country risk premium and the net foreign asset position of the domestic economy may be expressed in terms of domestic currency and the steady-state level of output,

$$\phi_t = \exp\left(\tilde{\phi}_t - \psi a_t\right) \quad (4.9)$$

$$a_t = \frac{e_{t-1} B_{t-1}^*}{\bar{Y} P_{t-1}} \quad (4.10)$$

where,  $\psi$  is the parameter that describes the relationship between foreign bond holdings and the output trend in the domestic economy. In addition  $\bar{Y}$  is the steady state level of real output, and  $\tilde{\phi}_t$  is the exogenous risk premium shock, which evolves as a first order autoregressive process:  $\tilde{\phi}_t = \rho_\phi \tilde{\phi}_{t-1} + \eta_t^\phi$ .

The household's optimization problem would then reduce to a decision that relates to expenditure that should be allocated to domestically produced and foreign goods. The resultant optimal expenditure allocation for each good that is within the continuum  $j \in [0, 1]$  is determined by the demand for each of the goods and can be expressed as:

$$C_{H,t}(i) = \left( \frac{P_{H,t}(i)}{P_{H,t}} \right)^{-\theta} C_{H,t} \quad (4.11)$$

and

$$C_{F,t}(i) = \left( \frac{P_{F,t}(i)}{P_{F,t}} \right)^{-\theta} C_{F,t}. \quad (4.12)$$

where,  $P_{H,t}$  and  $P_{F,t}$  denote the price indices for domestically produced and imported goods, respectively. The two prices could then be expressed using the Dixit-Stiglitz aggregator as:

$$P_{H,t} = \left( \int_0^1 P_{H,j,t}^{1-\theta} dj \right)^{\frac{1}{1-\theta}} \text{ and } P_{F,t} = \left( \int_0^1 P_{F,j,t}^{1-\theta} dj \right)^{\frac{1}{1-\theta}}.$$

Under the assumption of asymmetry between all ( $j$ ) goods, the resultant optimal allocation of domestic expenditure between domestic and foreign goods is given by:

$$C_{H,t} = (1 - \alpha) \left( \frac{P_{H,t}}{P_t} \right)^{-\eta} C_t \quad (4.13)$$

and

$$C_{F,t} = \alpha \left( \frac{P_{F,t}}{P_t} \right)^{-\eta} C_t. \quad (4.14)$$

where, the aggregate consumer price index is expressed as,  $P_t = [(1 - \alpha) P_{H,t}^{1-\eta} + \alpha P_{F,t}^{1-\eta}]^{\frac{1}{1-\eta}}$ . The total consumption expenditure for domestic households could then be expressed as:  $P_t C_t = P_{H,t} C_{H,t} + P_{F,t} C_{F,t}$ .

If Lagrange multiplier for the optimization problem for the utility function in Equation (4.1), and the budget constraint in Equation (4.8) is given as,  $\Lambda_t^{z,\tau} = z_t P_t^d v_t^\tau$ . The resultant first order conditions with respect to the choice variables,  $C_{i,t}$ ,  $L_t$ ,  $(D_t + B_t)$  and  $B_t^*$  can be expressed as:

w.r.t  $c_t^\tau$ :

$$\varsigma_t^{gc} \left( c_t^\tau - h_\tau c_{t-1}^\tau \frac{1}{\mu_t^z} \right)^{-\sigma_\tau} - \beta h_\tau E_t \varsigma_{t+1}^{gc} (c_{t+1}^\tau \mu_{t+1}^z - h c_t^\tau)^{-\sigma_\tau} - \Lambda_t^{z,\tau} P_t = 0 \quad (4.15)$$

w.r.t  $l_t$ :

$$- \Lambda_t^{z,b} + \beta E_t \left[ \frac{R_t^b}{\mu_{t+1}^z \pi_t} \left\{ [\Omega + (1 - \Omega) \pi_b] \Lambda_{t+1}^{z,b} + (1 - \Omega) \pi_s \Lambda_{t+1}^{z,s} \right\} \right] = 0 \quad (4.16)$$

w.r.t  $(d_t + b_t)$ :

$$- \Lambda_t^{z,s} + \beta E_t \left[ \frac{R_t}{\mu_{t+1}^z \pi_{t+1}} \left\{ (1 - \Omega) \pi_b \Lambda_{t+1}^{z,b} + [\Omega + (1 - \Omega) \pi_s] \Lambda_{t+1}^{z,s} \right\} \right] = 0 \quad (4.17)$$

w.r.t  $b_t^*$ :

$$- \Lambda_t^{z,s} + \beta E_t \left[ \frac{e_{t+1}}{e_t} \frac{R^* \phi_t}{\mu_{t+1} \pi_{t+1}} \left\{ (1 - \Omega) \pi_b \Lambda_{t+1}^{z,b} + [\Omega + (1 - \Omega) \pi_s] \Lambda_{t+1}^{z,s} \right\} \right] = 0 \quad (4.18)$$

## 4.3.2 Firms

Production in the economy is assumed to take place in two stages. In the first stage, a continuum of monopolistically competitive intermediate goods firms supply raw materials. The second stage is comprised of perfectly competitive final goods producers that supply finished products to households and to government.

### 4.3.2.1 Intermediate goods producers

The monopolistically competitive intermediate goods firms produce a continuum of differentiated goods, indexed by  $j \in [0, 1]$ , using the following linear production technology:

$$Y_{j,t} = Z_t n_{j,t} \quad (4.19)$$

where  $Z_t$ , captures the exogenous, possibly time-varying productivity shock that evolves as an AR(1) process, and  $n_{j,t}$ , represents labour inputs used in the production of intermediate goods.

Nominal rigidities are introduced into the intermediate goods producing sector, by assuming that each firm sets prices in a staggered manner, using the Calvo-style price setting mechanism (Calvo, 1983). In each period  $t$ , a subset of firms adjust their prices to a new level. Firms that adjust their prices, do so optimally, with a probability  $(1 - \theta_H)$ , after they have received the signal to adjust their prices. The remaining firms represented by probability  $\theta_H$ , maintain the price level from the previous period. Thus the size of  $\theta_H$  would determine the degree of price stickiness in the domestic economy, where fairly large values would infer a greater degree of price stickiness. Additional persistence in the pricing mechanism is introduced by assuming that current domestic prices are determined by prices and the inflation rate in the previous period, expressed using the following

indexation rule:

$$\log P_{H,t} = \log P_{H,t-1} + \delta_H \pi_{H,t-1} \quad (4.20)$$

where  $\pi_{H,t} = \log(P_{H,t}/P_{H,t-1})$  is the inflation rate and  $\delta_H$  is a measure for the degree of indexation to the previous inflation rate. As noted previously, the price index for home goods evolves as:

$$P_{H,t} = \left[ \theta_H \left( P_{H,t-1} \pi_{H,t-1}^{\delta_H} \right)^{1-\varepsilon} + (1 - \theta_H) P_H^{1-\varepsilon} \right]^{\frac{1}{1-\varepsilon}} \quad (4.21)$$

The problem faced by each intermediate goods producing firm with the ability to change prices is to maximize the expected present discounted value of earnings. The intermediate firm thus seeks to solve the following optimization function,

$$\max E_t \sum_{T=t}^{\infty} \theta_H^{T-t} Q_{t,t+k} Y_{j,t+k} \left[ P_{H,t} \pi_{H,t+k-1}^{\delta} - P_{H,t+k} MC_{t+k} \right] \quad (4.22)$$

subject to the condition that production of intermediate goods equals the demand for intermediate goods by the final goods producers:

$$Y_{j,t} = \left[ \frac{P_{H,t}(j) \pi_{H,t+k-1}^{\delta_H}}{P_{H,t}} \right]^{-\varepsilon} Y_t \quad (4.23)$$

where  $MC_{t+k} = W_{t+k}/(P_{H,t+k} Z_{t+k})$  represents the real marginal cost of each intermediate firm, and  $\theta_H^{T-1}$  denotes the probability that the intermediate goods firm will not adjust prices in the next  $(T - t)$  periods. The firms' optimization problem therefore implies the following first-order condition:

$$E_t \sum_{T=t}^{\infty} \theta_H^{T-1} Q_{t,t+k} Y_{j,t+k} \left[ P_{H,t} \pi_{H,t+k-1}^{\delta} - \frac{\theta_H}{\theta_H - 1} P_{H,t+k} MC_{t+k} \right] = 0 \quad (4.24)$$

### 4.3.2.2 Final goods producers

The market for final domestic goods producers is assumed to be perfectly competitive. That is, where the producers of final goods utilize the output from the intermediate goods producers as inputs in the production of differentiated final goods, which are sold to households and government. The transformation of intermediate goods into final goods is described by a constant elasticity of substitution (CES) production technology of the form:

$$Y_t = \left[ \int_0^1 Y_{j,t}^{\frac{1}{\lambda_t}} dj \right]^{\lambda_t} \quad (4.25)$$

where  $\lambda_t = \theta_t/(\theta_t - 1)$  represents the time-varying markup for domestic goods that

follows an AR(1) process. In addition,  $\theta_t$  represents the elasticity of substitution between the intermediate goods. The output from the final goods producers may be consumed domestically, or exported. The assumption of perfect competition in the final goods market implies that the representative firm takes the price of final goods,  $P_t$ , and the price of the intermediate goods (inputs),  $P_{j,t}$ , as given. After solving the first order condition for the profit maximization problem of the final goods producing firm, the resultant demand function,  $Y_{j,t}$ , for each intermediate good  $j$  can be expressed as:

$$Y_{j,t} = \left( \frac{P_t}{P_{j,t}} \right)^{\frac{\lambda_t}{\lambda_t - 1}} Y_t, \quad (4.26)$$

Similarly, after making use of Equation (4.25) and rearranging, we obtain a relationship that expresses the aggregate price level of final goods in terms of intermediate goods' prices:

$$P_t = \left[ \int_0^1 P_{j,t}^{\frac{1}{1-\lambda_t}} dj \right]^{1-\lambda_t}. \quad (4.27)$$

where, the parameter  $\lambda_t$  is used to denote the extent of monopoly power of each intermediate goods producer. The interpretation of the monopoly power parameter is such that large values would indicate high levels of monopoly power.

Lastly, the foreign demand for domestic goods,  $C_{H,t}^*$ , could be expressed as,

$$C_{H,t}^* = (C_{H,t-1}^*)^\delta \left[ \alpha^* Y_t^* \left( \frac{P_t}{e_t P_t^*} \right)^{-\eta} \right]^{1-\delta} \quad (4.28)$$

where, the superscript \* is used to represent the foreign economy,  $\delta$  measures the relationship between previous exports and current exports,  $\alpha^*$  is the share of foreign produced goods in overall expenditure in the foreign economy.

### 4.3.2.3 Foreign produced goods

It is assumed that firms in the foreign market operate in a monopolistically competitive market, where they enjoy some degree of market power in setting prices. Consequently, firms employ the Calvo price setting framework, with the addition of indexation of current period prices to past inflation. The fraction of firms that are able to change prices is given by  $(1 - \theta_F)$  and firms set prices according to an indexation rule that is similar to the one employed by the domestic intermediate goods producers in Equation (4.20). The aggregate price index for the foreign produced goods is given by

$$P_{F,t} = \left[ \theta_F \left( P_{F,t-1} \pi_{F,t-1}^{\delta_F} \right)^{1-\varepsilon} + (1 - \theta_F) P_F^{1-\varepsilon} \right]^{\frac{1}{1-\varepsilon}} \quad (4.29)$$

### 4.3.3 The real exchange rate and the terms of trade

This section introduces the relationships between inflation, the real exchange rate, and the terms of trade, which are common variables used in open-economy models. In the case of a small open-economy model, it is assumed that the law-of-one-price (LOP) holds for the export sector, while there is incomplete pass-through for the import sector, as domestic retailers may apply different margins on imports. This assumption follows from the notion that Uganda is a small open-economy, and hence would be a price taker, as it has little influence on international market prices. Thus, for imports, the LOP only holds at the port of entry, as the different margins of domestic retailers allow for domestic import prices to differ from the world price.

#### 4.3.3.1 The terms of trade

The bilateral terms of trade (TOT),  $S_{j,t}$ , between a home country and a foreign country is the measure of the relative price of the home country's imported goods in terms of home produced goods, and may be expressed as:

$$S_{i,t} = \frac{P_{i,t}}{P_{H,t}} \quad (4.30)$$

When this ratio is calculated for the home country and all the trading partner countries, the resultant ratio is referred to as the effective TOT,  $S_t$ , and may be expressed as:

$$\begin{aligned} S_t &\equiv \frac{P_{F,t}}{P_{H,t}} \\ &= \left( \int_0^1 S_{i,t}^{1-\gamma} di \right)^{\frac{1}{1-\gamma}} \end{aligned} \quad (4.31)$$

#### 4.3.3.2 Law of one price

The law of one price states that once differences in exchange rates have been incorporated, prices for the same commodities in different countries should be similar. Consequently, one of the key assumptions in small open-economy models is that the law-of-one-price holds for foreign goods. However, it is also claimed that the assumption of monopolistic competition among retailers in the domestic economy introduces price rigidities into the import goods sector. Given these rigidities, prices of imported goods in the domestic economy may deviate from world prices. The difference between import prices in the domestic and foreign economy is captured by the law of one price gap, which is expressed as:

$$\psi_{F,t} = \frac{e_t P_{F,t}^*}{P_{F,t}} \quad (4.32)$$

where  $e_t$  is the nominal exchange rate, and  $P_{F,t}^*$  is the price of imported goods in the foreign economy. Since the domestic country's exports are assumed to be a small fraction of total world trade,  $P_{F,t}^*$  can be approximated by the foreign CPI,  $P_t^*$ . The TOT in Equation (4.31) may thus be re-written as:

$$S_t = \frac{e_t P_t^*}{P_{H,t}} \quad (4.33)$$

### 4.3.3.3 Real exchange rate

Foreign inflation and domestic exchange rate depreciation affect the TOT by making exported goods more expensive. The real exchange rate,  $Q_t$ , could therefore be described as,

$$Q_t = \frac{e_t P_t^*}{P_t} \quad (4.34)$$

### 4.3.4 International risk sharing and uncovered interest parity

The open-economy model allows saving households to hold foreign bonds. However, the prices of such bonds are determined in the foreign market, and the saving households have little influence over these prices. As a result, the saving household's preference for foreign bonds over domestic bonds would be influenced by the real rate of return on foreign bonds, relative to that of domestic bonds. In addition, disturbances that affect the prices of bonds may introduce instability into the saving household's portfolios. Thus, it becomes necessary to close off the open-economy features of such a model. Accordingly, we adopt the assumption of complete asset markets with international risk sharing to induce stationarity into the model. A detailed discussion on the approaches to closing-off small open-economy models is contained in [Schmitt-Grohé and Uribe \(2003\)](#).<sup>9</sup>

We adopt the specification in [Gali and Monacelli \(2005\)](#), where the assumption of a complete securities market is expressed using the intratemporal optimality condition for the external economy

$$Q_{t+1}^i = \beta \left( \frac{C_{t+1}^i}{C_t^i} \right)^{-\sigma} \left( \frac{P_t^i}{P_{t+1}^i} \right) \left( \frac{e_t^i}{e_{t+1}^i} \right) \quad (4.35)$$

and

$$C_t = \vartheta_i C_t^i Q_{i,t}^{\frac{1}{\sigma}} \quad (4.36)$$

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<sup>9</sup>[Schmitt-Grohé and Uribe \(2003\)](#), introduces several approaches to induce stationarity in open-economy models, but states that the different approaches give identical results for business cycle dynamics.

where, Equation (4.36) is obtained by combining Equation (4.34) and Equation (4.35).

The exchange rate dynamics in the SOE can be obtained through the application of the uncovered interest rate parity (UIP) condition, which relies on the complete international risk sharing assumption. It is argued that, due to the assumption of complete international financial markets and free capital movement, the expected nominal returns from risk-free bonds in the domestic economy would equal the expected nominal return of the risk free foreign economy bonds, when expressed in the domestic currency. Perfect risk-sharing is possible because households in one country may invest in another country. As a result, the stochastic discount factor in the domestic and foreign economy would be equal, and may be expressed as:

$$\beta \left[ \frac{\lambda_{t+1}}{\lambda_t} \cdot \frac{P_t}{P_{t+1}} \right] = Q_{t,t+1} = \beta \left[ \frac{\lambda_{t+1}^*}{\lambda_t^*} \cdot \frac{P_t^* e_t}{P_{t+1}^* e_{t+1}} \right] \quad (4.37)$$

Equation (4.37) can be used to obtain the uncovered interest rate parity condition in log-linearized form as:

$$E_t q_{t+1} - q_t = (R_t - E_t \pi_{t+1}) - (R_t^* - E_t \pi_{t+1}^*) + \phi_{uip} a_t + \varepsilon_t^{rp} \quad (4.38)$$

where the superscript \* again refers to the foreign country and  $q_t = e_t + p_t^* - p_t$  is the real exchange rate. The term  $\phi_{uip} a_t$  denotes the country risk premium, where the coefficient  $\phi_{uip}$  is the elasticity parameter in the UIP and  $a_t$  is the net foreign asset position of the country, and  $\varepsilon_t^{rp}$  is the risk premium shock which follows an AR(1) process. The linearized UIP condition equation implies that agents include a stochastic risk premium while trading in a frictionless international bond market. The resultant net foreign asset position of the domestic country, from Equation (4.38), may be expressed in a linearized form as

$$a_t = \frac{1}{\beta} a_{t-1} - \alpha (s_t + \psi_{F,t}) + y_t - c_t \quad (4.39)$$

### 4.3.5 Financial intermediaries

Credit markets in Uganda are neither efficient nor perfectly competitive, and Ugandan lending rates experience downward rigidities. Evidence of this is provided in the November 2012 monetary policy statement of the Governor of the BoU, “. . . whereas inter-bank rates, wholesale deposit interest rates and securities yields have all followed the downward trend of the CBR, commercial bank’s lending rates have been sticky downwards (Tumusiime-Mutebile, 2012)”. Such a weakness in the financial sector may reduce the effectiveness of monetary policy, and may increase non-performing loans. Difference in the marginal utility of consumption between the saving and borrowing households may be another source of financial friction in the economy. It seems then that, incorporating

financial frictions in a monetary model for the Ugandan economy could produce a more appropriate model for this LIC.

In this section, we introduce financial frictions into the model by assuming that the financial intermediaries in the economy take real deposits,  $d_t$ , from the saving households and lend a fraction, in the form of real loans,  $l_t$ , to the borrowing households. However, not all households who borrow fulfill their obligations. We thus make provision for bad debts, and assume that a fraction  $\chi_t(l_t)$  of the loans that were extended will not be repaid at the end of the period. This loss rate,  $\chi_t$ , is a non-negative function that depends on macroeconomic conditions (such as economic activity, the inflation rate and interest rates). This variable would vary from one period to the next, depending on underlying macroeconomic conditions. Furthermore, we restrict the operations of the financial intermediaries to the domestic economy, which indicates that foreign currency deposits and loans in the banking sector are a small proportion of total loans. Consequently, the real profits of financial intermediaries, which are discounted by the expected fraction of loan defaults, would be expressed as:

$$D_t^{int,r} = d_t - l_t - \chi_t(l_t) \quad (4.40)$$

where  $\chi_t(l_t) = \chi_t^{1+\eta_\chi}$ .

In addition, we assume that the loans that are extended in period  $t$  are paid in the following period,  $t+1$ . At the time of repayment, the intermediaries receive,  $l_t R_t^b$ . Because the loans are sourced from the deposits, the intermediaries would pay  $d_t R_t$  to the savers for their deposits. Consequently, the earnings of the financial intermediaries would depend on the spread ( $\omega_t$ ) between the lending rate ( $R_t^b$ ) and the deposit rate ( $R_t$ ), which is expressed as:

$$R_t^b = \omega_t R_t. \quad (4.41)$$

Thus, the problem for financial intermediaries reduces to the maximization of profits, given in Equation (4.40), by choosing the volume of loans,  $l_t$ . The resultant first order condition from this optimization problem yields the following equation for the interest rate spread:

$$\omega_t = 1 + (1 + \eta_\chi) \chi_t l_t^{\eta_\chi} + \eta_\Phi \Phi_t l_t^{\eta_\Phi - 1} \quad (4.42)$$

where Equation (4.42) implies that the interest rate spread is an increasing function of the fraction of non-performing loans,  $\chi_t$  and the volume of loans extended,  $l_t$  (when  $\eta_\Phi > 0$ ). A decline in economic activity could negatively affect business balance sheets, which could constrain the firm's ability to pay back the borrowed funds, and possibly

lead to an increase in non-performing loans. In contrast, the effect of inflation on non-performing loans could either be positive or negative, depending on how it affects the wealth level. For instance, an increase in inflation could erode the wealth of a household and weaken the ability of a household to pay back borrowed funds. An increase in inflation could reduce the real value of borrowed funds, which would make it easier for firms to pay back loans, which would reduce the amount of non-performing loans. Furthermore, an increase in the rate of inflation could also result in an increase in the nominal interest rate, which would again affect the cost of funds, and the level of non-performing loans. Therefore, we express the evolution of non-performing loans as:

$$\chi_t = \chi_{t-1}^{\rho_\chi} \Theta_t^{-\theta_\chi} \epsilon_t^\chi \quad (4.43)$$

where  $\Theta_t > 0$  is a measure of the economic conditions indicator (output or inflation), and  $\epsilon_t^\chi$  denotes an exogenous shock to the fraction of non-performing loans.

### 4.3.6 Government

Government expenditure evolves fairly smoothly over time, and may be described by the process,

$$g_t = (1 - \rho_g) g + \rho_g g_{t-1} + \eta_t^{g_t} \quad (4.44)$$

where,  $g$  is the steady state level of government spending and  $\eta_t^{g_t}$  represents a shock to government spending. After the variable is demeaned, and we assume that the steady state level of government spending is zero, this expression reduces to,

$$g_t = \rho_g g_{t-1} + \eta_t^{g_t} \quad (4.45)$$

### 4.3.7 Central Bank

The BoU adopted ITL in 2011. This monetary policy framework has features that are similar to the forward-looking policies that are applied in many advanced and emerging market economies. Thus, it is assumed that the central bank's monetary policy framework follows the generalized [Taylor \(1993\)](#) rule, when it sets the short-term nominal interest rate. In this characterisation, it is assumed that the central bank adjusts its policy instrument in response to developments in core inflation, the output gap (measured as the deviation of actual output from its stochastic trend), and a nominal exchange rate depreciation. The inclusion of the exchange rate in the Taylor rule is supported by [Blanchard et al. \(2010\)](#), who suggest that central banks in small open economies should openly recognize exchange rate stability as part of their objective. The monetary policy rule is expressed as:

$$R_t = \rho_R R_{t-1} + (1 - \rho_R) [\rho_\pi \pi_t + \rho_y y_t + \rho_e \Delta e_t] + \varepsilon_t^R \quad (4.46)$$

where  $\rho_R$  is the parameter measuring the degree of interest rate smoothing,  $\rho_\pi$  is the weight attached to inflation,  $\rho_y$  is the weight attached to developments in the output, and  $\rho_e$  is the weight attached to nominal exchange rate depreciation. The term  $\varepsilon_t^R$  is an uncorrelated monetary policy shock that follows an AR(1) specification.

In several countries, including Uganda, monetary policy also responds to financial conditions, but mostly in an ad hoc manner. For instance, during periods of rapid credit growth, monetary policy could be tightened to induce a slowdown in credit growth. Similarly, a expansive monetary policy could be pursued when private sector credit growth decelerates. In addition, [Vredin \(2015\)](#), suggests that monetary policy rules should include indicators of financial instability. Therefore, in order to consider the possible benefits that may be derived from explicitly including such actions in the monetary policy rule, a measure of financial frictions is introduced in Equation (4.46), as follows:

$$R_t = \rho_R R_{t-1} + (1 - \rho_R) [\rho_\pi \pi_t + \rho_y y_t + \rho_e \Delta e_t - \rho_\omega \omega_t] + \varepsilon_t^R \quad (4.47)$$

where  $\rho_\omega$  is the weight attached to the financial friction in the monetary policy rule, measured by the interest rate spread. The negative sign for the coefficient follows the proposal that the nominal interest rate should be lowered when lending spreads widen (c.f. [Taylor, 2009](#); [McCulley and Toloui, 2008](#)).

### 4.3.8 Foreign economy

The foreign economy is assumed to be exogenous to the domestic economy. That is, developments in the foreign economy affect the domestic economy, but developments in the domestic economy do not affect the foreign economy. The equations that capture the key relationships in the foreign economy are modeled as AR(1) processes, expressed as:

$$y_t^* = \rho_{y^*} y_{t-1}^* + \eta_t^{y^*} \quad (4.48)$$

$$\pi_t^* = \rho_{\pi^*} \pi_{t-1}^* + \eta_t^{\pi^*} \quad (4.49)$$

$$R_t^* = \rho_{R^*} R_{t-1}^* + \eta_t^{R^*} \quad (4.50)$$

where  $y_t^*$ ,  $\pi_t^*$  and  $r_t^*$  denote foreign economy measures for output, inflation, and the interest rate, respectively. The parameters,  $\eta_t^{y^*}$ ,  $\eta_t^{\pi^*}$  and  $\eta_t^{R^*}$  represent i.i.d shocks to foreign output, inflation, and the interest rate, respectively.

### 4.3.9 Aggregate demand and output

Lastly, it is assumed that the goods market clears in the domestic economy, which requires that domestic output matches the sum of domestic consumption and foreign consumption of all domestically produced goods (i.e. exports). Thus

$$y_t = (1 - \alpha) C_{H,t} + \alpha C_{H,t}^* \quad (4.51)$$

Using the specification of the demand functions in Equation (4.14), we can then provide the relationships

$$C_{H,t} = (1 - \alpha) \left( \frac{P_{H,t}}{P_t} \right)^{-\eta} C_t \quad (4.52)$$

and

$$C_{H,t}^* = \alpha \left( \frac{e_t P_{H,t}}{P_t^*} \right)^{-\eta} C_t^* \quad (4.53)$$

which can be log linearized into:

$$c_{H,t} = -\eta (p_{H,t} - p_t) + c_t \quad (4.54)$$

$$= \alpha \eta s_t + c_t \quad (4.55)$$

$$c_{H,t}^* = -\eta (e_t + p_{H,t} - p_t^*) + c_t^* \quad (4.56)$$

$$= -\eta (p_{H,t} - p_{F,t} - \psi_t) + c_t^* \quad (4.57)$$

$$= \eta (s_t + \psi_t) + c_t^* \quad (4.58)$$

Substituting Equation (4.54) and Equation (4.56) into Equation (4.51) yields the final specification for the clearing of the goods market:

$$y_t = (1 - \alpha) [\eta \alpha s_t + c_t] + \alpha [\eta (s_t + \psi_t) + c_t^*] \quad (4.59)$$

$$= (1 - \alpha) c_t + \alpha c_t^* + (2 - \alpha) \alpha \eta s_t + \alpha \eta \psi_t \quad (4.60)$$

### 4.3.10 State space model representation

In this section, the complete model is presented in state-space form, which establishes the basis for a calculation of the likelihood function used in the Bayesian estimation. The model consists of measurement and transition equations that are represented by:

$$Y_t = \Lambda(\theta) Z_t + \mu_t$$

$$Z_t = \Phi_1(\theta) Z_{t-1} + \Phi_2(\theta) \varepsilon_t \quad (4.61)$$

where the first equation corresponds to the measurement equation that links the state variables with the observable data through the function  $\Lambda(\theta)$ , and the second equation is the transition equation. The state space representation of the vector of observable variables is contained in  $Y_t$ , the state variables of the model are stacked in  $Z_t$ . The term  $\varepsilon_t$  denotes the structural shocks that affect all the variables, and  $\mu_t$ , is the measurement error term. The micro founded coefficients are contained in the matrices,  $\Phi_1$ , and  $\Phi_2$ . These coefficients depend on the structural DSGE parameters, such as technologies and policies, which are stacked in the vector  $\theta$ .

## 4.4 Data, Estimation, and Prior Distributions

### 4.4.1 Data

The model makes use of quarterly data for Uganda and its main trading partners. The sample spans the period 2000Q1 to 2015Q4, and includes all available quarterly output data for the Ugandan economy. Over this period, the main objective of the central bank was price stability. However, prior to July 2011, the official policy of the central bank was one of monetary aggregate targeting (which was implemented as a form of pseudo inflation-targeting). Thereafter, formal inflation targeting was adopted. When considering the properties of the data, we note that the evolution of the key interest rates during the two possible regimes (prior and post 2011) is fairly similar, suggesting that a consistent monetary policy has been applied over the full sample from 2000Q1.

The analysis makes use of ten observed variables to estimate the model parameters. These include: Measures of the nominal interest rate, consumer price inflation, output, terms of trade, real exchange rate, lending rate, non-performing loans, foreign output, foreign inflation rate, and foreign interest rate. The measures for the foreign economy are computed from the trade weights of Uganda's key trading partners (as used in the calculation of the real effective exchange rate). Those variables that have seasonal patterns are seasonally adjusted, and all the variables are demeaned to provide implied steady-state values of zero. The domestic data is sourced from the BoU and UBOS, while the foreign

economy data is sourced from the OECD and IMF. Table 4.1, provides a summary of the variables and data sources.

Table 4.1: Observable variables and data source.

Variables	Series	Source
<u>Uganda</u>		
$\Delta \ln(y_t)$	Domestic real GDP	UBOS
$\Delta \ln(s_t)$	Terms of trade	BoU
$\Delta \ln(q_t)$	Nominal exchange rate	BoU
$R_t$	Domestic policy rate	BoU
$\pi_t$	Inflation rate	UBOS
$R_t^b$	Lending rate	BoU
$\chi_t$	Non-performing loans to total loans	BoU
<u>Foreign economy</u>		
$\Delta \ln(y_t^*)$	Foreign real GDP	OECD
$R_t^*$	Foreign policy rate	OECD and IMF
$\pi_t^*$	Foreign inflation rate	OECD and IMF

#### 4.4.2 Estimation methodology

The model is estimated with the aid of Bayesian methods, as the literature attributes important advantages to these procedures. [An and Schorfheide \(2007\)](#), provide an informative summary of the advantages that may be derived from estimating these models with Bayesian techniques. They note that these methods are able to draw on a rich information set by combining both the initial information about the model and its parameters with empirical estimates from the likelihood function. The other advantages attributed to these techniques include their ability to deal with identification challenges, misspecification problems, and parameter uncertainty problems (c.f. [An and Schorfheide, 2007](#); [Fernández-Villaverde, 2010](#)). For our model, the Kalman filtering technique is used to construct the likelihood function for the DSGE model, as many of the variables are unobserved. In practice, the Bayesian inference consists of three parts. Firstly, a prior distribution  $P(\theta)$  is formed about the structural parameters  $\theta$ , before we observe the data,  $Y$ . Secondly, the likelihood function,  $L(\theta|Y)$ , is derived after observing the data. Lastly, the posterior distribution,  $P(\theta|Y)$  is derived by combining the prior and likelihood functions, with aid of Bayes' theorem:

$$P(\theta|Y) = \frac{L(\theta|Y) P(\theta)}{\int L(\theta|Y) P(\theta) d\theta} \quad (4.62)$$

where the denominator of Equation (4.62) is the marginal likelihood.

### 4.4.3 Calibration

While the objective was to estimate most of the parameters, it was necessary to calibrate a few of the parameters that could not be identified by the ten observed variables. The values for the calibrated parameters are derived from similar studies, or from the long run properties of the data, and Table 4.2 presents a summary of the calibrated parameters. The discount factor,  $\beta$  is set to 0.9951, following Berg et al. (2010a), who look to match the trend in the Ugandan real interest rate. The constant in the disutility of labour,  $\Lambda_L$  is set to 7.5, which assumes that households work for eight hours a day, on average. To calibrate the coefficient that represents the degree of openness in the domestic economy,  $\alpha$ , the average ratio of imports to gross domestic product over the last 10 years is used, and is set to 29%. This shows that roughly one third of the output in the domestic economy is imported.

Table 4.2: Calibrated parameters.

Parameter	Description	Value
$\beta$	Discount factor	0.9951
$\Lambda_L$	Labour disutility constant	7.5
$\sigma_L$	Inverse elasticity of labour supply	2.5
$\eta$	Elasticity of substitution between home and imported goods	1.5
$\alpha$	Import share in the domestic economy	0.29
<u>Heterogeneous households</u>		
$\pi_b$	Share of borrowers	0.5
$\Omega$	probability of draw for type change	0.975
$\sigma_s^{-1}$	Constant elasticity of savers	1.667
$\sigma_b^{-1}$	Constant elasticity of borrowers	3.333
<u>Financial intermediaries</u>		
$\omega$	Steady state gross spread	$1.110^{1/4}$
$\eta_\chi$	Elasticity of NPL	1.0
$\chi$	Steady state of NPL	0.05
$\rho_\chi$	NPL persistence	0.8

Because data for the labour market is scarce, the labour supply elasticity,  $\sigma_L$ , is set to 2.5. This is a typical value that is found in the literature and was also used in Berg et al. (2010a). The elasticity of substitution between domestic and imported goods,  $\eta$  is set to 1.5, which falls within the 1-2 range found in the general literature. Calibration for the parameters that are used to introduce financial frictions into the small open-economy model is based largely on Curdia and Woodford (2010). The parameter reflecting the initial share of borrowers in the economy,  $\pi_b$  is set to 0.5, because we assume that there is an equal number of savers and borrowers for the initial iteration. It is assumed that it takes approximately ten years on average, for a household to change from a borrower to a saver (and vice versa), thus the transition probability,  $\Omega$ , is set to 0.975. Borrowers are assumed to be more willing than savers to substitute consumption and therefore the ratio

between the two types,  $\sigma_b/\sigma_s$ , is set to 2. It should be noted that [Curdia and Woodford \(2010\)](#) uses values of both 2 and 5 for this ratio. However, we assume that the household types may not react all that strongly to changes in interest rates in Uganda, and therefore use the more conservative value.<sup>10</sup>

Lastly, for the financial intermediation process, the parameter reflecting the steady-state lending spread,  $\omega$  is calibrated to  $1.110^{1/4}$ , which corresponds to an annual spread of about 1100 basis points. In addition, the steady-state of the non-performing loans,  $\chi$  is calibrated to 5%, which matches the historical average of the ratio of non-performing loans to total loans observed in the Ugandan data. The parameter measuring the persistence in this variable,  $\rho_\chi$  is set at 0.8, a value obtained from a simple regression. This means that there is relatively high persistence in non-performing loans in the Ugandan economy. The measure of the elasticity of non-performing loans,  $\eta_\chi$  is set to 1, as we assume a uniform relationship among lending, non-performing loans, and the lending spread.

#### 4.4.4 Prior distributions

Table 4.3 presents a summary of the first two moments of the priors and their distributions. Beta distributions are used for the parameters that are restricted to lie between zero and one, while gamma distributions are used for the parameters that take on positive values ( $\mathfrak{R}^+$ ). Consequently, all prior persistence parameters are assumed to take on the beta distribution, while the structural shocks are assumed to follow an independent inverse gamma distribution. The remaining prior parameters, including those describing the monetary policy rule, are assumed to follow gamma distributions.

Most of the values for the first two moments of the prior parameter distributions follow [Berg et al. \(2010a\)](#), [Berg et al. \(2010b\)](#) and [Justiniano and Preston \(2010\)](#). The parameter for the habit formation of savers follows a beta distribution with a mean of 0.7 and a relatively small standard deviation of 0.05. The Calvo price parameters allow for the presence of nominal rigidities, which is measured by the level of price stickiness in the domestic ( $\theta_H$ ) and foreign ( $\theta_F$ ) economy. It is assumed that these parameters take on beta distribution with reasonably flat prior values, where the mean values are 0.5 and standard deviations are set to 0.1. Similarly, the indexation parameters for the domestic and foreign economy ( $\delta_H$  and  $\delta_F$ ), are also assigned beta distributions, with identical mean and standard deviation values (as per the Calvo parameters). A gamma distribution is utilised for the ratio that measures the elasticity of non-performing loans to output, where the prior mean value is 0.4 and the standard deviation is 0.1. The external risk premium,  $\phi$ , is assumed to follow an inverse-gamma distribution with a mean value of 0.01, following [Justiniano and Preston \(2010\)](#).

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<sup>10</sup>The existence of underdeveloped financial and capital markets, and statements by the central bank Governor on the inefficiency of monetary policy transmission, support a more conservative estimate for these parameters.

Turning to the coefficients in the monetary policy rule, the prior parameter for persistence in interest rate shocks follows a beta distribution and its mean and standard deviation are set to 0.8 and 0.05, respectively. The other parameters, which measure the central banks' reaction to developments in output, inflation and exchange rate, are assumed to follow prior gamma distributions, with mean values set to 1.7, 0.5 and 0.05, respectively. The corresponding standard deviations are 0.1, 0.05 and 0.03.

Lastly, the parameter that introduces the evolution of financial conditions in the policy reaction function follows a gamma distribution, with a prior mean of 0.4 and a standard deviation of 0.1. The value for the mean of this prior parameter is similar to the posterior estimate that was derived in [Steinbach et al. \(2014\)](#). All the other persistence parameters are assumed to be fairly large, and this is reflected in their beta prior mean values, which are set to 0.8, with standard deviations of 0.1. As is the practice in most studies, the parameters for the structural shocks take small mean values and an infinite standard deviation.

## 4.5 Results

### 4.5.1 Markov Chain Monte Carlo

The estimation procedure utilizes the Markov chain Monte Carlo (MCMC) algorithm and the [Brooks and Gelman \(1998\)](#) measure of convergence, where five chains of 100,000 draws are used for randomly selected starting values. The average acceptance rate for all the chains is about 25.07%, and for each chain 40,000 draws are kept after the initial burn in phase. Convergence is monitored with the aid of univariate MCMC plots and multivariate diagnostic MCMC plots.

The results from the MCMC multivariate diagnostic plots ([Figure A.2](#)) suggests that convergence has been attained, and that the results do not reflect local maxima. The measures of the parameter vector for both within and between chains are fairly constant, and converge quite quickly after about 50,000 draws.

### 4.5.2 Parameter estimates

The posterior parameter mean estimates and their corresponding 10%-90% percentile values for the posterior distribution are presented in [Table 4.3](#), and the respective prior and posterior density plots are presented in [Figure A.1](#), which is in the appendix. In general, the results show that the posterior parameter estimates fall within plausible ranges found in the literature. Notably, the parameter that captures the response of the monetary authority to changes in the lending spread ( $\phi_\omega$ ) has a mean posterior estimate of -0.41. This estimate is close to the one obtained by [Steinbach et al. \(2014\)](#) for the

Table 4.3: Prior and posterior estimation.

Parameter	Description	Prior			Posterior	
		Density*	Mean	Std.Dev	Mean	90% interval
<u>Consumption</u>						
$b_s$	Habit formation by savers	[B]	0.7000	0.0500	0.6607	[0.5540; 0.7716]
<u>Calvo parameters</u>						
$\theta_H$	Domestic prices	[B]	0.5000	0.1000	0.8354	[0.8114; 0.8650]
$\theta_F$	Imported prices	[B]	0.5000	0.1000	0.1903	[0.1476; 0.2336]
<u>Indexation</u>						
$\delta_H$	Domestic prices	[B]	0.5000	0.1000	0.2659	[0.1490; 0.3743]
$\delta_F$	Import prices	[B]	0.5000	0.1000	0.3456	[0.1985; 0.4962]
<u>Exchange rate</u>						
$\phi_{uip}$	Risk premium	[IG]	0.01	Inf	0.0035	[0.0021; 0.0048]
<u>Non-performing loans</u>						
$\theta_y$	NPL/output elasticity	[G]	0.4000	0.1000	0.3948	[0.2326; 0.5463]
<u>Taylor Rule</u>						
$\rho_R$	Smoothing Inflation	[B]	0.8000	0.0500	0.8101	[0.7687; 0.8513]
$\rho_\pi$	Inflation	[G]	1.700	0.1000	1.8194	[1.6421; 1.9965]
$\rho_y$	Output gap	[G]	0.5000	0.0500	0.5361	[0.4488; 0.6236]
$\rho_{\Delta e}$	Exchange rate	[G]	0.050	0.0300	0.0432	[0.0062; 0.0796]
$\rho_\omega$	Interest rate spread	[G]	0.4000	0.1000	0.4069	[0.2409; 0.5755]
<u>Persistence parameters</u>						
$\rho_z$	Technology	[B]	0.800	0.100	0.4090	[0.2719; 0.5534]
$\rho_g$	Government spending	[B]	0.800	0.100	0.8000	[0.6461; 0.9608]
$\rho_{gc}$	Preference	[B]	0.800	0.100	0.7558	[0.6321; 0.9233]
$\rho_{cp}$	Cost-push	[B]	0.800	0.100	0.9417	[0.8967; 0.9898]
$\rho_{rp}$	Risk premium	[B]	0.800	0.100	0.6808	[0.5322; 0.8196]
$\rho_{\pi^*}$	Foreign inflation	[B]	0.800	0.100	0.5651	[0.4180; 0.7117]
$\rho_{y^*}$	Foreign output	[B]	0.800	0.100	0.8580	[0.7852; 0.9382]
$\rho_{R^*}$	Foreign interest rate	[B]	0.800	0.100	0.8724	[0.8012; 0.8915]
<u>Structural shocks</u>						
$\eta^z$	Technology	[IG]	0.054	Inf	0.1133	[0.0745; 0.1548]
$\eta^g$	Government spending	[IG]	1.300	Inf	1.3269	[0.2936; 2.2213]
$\eta^{gc}$	Preference	[IG]	0.050	Inf	0.2809	[0.0739; 0.4633]
$\eta^{cp}$	Cost-push	[IG]	0.200	Inf	0.2100	[0.1479; 0.2702]
$\eta^{rp}$	Risk premium	[IG]	0.040	Inf	0.0284	[0.0180; 0.0375]
$\eta^\chi$	Non-performing loans	[IG]	1.500	Inf	1.2306	[1.0490; 1.4063]
$\eta^R$	Monetary policy	[IG]	0.006	Inf	0.0071	[0.0059; 0.0084]
$\eta^{\pi^*}$	Foreign inflation	[IG]	0.010	Inf	0.0073	[0.0062; 0.0083]
$\eta^{y^*}$	Foreign output	[IG]	0.040	Inf	0.0056	[0.0048; 0.0064]
$\eta^{R^*}$	Foreign interest rate	[IG]	0.040	Inf	0.0011	[0.0010; 0.0013]

Note: \* represent [B] - beta, [G] - gamma, [IG] - inverse gamma, [U] - uniform

South African economy, but falls below the one-for-one adjustment that was proposed

by [McCulley and Toloui \(2008\)](#) and [Taylor \(2009\)](#).

The parameter that measures the degree of habit formation of savers has an estimated value of 0.66. This estimate is slightly lower than the prior mean, but nevertheless it falls within the values found in the literature. The estimates for the nominal price rigidities suggest that the prices for domestic goods are revised after every 6 quarters (on average), while the prices for foreign goods are revised every 1.4 quarter (on average). This implies that there is a fairly high degree of price persistence for domestic goods. The low persistence of foreign goods prices could be capturing the effects of frequent exchange rate movements.

The inflation indexation parameter for both domestic goods prices and foreign goods prices are estimated to be around 0.3 and 0.4, respectively. This shows that the price indexation process for both types of goods place a higher weight on current inflation, than on past inflation. The estimate for the risk premium parameter in the UIP condition is fairly small, at 0.004, while the parameter estimate that measures the responsiveness of non-performing loans to changes in output is 0.40.

The estimates for the parameters in the monetary policy rule show that the degree of interest rate smoothing by the central bank is 0.81. This suggests that the BoU places emphasis on interest rate stabilization in monetary policy formulation.<sup>11</sup> In addition, the parameter that captures the response of the central bank to changes in inflation has a posterior parameter estimated value of 1.82, which is slightly higher than expected, but still within the range reported in the literature. This shows that the BoU reacts fairly aggressively to inflationary pressures. The parameters that measure the reaction of the central bank to changes in output and the exchange rate are estimated to be 0.54 and 0.04, respectively.

We find that cost-push shocks are the most persistent, while technology shocks are the least persistent. Since cost-push shocks influence the inflation process, this indicates that shocks to the measure of core inflation subside over a long period. The estimates for the standard deviation of shocks vary widely in magnitude, with the foreign interest rate displaying the least amount of volatility, while government spending shocks are more volatile than expected. This suggests that business cycle fluctuations in the Ugandan economy are influenced more by volatility in domestic government spending than by volatility in the foreign interest rate (trade weighted interest rate). In general, the volatility of domestic shocks is greater than the volatility of foreign shocks, showing that domestic shocks play an important role in business cycle fluctuations in the Ugandan economy.

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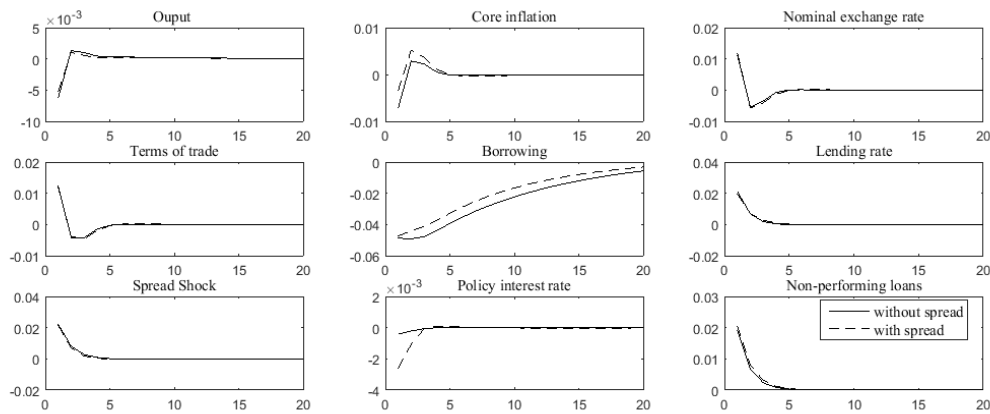
<sup>11</sup>A number of researchers have also suggested that large estimates for the interest rate smoothing parameter indicate fairly persistent inflationary shocks ([Rudebusch, 2002](#)).

### 4.5.3 Dynamics of the model: Impulse response functions that follow a financial shock

In this section, we discuss the dynamic response in each of the variables to a financial shock, which is represented by a positive innovation to non-performing loans due to the widening of the lending spread. These responses are displayed in (Figure 4.1). To show the effects of including financial friction in the monetary policy rule, we generate an additional set of estimation results, in which we set  $\phi_\omega = 0$ , for comparative purpose. Impulse functions without financial frictions are represented by a solid line, while the results of the model with financial frictions are represented by a dashed line.<sup>12</sup>

Note that in the model with financial frictions, a positive innovation to the lending spread induces a similar change to the lending rate faced by borrowers. The level of borrowing in the economy declines, as new loans become expensive. The slow-down in borrowing constrains economic activity, which reduces demand pressure and inflation. These factors allow for the monetary authority to lower the central bank interest rate, which results in a nominal exchange rate depreciation, as foreign exchange inflows fall. The terms of trade follow a similar path as the nominal exchange rate, because of the combined effect of domestic inflation and exchange rate developments.

Figure 4.1: Impulse response of a financial shock



We note similar behaviour in the response of the variables in the model that does not include financial frictions. However, the monetary policy actions are more muted, as the lending spreads are not included in the response function. Despite this behaviour, borrowing declines by a greater margin in the model that excludes financial frictions, as this element helps to reduce the effect of the increased spread on the level of borrowing. This indicates that there would be more credit in the economy if monetary policy models

<sup>12</sup>Here, we wish to compare the impulse response functions from two models. The results thus reflect the mean dynamic responses of the variables. The corresponding separate Bayesian impulse response functions that include 90% confidence intervals for the posterior distributions are included in Figure A.3 and Figure A.4 in the appendix.

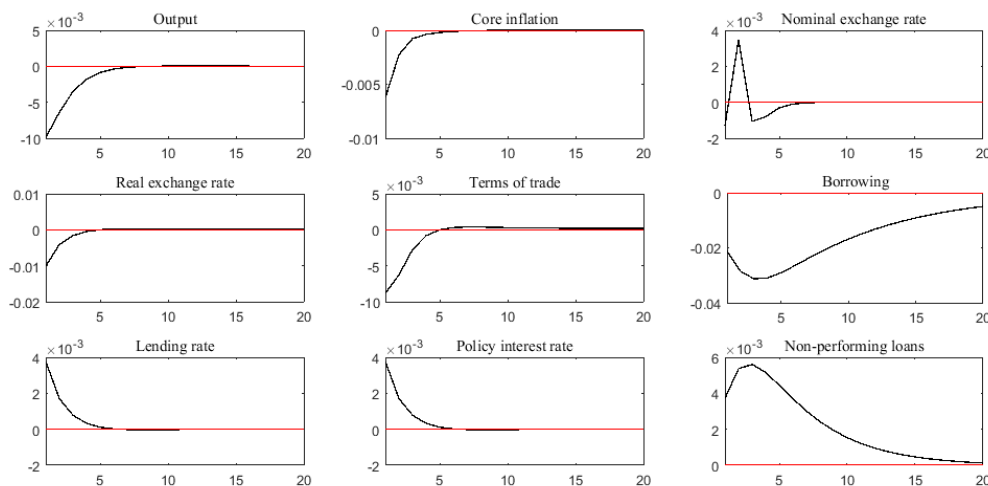
incorporate financial frictions. When comparing the impulse response functions of the two models, it is also worth noting that inflation overshoots by a slightly higher magnitude in the model with financial frictions. However, it converges to the pre-shock level in roughly the same amount of time in both models.

#### 4.5.4 Dynamics of the model: Impulse response functions that follow a monetary policy shock

Figure 4.2, shows the response of selected variables in the model to a monetary policy shock, which is represented by an increase in the central bank interest rate.<sup>13</sup> Such a shock gives rise to a similar change in the lending rate, which reduces borrowing and leads to a decline in economic activity. This makes it difficult for firms to service their loans and increases the amount of non-performing loans. The fall in economic activity also contributes to a decline in inflation, while the exchange rate appreciates, because the increase in the domestic interest rate attracts foreign exchange inflows.

The effect of the monetary policy shock largely dissipates after about 6 to 7 quarters. However, its effect on the financial variables (which include the borrowing level and non-performing loans) takes longer to erode. Even after 20 quarters, these variables do not attain their pre-shock levels.

Figure 4.2: Impulse response of a monetary policy shock.



#### 4.5.5 Historical decomposition

Figures A6 to A12, display the historical decomposition for measures of output, inflation, nominal exchange rate, real exchange rate, terms of trade, policy rate, and lending rate.

<sup>13</sup>This IRF corresponds to the mean values of the posterior distribution. The complete Bayesian IRF for the mean values of the posterior distribution and the 90% confidence interval are included in the appendix (Figure A.5).

The figures show that the variables in the model are mainly driven by shocks to consumption preferences, non-performing loans, cost-push, technology, government spending, and risk premium. The influence of monetary policy shocks in propagating the key model variables is fairly small. This is because monetary policy mainly responds to other shocks, such as cost-push shocks.

We consider the steady-state dynamics of output, and note that consumer preferences, non-performing loans, the risk premium and cost-push shocks are the major driving forces of changes in output. For instance, during 2011-2012, when Uganda experienced excessive inflationary pressure, innovations from non-performing loans contributed negatively to output, while a pronounced contribution was made by cost-push shocks. During 2015, innovations in non-performing loans were mostly above the sample average, while the size of the risk premium and cost-push shocks were mostly below the sample average. This indicates that in 2015 the risk premium and cost-push shocks contributed negatively towards measures of output.

The historical decomposition of the core inflation rate suggests that inflationary pressure in Uganda is mostly driven by cost-push shocks, consumer preference, and shocks to the level of loans. These findings also show that, to a lesser extent, inflation is also driven by government spending shocks, and shocks to the risk premium that affect the real exchange rate. For instance, in 2011-2012, the main driving forces behind the high rate of inflation were the cost-push, non-performing loans, and risk premium shocks. Towards the end of this period, when the central bank raised the benchmark policy rate, non-performing loans rose, and this, together with the decline in the cost-push shock, helped to relieve inflationary pressure.

These results also suggest that shocks from non-performing loans, consumption preferences, government spending, and consumer prices are the main driving forces behind lending rates in Uganda. For instance, increase in the lending rate between 2011 and 2012 was largely driven by a monetary policy tightening to reduce inflationary pressure (due to several large cost-push shocks). Shocks from non-performing loans also pushed lending rates up, as commercial banks implemented stricter credit policies.

#### **4.5.6 Optimal monetary policy rule for reduced volatility**

This section considers the use of an optimal monetary policy rule that would reduce the volatility in key macroeconomic variables. To satisfy this objective, we identify the parameter estimates in the monetary policy rule that minimise a loss function that incorporates the second-order moments of selected macroeconomic variables. Our specification of the central bank loss function takes into account the inflation-targeting monetary policy regime that the BOU follows. We assume that the central bank also pursues other objectives, such as the stabilisation of output, exchange rate, and interest rates. Since the

model includes financial frictions, the volatility in the interest rate spread is also included in the loss function of the monetary authority.<sup>14</sup> Therefore, the central bank's problem is to choose the parameters in the policy rule that minimize the expected loss, subject to the constraints imposed by the model. The loss function may then be expressed as:

$$L_t(\phi_\pi, \phi_y, \phi_{\Delta e}, \phi_\omega, \rho_R) = \min E \sum_t^\infty \beta^t [(\pi_t)^2 + \lambda_y (y_t)^2 + \lambda_{\Delta e} (\Delta e_t)^2 + \lambda_\omega (\omega_t)^2 + \lambda_R (R_t)^2] \quad (4.63)$$

where  $\beta$  denotes the discount rate, the symbol  $E$  represents the unconditional expectation,  $\lambda_\iota \geq 0$  and  $\iota = \{y, \Delta e, \omega, R\}$  refer to the parameters that capture the weights that the monetary authority places on the variations in output, the exchange rate, the interest rate spread, and interest rate, relative to the variation in inflation. The loss function of the monetary authorities implies that the central bank's monetary policy attempts to minimize the expected weighted average of the variation in inflation, output, the exchange rate, and interest rate spreads. In addition, the central bank also attempts to smooth its interest rate path, to provide policy inertia, where possible.

The results from this exercise are presented in Table 4.4 for the two different weighting schemes of  $\lambda_\iota$ . The estimated monetary policy rule coefficients (values extracted from Table 4.3) have also been included in this table, for comparison.

The main difference between the third and fourth columns relates to the assumed weight that the monetary authority places on the stabilisation of output and the interest rate. In the third column, it is assumed that the weight the monetary authority places on output stabilisation is twice that of the weight that is placed on the smoothing of interest rates. In the fourth column, this assumption is reversed. In addition, it is assumed that in both columns (three and four), the monetary authority places small weights on the stabilisation of the exchange rate and the interest rate spread.<sup>15</sup>

In general, the results suggest that the estimated parameter values are comparable to the optimal coefficient estimates that are obtained under both assumptions for  $\lambda_\iota$ . Specifically, column three suggests that the optimal coefficients for stabilizing inflation, output and the interest rate are larger than the estimated monetary policy rule coefficients. Note, also, that the optimal coefficients for stabilizing the exchange rate are small, compared to the estimated monetary policy rule coefficients. Similarly, column four suggests that the optimal coefficients for inflation and output stabilisation are somewhat larger than the estimated coefficients in the monetary policy rule. The coefficients for the exchange rate and interest rate smoothing are fairly small, compared to the estimated monetary

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<sup>14</sup>As noted previously, Woodford (2012) suggests that measures of financial frictions should be included in monetary policy loss functions.

<sup>15</sup>Additional counter-factual experiments were performed by varying the weights on exchange rate and interest rate spreads between 0.1 to 0.2. These did not change the reported results by a significant degree.

policy rule coefficients. However, one of the most important finding of this analysis is that the coefficient for the interest rate spread is always larger than 0.4, despite the fact that the weight,  $\lambda_\omega$ , is small. This indicates that the central bank should respond to changes in the interest rate spread when formulating policy, to reduce aggregate macroeconomic volatility.

When considering the aggregate value of the loss function, the results suggests that the central bank may wish to place more weight on stabilizing output and inflation, where the volatility in these variables is important (reflected in column four). It is also noted that this case generates the least amount of aggregate volatility, measured by the value of the loss function.<sup>16</sup>

Table 4.4: Optimal monetary policy rule coefficients.

Taylor rule coefficients	Estimated	Optimal rule with weights ( $\lambda_y, \lambda_{\Delta e}, \lambda_\omega, \lambda_R$ )	
		(0.5, 0.1, 0.2, 1)	(1, 0.1, 0.2, 0.5)
Inflation	1.8194	1.8342	1.8783
Output	0.5361	0.5736	0.6431
Exchange rate	0.0432	0.0344	0.0416
Interest rate spread	0.4069	0.4055	0.4056
Smoothing parameter	0.8101	0.8825	0.6501
Loss function value ( $\times 10^{-3}$ )		16.1631	15.4417

#### 4.5.7 The sacrifice ratio of the optimal monetary policy rules

Monetary policy actions that seek to reduce inflationary pressure may contribute towards reduced levels of economic activity and employment. It is thus important for policy makers to evaluate the impact of alternative policies to reduce inflation. In what follows, we calculate the sacrifice ratio, which is the relative decline in output for a reduction in inflation, for the different optimal monetary policy rules. In addition, we make use of the impulse response functions from the estimated coefficients.<sup>17</sup>

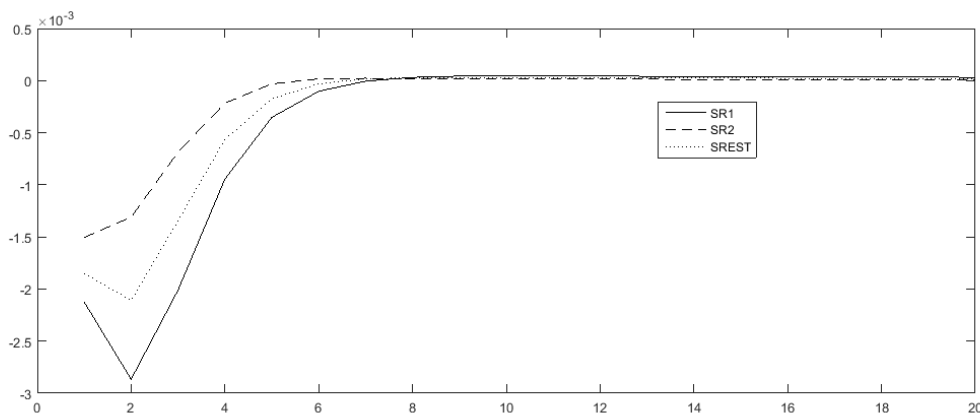
Figure 4.3, presents the results of the sacrifice ratio calculations, where SR1 and SR2 represent the sacrifice ratio that correspond to the optimal monetary policy rule estimates. These are shown in the third and fourth columns of Table 4.4, respectively. Thereafter, SREST, represents the sacrifice ratio that corresponds to the estimated monetary policy rule coefficients. There are notable differences in the size and adjustment process across the two sets of optimal monetary policy rules, where the optimal rule that is contained in the third column of Table 4.4, would generate the least sacrifice ratio (SR1). The most desirable outcome is provided by the optimal monetary policy rule that is presented in the fourth column of the table, where output and inflation are associated with fairly large

<sup>16</sup>This is consistent with the findings of [Alpanda et al. \(2010\)](#).

<sup>17</sup>In the early literature, the sacrifice ratio was obtained from the relationship between output and inflation that was largely based on time-series estimates of the Philips curve (c.f. [Okun, 1978](#); [Gordon et al., 1982](#)). More recently, [Ball, 1994](#) and [Cecchetti and Rich, 2001](#) use monetary policy impulse response functions, derived from vector autoregressive (VAR) models, to estimate the sacrifice ratio.

$\lambda_\tau$  weights.

Figure 4.3: Sacrifice ratio for the optimal monetary policy rule and the estimated policy rule.



## 4.6 Conclusion

The financial sector affects several other sectors of the economy, and challenges in this sector can give rise to macroeconomic instability. Following the recent global financial crisis, research on business cycles in many developed and some advanced emerging market economies has considered the inclusion of financial frictions in structural macroeconomic models. In this chapter our study extends this investigation to the economies of LICs, which have financial structures that differ from those of developed and advanced emerging markets. The research in this chapter estimates a small open-economy DSGE model with financial frictions, using Ugandan data. Financial frictions are introduced with the aid of a framework proposed by [Curdia and Woodford \(2010\)](#), which makes use of heterogeneous households (savers and borrowers). Most of the parameters in the model are estimated with the aid of Bayesian methods.

The results suggest that the key posterior parameter estimates are largely consistent with the values that are found in the general literature. The dynamics of the model suggest that the monetary authority reacts to an increase in lending spreads by lowering the policy interest rate. Borrowing consequently increases, along with output and inflation, while the exchange rate appreciates. In our analysis, the dynamics of a model without financial frictions are compared to those of one that incorporates these frictions. The results suggest that, as spreads widen, borrowing decreases by a smaller magnitude in the model with financial frictions. These results indicate that the central bank will lower the interest rate more in response to an increase in the spread, if financial frictions are included in the central bank response function. As a result, the output gap declines by a slightly larger magnitude, and inflation overshoots marginally. However, the response of both output and inflation are similar in both models, as, in both, they return to their pre-shock levels

after about five quarters.

The effect of a monetary policy innovation on the model with financial frictions suggests that the response of the variables broadly matches the monetary policy transmission literature. For example, in this model, a monetary policy shock leads to an increase in the lending rate, an increase in non-performing loans, a decrease in borrowing, a decline in the output gap, a fall in the rate of inflation, and an appreciation of the exchange rate.

When considering the results of our investigation into the optimal monetary policy rule, we note that the estimated coefficients are comparable to the optimal counterparts. This indicates the current response from the central bank is close to the optimal response. It is also worth noting that, in all cases, the value of the coefficient for the response to changes in the interest rate spread is substantially different from zero. This suggests that the central bank should respond to changes in the interest rate spread in order to reduce macroeconomic volatility. The results also suggest that the central bank could be slightly more aggressive in its response to changes in output and inflation to limit macroeconomic volatility and foster a more favourable sacrifice ratio.

# Chapter 5

## Monetary Policy, Financial Frictions and Structural Changes in Uganda: A Markov-switching SOE-DSGE Approach

### 5.1 Introduction

Many macroeconomic and financial time-series variables that are used in quantitative macroeconomic models may be subject to a number of regime-switching events that could influence the data-generating process. Some of these changes in regime could be attributed to shifts in policy, economic transformations or the effects of unusually large shocks that are more prevalent in low-income countries.<sup>1</sup> In addition, the periodic revision of data collection and compilation practices, which arise more frequently in low-income countries, may also give rise to a number of structural breaks.<sup>2</sup> The case of Uganda is of particular interest, as the central bank recently moved away from targeting monetary aggregates to implementing a modern inflation-targeting framework, which could result in different regimes for monetary policy. All of these factors could influence the values for the estimated structural parameters and the volatility that is associated with the model variables.

The early literature that has made use of dynamic stochastic general equilibrium (DSGE) models to analyse business cycle fluctuations assumes the presence of time-

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<sup>1</sup>These shocks include those that are due to external economic events, such as the Global Financial Crisis, which are transmitted to the domestic economy through movements in the terms of trade, export demand and volatile financial flows.

<sup>2</sup>[Aron et al. \(2015\)](#) describe a number important changes that have affected the macroeconomic data on Uganda. For example, coverage of the consumer price index (CPI) and gross domestic product (GDP) data was amended on two occasions between 2000 and 2015, while the base periods changed from 2000 to 2007, and recently to 2009/10. These changes were partly motivated by the need to account for the various structural transformations that had taken place in the domestic economy, where the service sector's contribution to GDP had increased, while the contribution of the agricultural sector had declined.

invariant structural parameters and constant variations in structural shocks over the entire sample period.<sup>3</sup> However, a number of studies have recently introduced Markov-switching to the DSGE framework, which allows for possible regime-switching behaviour in structural macroeconomic models. These models may also be used to contain the effects of large shocks that arise over particular periods of time. Notable contributors to this strand of literature include, [Liu et al. \(2009\)](#), [Farmer et al. \(2009\)](#), [Farmer et al. \(2011\)](#), [Liu and Mumtaz \(2011\)](#) and [Liu et al. \(2011\)](#).

While most of this literature has been applied to developed-world economies, these models have important features that may be relevant to most developing countries which are susceptible to the effects of large shocks.<sup>4,5</sup> Therefore, an investigation into the usefulness of Markov-switching DSGE (MS-DSGE) models within the context of low-income countries would be of interest to policy makers and researchers. The existing literature on structural models for Uganda has largely assumed time-invariant structural parameters and constant volatility in economic shocks, despite the Ugandan economy having undergone important structural shifts during recent periods.

In this chapter we extend the literature on structural models for low-income countries, to include MS-DSGE models that incorporate financial frictions and small open-economy features to describe the sources of macroeconomic fluctuations in Uganda. Hence, the model postulated in this chapter should be able to show whether or not there is any regime-switching behaviour in the response of the central bank to changes in financial frictions or other factors that influence the reaction function.<sup>6</sup> In addition, we considered whether the source of any potential changes in conducting monetary policy may be attributed to changes in the volatility of structural shocks. To the best of our knowledge, this is the first example of a MS-DSGE model that incorporates financial frictions, in both developed- and developing-country settings.<sup>7</sup>

To consider whether the addition of regime-switching behaviour provides a more accurate description of the data, we conducted an extensive in-sample and out-of-sample evaluation, where we compared the statistics for models that incorporate various regime-switching specifications against a model that does not include these features. The in-sample evaluation makes use of log-posterior, log-likelihood, log-prior and log-marginal

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<sup>3</sup>See, [Christiano et al. \(2005\)](#), [Smets and Wouters \(2003, 2007\)](#), and [Adolfson et al. \(2007\)](#), among others.

<sup>4</sup>[Balcilar et al. \(2016b\)](#) apply this methodology to South Africa, which is a relatively developed emerging market economy that is affected by shocks that are of a much smaller magnitude, and of a lower frequency.

<sup>5</sup>Uganda is an example of a relatively open low-income country that would be particularly susceptible to the effects of large shocks.

<sup>6</sup>The monetary policy rule that is employed in the analysis is the modified Taylor-type rule that incorporates interest rate spreads, and which in turn is used to capture the central bank response to financial frictions.

<sup>7</sup>There are very few examples of studies that have considered regime-switching behaviour in Uganda. An exception is due to [Hisali \(2012\)](#), who makes use of a univariate model and nominal exchange rate data to consider whether there are structural breaks in the exchange rate for Uganda.

data density Laplace statistics. When conducting the out-of-sample evaluation for the nested models, we reported on the respective root mean squared error (RMSE) statistics before we conducted the tests of [McCracken \(2007\)](#) and [Clark and West \(2006, 2007\)](#). In addition, we evaluated the distributions of the various forecasts after computing the probability integral transforms (PITs).

The remainder of the chapter is organised as follows. Section 5.2 describes the features of the model, while section 5.3 includes a discussion on the data that has been used and the estimation methodology employed. The results from the estimation and model evaluation are contained in section 5.4. The conclusion is presented in section 5.5.

## 5.2 Macroeconomic model with Markov-switching

This section describes the linearised structure of the model and the Markov-switching assumptions.

### 5.2.1 Structural model

The model structure incorporates several features that may characterise a small open-economy, as described in [Gali and Monacelli \(2005\)](#) and [Justiniano and Preston \(2010\)](#). This basic framework is then extended to incorporate financial frictions, where we allow for a heterogeneous household sector that distinguishes between savers and borrowers, per the methodology of [Curdia and Woodford \(2010\)](#). The model also incorporates a number of other nominal and real rigidities that influence the behaviour of the monopolistically competitive firms which produce intermediate goods, while perfectly competitive firms produce the final goods. It is also assumed that there is habit formation in consumption and incomplete asset markets that allows for the identification of country risk premia. Financial intermediaries are assigned the task of bridging the gap between savers and borrowers, while the government sector incorporates a central bank that is responsible for monetary policy. The foreign economic sector is constructed as a trade-weighted average of key trading partners. In what follows, we present details of the basic model in log-linearised form before providing details of how the model is augmented to incorporate various Markov-switching processes.

The first order optimisation condition for the intertemporal maximisation problem for heterogeneous households yields a partially forward-looking consumption equation that describes current consumption as a function of past and expected future levels of consumption. In addition, the current level of consumption is affected by the real interest rate and a demand (or preference) shock.

$$c_t = \frac{1}{1 + h_\tau} E_t (c_{t+1}^\tau) + \frac{h_\tau}{1 + h_\tau} c_{t-1}^\tau - \frac{1 - h_\tau}{\sigma_\tau (1 + h_\tau)} (R_t - E_t \pi_{t+1} - \varepsilon_t^c) \quad (5.1)$$

Note that  $\tau \in [b, s]$  denotes household borrowers and savers,  $c_t$  is the level of consumption in the current period,  $\sigma_\tau$  captures the inverse elasticity of intertemporal substitution, and  $h_\tau$  refers to the habits in consumption behaviour. The real interest rate is derived from  $R_t - E_t \pi_{t+1}$ , where  $R_t$  is the nominal interest rate and  $\pi_{t+1}$  represents the expected inflation rate for the next period. The parameter  $\varepsilon_t^c$  denotes the exogenous demand shock, which is assumed to follow a first order autoregressive process.

Domestic firms that produce intermediate goods for the economy are subject to a Calvo-type price setting mechanism. Therefore, a proportion of firms,  $(1 - \theta)$ , have an opportunity to change prices in a particular period, while the remaining proportion are not able to adjust their prices. When allowed to change prices, agents make use of information relating to past price movements (i.e. indexation) and future expected price movements. This behaviour allows for the derivation of a forward-looking new Keynesian Phillips curve that describes the evolution of domestic price inflation in terms of past inflation, expected future inflation, and the effects of real marginal costs. Hence, this relationship could be expressed as,

$$\pi_{H,t} = \delta_H \pi_{H,t-1} + \beta E_t (\pi_{H,t+1} - \delta_H \pi_{H,t}) + \theta_H^{-1} (1 - \theta_H) (1 - \beta \theta_H) mc_t \quad (5.2)$$

where  $\pi_{H,t}$  is domestic price inflation and  $\beta$  denotes the time-discount factor. The parameter  $\delta_H$  measures the degree of price indexation to past inflation in the domestic economy, and  $\theta_H$  is the Calvo price setting parameter for domestic firms. The term  $mc_t$  represents the real marginal cost of firms, which is derived as,

$$mc_t = \frac{\sigma}{1 - h_\tau} (c_t^\tau - h_\tau c_{t-1}^\tau) + \varphi y_t + \gamma s_t - (1 + \varphi) z_t \quad (5.3)$$

where,  $s_t$  represents the terms of trade and  $z_t$  captures the exogenous productivity shock that follows a first-order autoregressive process. The inverse of the elasticity of labour supply is represented by  $\varphi$  and  $\gamma$  is the import share of consumption. The term  $y_t$  in the above equation represents domestic output that is related to consumption through the goods market clearing condition,

$$y_t = (1 - \gamma) c_t + \gamma \eta (2 - \gamma) s_t + \gamma \eta \psi_t + \gamma y_t^* \quad (5.4)$$

In this case,  $y_t^*$  represents foreign output,  $\eta$  refers to the elasticity of substitution between domestic and foreign output, and  $\psi$  denotes the measure of the gap from the law of one price.<sup>8</sup> The terms of trade (TOT),  $s_t$ , can then be expressed as the ratio of the foreign price level,  $p_{F,t}$ , to the domestic price level,  $p_{H,t}$ . When expressed in a log-linearised form we have,

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<sup>8</sup>Note that the relationship in Equation (5.4) implies that domestic output equals the sum of domestic consumption and net exports.

$$s_t = p_{F,t} - p_{H,t} \quad (5.5)$$

After applying time differencing to Equation (5.5), we are able to obtain the stationary TOT as,  $s_t - s_{t-1} = \pi_{F,t} - \pi_{H,t}$ . The gap from the law of one price in Equation (5.4) plays an important role in the small open-economy literature, as it captures the degree of monopolistic competition among retail firms in the domestic economy. Consequently, the log-linearised equation that represents the gap from the law of one price in the model is given by,

$$\psi_t = q_t - (1 - \gamma) s_t \quad (5.6)$$

where  $q_t$  denotes the real exchange rate, which derives from the measure of nominal exchange rate,  $e_t$ , and which is deflated by the price differential between the foreign and domestic economy. This relationship may be expressed in levels as,  $q_t = e_t + p_t^* - p_t$ . After time differencing, we obtained the stationary real exchange rate equation,  $q_t - q_{t-1} = \Delta e_t + \pi_t^* - \pi_t$ . The equation that describes the relationship between the real exchange rate, the TOT and the law of one price gap may then be expressed as,  $q_t = (1 - \gamma) s_t + y_t^*$ .

The optimisation problem for firms in the foreign economy provides a similar forward-looking new Keynesian Phillips curve for foreign goods inflation:

$$\pi_{F,t} = \delta_F \pi_{F,t-1} + \theta_F^{-1} (1 - \theta_F) (1 - \beta \theta_F) \psi_t + \beta E_t (\pi_{F,t+1} - \delta_F \pi_{F,t}) + \varepsilon_t^{cp} \quad (5.7)$$

where,  $\delta_F$  measures the degree of price indexation to past inflation in the foreign economy,  $\theta_F$  is the Calvo price-setting parameter, which measures the probability that foreign firms will not adjust prices in a given period, and  $\varepsilon_t^{cp}$  denotes the import-cost-push shock, which follows a first-order autoregressive process. Since the overall consumer goods inflation in the domestic economy comprises both domestic goods inflation and foreign goods inflation, it may be expressed as,  $\pi_t = (1 - \gamma) \pi_{H,t} + \gamma \pi_{F,t}$ .

The uncovered interest rate parity (UIP) condition in the model relies on the assumption of incomplete asset substitution between domestic and foreign bonds, such that,

$$E_t q_{t+1} - q_t = (R_t - E_t \pi_{t+1}) - (R_t^* - E_t \pi_{t+1}^*) + \phi_{uip} a_t + \varepsilon_t^{rp} \quad (5.8)$$

where,  $R_t$  and  $R_t^*$  relate to the domestic and foreign interest rate, respectively. The  $\pi_t^*$  parameter refers to the foreign rate of inflation, while  $\phi_{uip}$  represents debt elasticity for the interest rate premium. The net foreign asset position for the domestic economy is denoted by  $a_t$  and  $\varepsilon_t^{rp}$  is the risk premium shock. It is assumed that shocks to the foreign interest and inflation rate, and the risk premium shock all follow independent first-order autoregressive processes.

The net-foreign-asset position from Equation (5.8) could then be expressed as:

$$a_t - \frac{1}{\beta}a_{t-1} = y_t - c_t - \gamma(q_t + \gamma s_t) \quad (5.9)$$

Heterogeneous households differ in their marginal utility of consumption, creating a role for financial intermediation. In this case, the households that deposit their excess financial resources with financial institutions are termed savers, while the borrowing households experience resource deficiencies and borrow money from financial intermediaries to finance their consumption needs. Thus, financial frictions are introduced into the model through the first-order condition that describes the evolution of the borrowing behaviour of households,  $l_t$ , which in log-linearised form may be expressed as;

$$l_t = \lambda_r (R_{t-1} - \pi_t) + \lambda_y y_t + \lambda_\Omega \Omega + \lambda_\omega \omega_t + \lambda_b (l_{t-1} + \omega_{t-1}) \\ + \lambda_\xi [\pi_b (1 - \pi_b) \eta_t^c - s_\Omega \bar{\sigma}^{-1} (g_t + \chi_t)] \quad (5.10)$$

where  $\bar{\sigma}$  is the average intertemporal elasticity of substitution for the two household types,  $\Omega$  is the probability of changing between household types, and  $\omega_t$  is the interest rate spread. The,  $\pi_b$  parameter denotes the probability that a borrowing household is drawn in the next period,  $g_t$  refers to government expenditure, and  $\eta_t^c$  denotes an exogenous financial shock. Government expenditure takes the form of a simple first-order autoregressive process.

The optimal first-order condition for the interest rate spread was then obtained from the financial intermediaries optimisation problem and it evolves according to the following expression;

$$\omega_t = \omega^{-1} [(1 + \eta_\chi) \chi l_t^{\eta_\chi}] (\chi_t + \eta_\chi l_t) \quad (5.11)$$

where  $\eta_\chi$  is the elasticity of non-performing loans,  $\chi$  is the steady state of non-performing loans, and  $l_t^{\eta_\chi}$  is an exogenous shock to the interest rate spread, which also follows an autoregressive process. Non-performing loans,  $\chi_t$ , are affected by the current state of economic conditions, which may be described by output and the rate of inflation. The log-linearised form of this expression is given by;

$$\chi_t = \rho_\chi \chi_{t-1} - \theta_\chi y_t + \eta_t^\chi \quad (5.12)$$

where  $\eta_t^\chi$  is the innovation to non-performing loans. The relationship between the interest rate spread, the borrowing rate,  $R_t^b$ , and the savings rate,  $R_t$ , may be expressed as  $R_t^b = R_t + \omega_t$ .

The relationships that describe the evolution of the inflation rate, output and the interest rate in the foreign economy are specified as:

$$\pi_t^* = \rho_{\pi^*} \pi_{t-1}^* + \varepsilon_{\pi_t^*} \quad (5.13)$$

$$y_t^* = \rho_{y^*} y_{t-1}^* + \varepsilon_{y_t^*} \quad (5.14)$$

$$R_t^* = \rho_{R^*} R_{t-1}^* + \varepsilon_{R_t^*} \quad (5.15)$$

where,  $\rho_{\pi^*}$ ,  $\rho_{y^*}$  and  $\rho_{R^*}$  are the parameters measuring persistence in foreign inflation, output and the nominal interest rate, respectively.

Then finally, it is assumed that the central bank conducts monetary policy through a generalisation of the rule that was proposed in [Taylor \(1993\)](#). Hence, in addition to the factors that affect output and inflation, the central bank reacts to changes in the exchange rate and interest rate spreads:

$$R_t = \rho_R R_{t-1} + (1 - \rho_R) [\rho_{\pi} \pi_t + \rho_y y_t + \rho_e \Delta e_t + \rho_{\omega} \omega_t] + \varepsilon_t^R \quad (5.16)$$

where,  $\Delta e$  represents nominal exchange rate depreciation,  $y_t$  is the domestic output gap, and  $\varepsilon_t^R$  is the monetary policy shock, which is assumed to follow a first-order autoregressive process. The term,  $\rho_R$  is the interest rate smoothing parameter, while  $\rho_{\pi}$ ,  $\rho_y$ ,  $\rho_e$  and  $\rho_{\omega}$  provide measures for the sizes of the reactions to changes in the associated variables.

## 5.2.2 Markov switching

We considered two variants of regime-switching models, where the first model allows for the presence of Markov-switching in the domestic monetary policy rule. Hence the formulation of Equation (5.16) may be expressed as,

$$R_t = \rho_{\theta,R} R_{t-1} + (1 - \rho_{\theta,R}) [\rho_{\theta,\pi} \pi_t + \rho_{\theta,y} y_t + \rho_{\theta,e} \Delta e_t + \rho_{\theta,\omega} \omega_t] + \varepsilon_{R,t} \quad (5.17)$$

where the subscript  $\theta$  denotes the unobserved regimes in the monetary policy rule that are described as two-state discrete Markov processes, which may be expressed as  $\theta \in [1, 2]$ . The probability of moving from one regime to the other may be denoted by  $\kappa^{1-2}$  and  $\kappa^{2-1}$ , respectively. In this case, the superscripts in the first of these terms indicate the transition from regime one to regime two, while the second term refers to the transition probability of moving from regime two to regime one. Note that the current state of the economy may be summarised in many ways by the values of the variables in the monetary policy rule. This could possibly allow for the central bank to respond either strongly or weakly

to deviations of variables from their steady-state values.<sup>9</sup>

The second variant of the model incorporates regime-switching in both the monetary policy rule and the volatility of the structural shock processes. Therefore, in addition to the earlier modification in the monetary policy rule that is contained in Equation (5.17), the second scenario also incorporates an additional independent two-state discrete Markov process which is attached to the variances of the structural shock processes. Thus, the regime switches in the volatility of the shock processes, may be expressed as  $\eta_\nu^j$ , where the superscript  $j$  denotes a given type of structural shock. The subscript  $\nu$  is then used to denote the discrete two-state Markov process, which may be expressed by  $\nu \in [1, 2]$ . Similarly, the volatility of the shock process also contains two regimes, where the first volatility regime is denoted ( $\nu = 1$ ) and the second ( $\nu = 2$ ). In this case, the transition probability of moving from the first volatility regime to the second one may be denoted  $\zeta^{1-2}$ , and the transition probability of moving from the second volatility regime to the first one would be  $\zeta^{2-1}$ .<sup>10</sup>

## 5.3 Data and estimation methodology

### 5.3.1 Data

The data for the ten observed variables comprises quarterly measures for the Ugandan economy and its main trading partners over the period 2000Q1 to 2015Q4. This includes all available quarterly measures of official output data for Uganda. All of the variables are stationary and include measures for the nominal interest rate, inflation rate, foreign inflation rate and foreign interest rate. The terms of trade and real exchange rate are expressed as growth rates and are used to identify the country risk premium, while the lending rate and non-performing loans as a ratio of total loans are used to identify the parameters that pertain to the financial frictions.

The measures for output, which include domestic and foreign gross domestic product (GDP), are expressed as growth rates, and those variables that exhibit seasonality were adjusted accordingly.<sup>11</sup> The domestic data was sourced from the Bank of Uganda (BoU)

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<sup>9</sup>Thus, we use the notation ( $\theta = 1$ ) to denote the first monetary regime, and the notation ( $\theta = 2$ ) to denote the second monetary regime.

<sup>10</sup>We also estimated models that were restricted to MS in the financial frictions only, to consider whether the recommendations made by the banking supervision and stability divisions of the central bank to the monetary policy divisions could be describe by regime-switching behaviour. [Vlcek and Roger \(2012\)](#) note that the institutional arrangements in most central banks separate the monetary policy analysis divisions from the banking supervision and stability divisions. We also considered the use of an additional model that was restricted to the response to open-economy features, and found that there was no MS in any of these additional models.

<sup>11</sup>When conducting an out-of-sample forecasting exercise, a measure of output growth is usually preferred to measures of the output gap, as it does not make any assumptions about the stochastic trend in the respective variables.

and the Uganda Bureau of Statistics (UBOS), while the foreign data was sourced from the Organisation for Economic Co-operation and Development (OECD) and the International Monetary Fund (IMF).<sup>12</sup>

### 5.3.2 Estimation methodology

In the models that incorporate rational expectations and Markov-switching, the solution in each state will be a function of the solution in all other states, and vice versa. This interdependence precludes the use of traditional rational expectations solution methods, which assume that all the parameters are constant. Therefore, we followed the approach that is based on a higher-order perturbation strategy, which is described in [Maih \(2012\)](#). This approach is largely based on the Newton techniques that follow the concept of minimum state variable (MSV), while the stable parameters were obtained from a characterisation that is based on the concept of mean square stability (MSS).<sup>13</sup> Similar techniques that are closely related to this approach may be found in [Farmer et al. \(2008\)](#), [Farmer et al. \(2011\)](#), [Davig and Doh \(2014\)](#). To apply this methodology, all the model equations were log-linearised, and the first-order Markov chains maintained constant transition probabilities for the two regimes. Thus, the general form of the Markov-switching rational expectations model may be summarised as;

$$E_t \{ A_{s_{t+1}}^+ x_{t+1}(\bullet, s_t) + A_{s_t}^0 x_t(s_t, s_{t-1}) + A_{s_t}^- x_{t-1}(s_{t-1}, s_{t-2}) + B_{s_t} \varepsilon_t \} = 0 \quad (5.18)$$

where  $x_t$  is a  $n \times 1$  vector of all the observed and unobserved endogenous variables and  $\varepsilon_t \sim N(0, 1)$  is the vector of structural shock processes. The stochastic regime index  $s_t$  contains the states of the different Markov chains, which switch between a finite number of possibilities with cardinality  $h$ , where  $s_t = 1, 2, \dots, h$ . In the case where there were two possible regimes, we assumed that these probabilities are constant, so that  $s_t$  represents the current period state and  $s_{t-1}$  denotes the previous period state.

Hence, the Markov transition probabilities may be expressed as  $p_{ij} = p_{s_{t-1}, s_t}$ , where the subscripts denote the probability of moving from the previous period state,  $s_{t-1}$ , to the current period state,  $s_t$ . Therefore, the first expectational term from Equation (5.18) may be defined as;

$$E_t A_{s_{t+1}}^+ x_{t+1}(\bullet, s_t) \equiv \sum_{s_{t+1}=1}^2 p_{s_t, s_{t+1}} A_{s_{t+1}} E_t x_{t+1}(s_{t+1}, s_t) \quad (5.19)$$

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<sup>12</sup>For details on the data sources for the different variables, refer to Table 4.1, which is contained in the previous chapter.

<sup>13</sup>Extensive use of this terminology may be found in the field of engineering. In the area of structural macroeconomic models, another notable contribution can be found in [Svensson and Williams \(2005\)](#).

The model likelihood function was evaluated with the aid of a filtering procedure, as this class of model assumes the presence of unobserved states and variables.<sup>14</sup> Bayesian techniques were used to estimate the model parameters, as this procedure allows one to treat the model parameters, unobserved variables and unobserved states as random variables. Therefore, information from the likelihood function was combined with the prior densities of the parameters to form the posterior kernel, which was used to derive the mode of the posterior distribution. The estimates of the mode were also used to internalise the Markov Chain Monte Carlo (MCMC) algorithm, from which we obtained the full posterior distribution and log marginal data density (MDD) that was estimated with the aid of a Laplace approximation.

## 5.4 Results

### 5.4.1 Prior and posterior estimates

Table 5.1, contains details of the prior distributions and the estimation results for the model that does not include regime-switching features. The priors were specified in such a way that 90% of the distribution falls between the bounded values. The table suggests that the mode of the posterior parameter values are broadly comparable to those that are found in similar studies.<sup>15</sup>

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<sup>14</sup>The algorithms that we used to solve the model are contained in the Rationality In Switching Environments (RISE) package, which is an object-oriented Matlab toolbox.

<sup>15</sup>The stochastic term  $\eta^{Rb}$  refers to the measurement error that is associated with the lending rate.

Table 5.1: Prior and posterior parameter estimates for the model without switching.

Parameter	Prior dist.	Prior Low	Prior High	Post Mode	Post Std.
<u>Consumption</u>					
$b_s$	[B]	0.615	0.7795	0.6377	0.0709
<u>Calvo parameters</u>					
$\theta_H$	[B]	0.3351	0.6649	0.8689	0.0130
$\theta_F$	[B]	0.3351	0.6649	0.1647	0.0208
<u>Indexation</u>					
$\delta_H$	[B]	0.3351	0.6649	0.2505	0.0681
$\delta_F$	[B]	0.3351	0.6649	0.3222	0.0928
<u>Exchange rate</u>					
$\phi_{uip}$	[IG]	0.0021	0.0281	0.002	0.0006
<u>Non-performing loans</u>					
$\theta_y$	[G]	0.2509	0.5774	0.375	0.0968
<u>Taylor rule</u>					
$\rho_R$	[B]	0.7125	0.8766	0.8167	0.0234
$\rho_\pi$	[G]	1.539	1.868	1.813	0.1048
$\rho_y$	[G]	0.4207	0.585	0.5198	0.0535
$\rho_{\Delta e}$	[G]	0.0127	0.1073	0.0276	0.0203
$\rho_\omega$	[G]	0.1953	0.6809	0.3516	0.1395
<u>Persistence parameters</u>					
$\rho_z$	[B]	0.6146	0.9389	0.4024	0.0875
$\rho_g$	[B]	0.6146	0.9389	0.8462	0.1001
$\rho_c$	[B]	0.6146	0.9389	0.8055	0.0793
$\rho_{cp}$	[B]	0.6146	0.9389	0.9614	0.0278
$\rho_{rp}$	[B]	0.6146	0.9389	0.6977	0.0929
$\rho_{\pi^*}$	[B]	0.6146	0.9389	0.5562	0.0929
$\rho_{y^*}$	[B]	0.6146	0.9389	0.8654	0.0480
$\rho_{R^*}$	[B]	0.6146	0.9389	0.8822	0.0433
<u>Structural shocks</u>					
$\eta^z$	[IG]	0.0114	0.152	0.1103	0.0191
$\eta^g$	[IG]	0.274	3.658	0.4333	0.2502
$\eta^c$	[IG]	0.0105	0.1407	0.2024	0.1049
$\eta^{cp}$	[IG]	0.0422	0.5628	0.1921	0.0351
$\eta^{rp}$	[IG]	0.0084	0.1126	0.025	0.0052
$\eta^\chi$	[IG]	0.3162	4.221	1.212	0.106
$\eta^R$	[IG]	0.0013	0.0169	0.0068	0.0007
$\eta^{\pi^*}$	[IG]	0.0021	0.0281	0.0072	0.0006
$\eta^{y^*}$	[IG]	0.0008	0.0113	0.0055	0.0005
$\eta^{R^*}$	[IG]	0.0008	0.0113	0.0011	0.0001
$\eta^{Rb}$	[IG]	0.005	1	0.0076	0.0007

Note: Prior distributions represent [B] - beta, [G] - gamma, [IG] - inverse gamma.

Table 5.2 presents the results of the prior and posterior parameter estimates, together with details relating to the posterior parameter distribution for the model with regime-switching in the monetary policy rule only. For each parameter, the priors for the two regimes were assumed to be equivalent. The posterior results suggest that there are substantial differences between the first regime ( $\theta = 1$ ) and the second ( $\theta = 2$ ). For instance, the results suggest that there is a greater degree of interest rate smoothing during the second regime. In addition, we noted that the central bank responds at least one-and-a-half times more strongly to changes in each of the monetary policy rule coefficients in the first regime, relative to the second. For example, the central bank response to

changes in the inflation rate is  $(1 - \rho_R) \rho_\pi = 0.4059$  in the first regime and 0.2542 in the second. Similarly, the central bank response to changes in output in the first regime is  $(1 - \rho_R) \rho_y = 0.1129$  and 0.0745 in the second. However, the response to changes in the exchange rate and the interest rate spread in the first regime are 0.0067 and 0.0783, compared with respective responses of 0.0044 and 0.0524 in the second regime. Therefore, these results suggest that when regime-switching features are incorporated in the monetary policy rule only, the central bank response will be more aggressive when in the first regime, as there is less interest rate smoothing and a much stronger response to changes in inflation and output (while the response to the exchange rate and interest rate spread is also slightly stronger).

Table 5.2: Prior and posterior parameter estimates for the model with switching in the monetary policy rule.

Parameter	Prior dist.	Prior Low	Prior High	Post Mode	Post Std.
$\rho_R(\theta = 1)$	[B]	0.7125	0.8766	0.7772	0.0400
$\rho_R(\theta = 2)$	[B]	0.7125	0.8766	0.8511	0.0338
$\rho_\pi(\theta = 1)$	[G]	1.539	1.868	1.822	0.1133
$\rho_\pi(\theta = 2)$	[G]	1.539	1.868	1.707	0.1051
$\rho_y(\theta = 1)$	[G]	0.4207	0.585	0.5065	0.0524
$\rho_y(\theta = 2)$	[G]	0.4207	0.585	0.5	0.0509
$\rho_{\Delta e}(\theta = 1)$	[G]	0.0127	0.1073	0.0302	0.0223
$\rho_{\Delta e}(\theta = 2)$	[G]	0.0127	0.1073	0.0299	0.0224
$\rho_\omega(\theta = 1)$	[G]	0.1953	0.6809	0.3513	0.1393
$\rho_\omega(\theta = 2)$	[G]	0.1953	0.6809	0.3519	0.1396
$\kappa^{1-2}$	[U]	-1.559	1.559	0.2058	0.3125
$\kappa^{2-1}$	[U]	-1.559	1.559	0.5954	0.5361

Note: Prior distributions represent [B] - beta, [G] - gamma, [U] - uniform.

The posterior parameter estimates for the model that incorporates regime-switching features in both the monetary policy rule and the volatility of the shocks are presented in Table 5.3. These results suggest that there are substantial differences in the posterior estimates, when comparing the two regimes. For example, there would appear to be relatively more interest rate smoothing in the first regime, in comparison with the second. Hence, the results suggest that the central bank responds more aggressively in the second regime, relative to the first. For instance, the measure for the central bank response to changes in inflation is 0.4069 in the second regime, compared with a response of 0.2418 in the first. In addition, the central bank response to changes in output, and the exchange and interest rate spreads during the second regime are 0.1095, 0.0064 and 0.0778, respectively, compared with responses of 0.0708, 0.0042 and 0.0498 in the first regime. This result is contrary to those that are reported in Table 5.2, where the central bank response in the first regime may be characterised by lower degrees of interest rate smoothing and a stronger response to changes in inflation, output, the exchange rate and the interest

rate spread. Implying that the incorporation of regime changes in the volatility of shocks alters the behaviour of the central bank in response to changes in the variables in the monetary policy rule.

Table 5.3: Prior and posterior parameter estimates for the model with switching in the monetary policy rule and the variance of shocks.

Parameter	Prior dist.	Prior Low	Prior High	Post-mode	Post Std
$\rho_R(\theta = 1)$	[B]	0.7125	0.8766	0.858	0.0328
$\rho_R(\theta = 2)$	[B]	0.7125	0.8766	0.7791	0.0538
$\rho_\pi(\theta = 1)$	[G]	1.539	1.868	1.703	0.1052
$\rho_\pi(\theta = 2)$	[G]	1.539	1.868	1.842	0.3353
$\rho_y(\theta = 1)$	[G]	0.4207	0.585	0.4985	0.0539
$\rho_y(\theta = 2)$	[G]	0.4207	0.585	0.4957	0.1153
$\rho_{\Delta e}(\theta = 1)$	[G]	0.0127	0.1073	0.0297	0.0223
$\rho_{\Delta e}(\theta = 2)$	[G]	0.0127	0.1073	0.0290	0.0218
$\rho_\omega(\theta = 1)$	[G]	0.1953	0.6809	0.351	0.1392
$\rho_\omega(\theta = 2)$	[G]	0.1953	0.6809	0.3521	0.1397
$\eta^R(\nu = 1)$	[IG]	0.0013	0.0169	0.00634	0.3672
$\eta^R(\nu = 2)$	[IG]	0.0013	0.0169	0.0092	0.5627
$\eta^X(\nu = 1)$	[IG]	0.3162	4.221	0.899	0.0011
$\eta^X(\nu = 2)$	[IG]	0.3162	4.221	3.748	0.0029
$\eta^{g^c}(\nu = 1)$	[IG]	0.0105	0.1407	0.1012	0.0983
$\eta^{g^c}(\nu = 2)$	[IG]	0.0105	0.1407	0.1369	1.535
$\eta^g(\nu = 1)$	[IG]	0.274	3.658	0.4333	0.3079
$\eta^g(\nu = 2)$	[IG]	0.274	3.658	0.4333	0.401
$\eta^{rp}(\nu = 1)$	[IG]	0.0084	0.1126	0.0239	0.2502
$\eta^{rp}(\nu = 2)$	[IG]	0.0084	0.1126	0.0132	0.2502
$\eta^z(\nu = 1)$	[IG]	0.0114	0.152	0.1141	0.0083
$\eta^z(\nu = 2)$	[IG]	0.0114	0.152	0.0134	0.0052
$\eta^{cp}(\nu = 1)$	[IG]	0.0422	0.5628	0.2043	0.0711
$\eta^{cp}(\nu = 2)$	[IG]	0.0422	0.5628	0.0891	0.0046
$\eta^{y^*}(\nu = 1)$	[IG]	0.0008	0.0113	0.0040	0.0378
$\eta^{y^*}(\nu = 2)$	[IG]	0.0008	0.0113	0.0123	0.0295
$\eta^{\pi^*}(\nu = 1)$	[IG]	0.0021	0.0281	0.0073	0.0004
$\eta^{\pi^*}(\nu = 2)$	[IG]	0.0021	0.0281	0.0048	0.0036
$\eta^{R^*}(\nu = 1)$	[IG]	0.0008	0.0113	0.0010	0.0007
$\eta^{R^*}(\nu = 2)$	[IG]	0.0008	0.0113	0.0016	0.0015
$\kappa^{1-2}$	[U]	-1.559	1.559	0.6204	0.0001
$\kappa^{2-1}$	[U]	-1.559	1.559	0.229	0.0006
$\zeta^{1-2}$	[U]	-1.559	1.559	0.0823	0.0401
$\zeta^{2-1}$	[U]	-1.559	1.559	0.1816	0.2135

Note: Prior distributions represent [B] - beta, [G] - gamma, [IG] - inverse gamma, [U] - uniform.

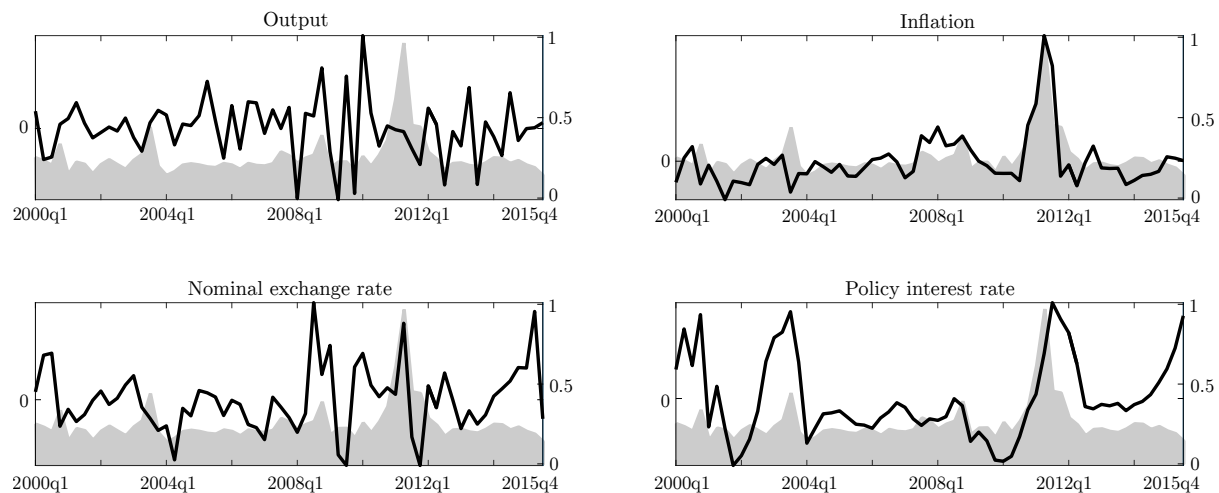
In terms of the volatility of the shock processes, the volatility in the interest rate and interest rate spread, preferences in consumption, foreign output and foreign interest rate shocks are higher in the second regime. This is in contrast to the volatility in the

risk premium, technology, the cost-push and foreign inflation shocks which are higher in the first regime. While such a result is plausible, it is not easy to interpret without the information from the transition probabilities, which is included below.

### 5.4.2 Transition probabilities

The results of the smoothed transition probabilities for the models that include regime-switching features are displayed in Figures 5.1 through 5.3. The first two of these figures shows the results of the transition probabilities that pertain to the monetary policy rule, which utilise information from  $\theta$  and  $\nu$ . In both figures, when the value of the transition probability (represented by the shaded area) is one (as seen from the right-hand axis), it would represent a more aggressive central bank response (i.e.  $\theta = 1$ ). These results suggest that the smoothed transition probabilities that capture changes in the behaviour of the monetary authority do not incorporate a level shift in the policy rule. This implies that although the central bank adopted an inflation targeting framework in 2011, monetary policy has been implemented in a fairly consistent manner throughout the sample period. Hence, the conducting of monetary policy that made use of monetary targeting during the period prior to 2011, where the broad objective was to maintain a low and stable rate of inflation, could be regarded as a period of quasi-inflation targeting.

Figure 5.1: Smoothed transition probability ( $\theta = 1$ ): switching in the monetary policy rule.



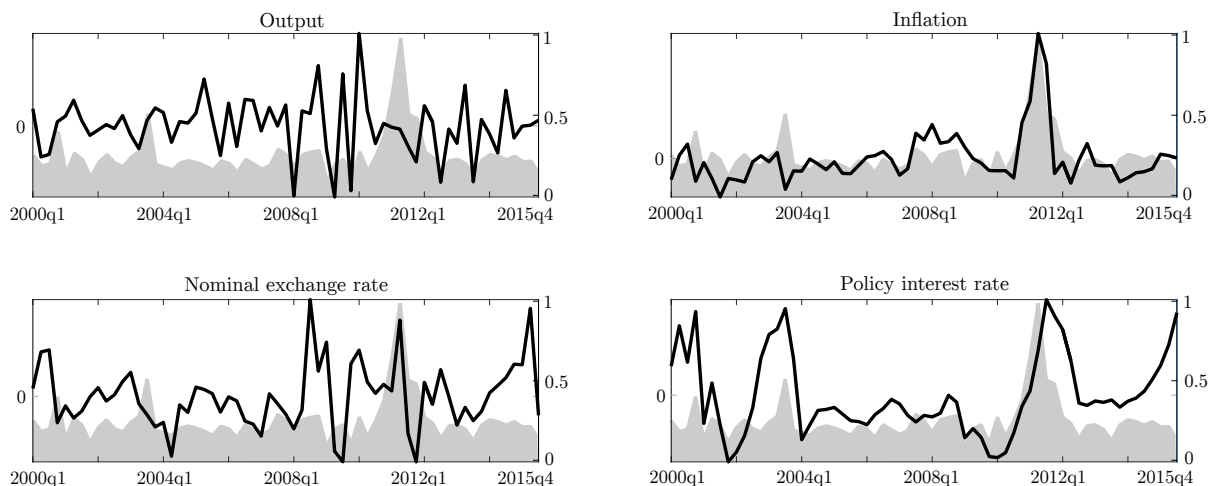
Note: The left axis is the data (solid line), and right axis is the probability (shaded area).

However, while there is no evidence of a level shift when a new monetary policy framework was adopted, there is evidence of a pulse effect in the transition probabilities over this period. An explanation for this event should be considered in light of the behaviour of the underlying macroeconomic variables; for example, where we observed a particularly large increase in consumer prices, as inflation rose to almost 31% in October 2011. This would have been a major concern for policymakers, and it resulted in a more

aggressive response by the central bank, as the nominal interest rate increased by 1,000 basis points.

It is also worth noting that the smoothed transition probabilities for the two variants of regime-switching models, which are contained in Figures 5.1 and 5.2, are extremely similar. If anything, the smoothed transition probabilities for the regime-switching model that incorporates this feature in both the monetary policy rule and the volatility of shocks encounters a more absolute transition to the more aggressive central banking regime.

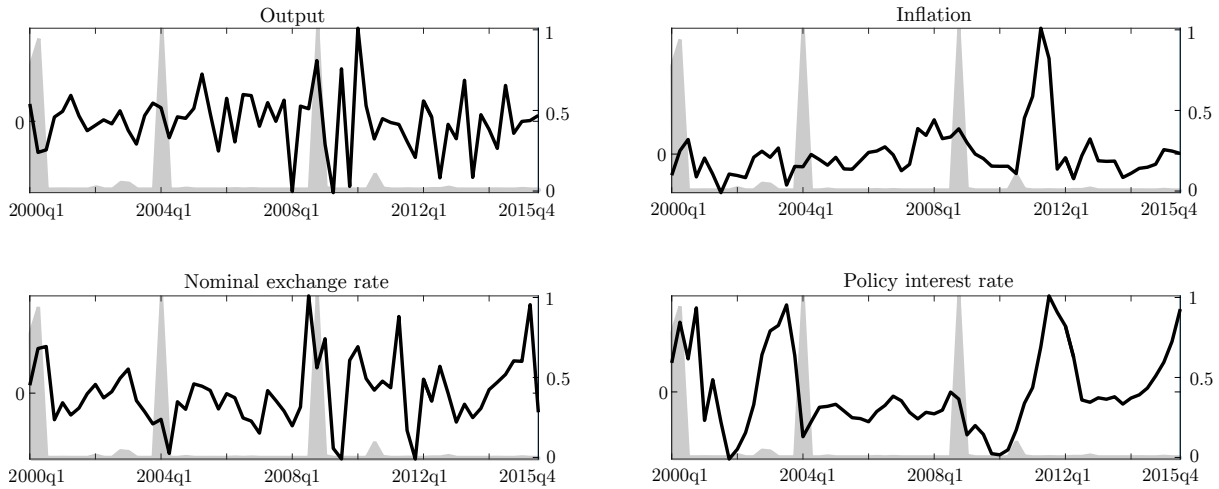
Figure 5.2: Smoothed transition probability ( $\theta = 1$ ): switching in the monetary policy rule and volatility of shocks.



Note: The left axis is the data (solid line), and right axis is the probability (shaded area).

Turning our attention to the smoothed transition probabilities for the volatility of the shock processes, which are contained in Figure 5.3, we note that the model finds itself mostly in regime one. However, there are three distinct periods when the smoothed transition probabilities for the variances of the shock processes switch to regime two. These appear to capture key events, such as the period of a relatively large exchange rate shock in 2000Q1, the period of a heightened interest rate shock in 2004Q1, and the period in which both output and the exchange rate shocks were relatively high in 2008Q4.

Figure 5.3: Smoothed transition probability ( $\nu = 2$ ): switching in the monetary policy rule and volatility of shocks.



Note: The left axis is the data (solid line), and right axis is the probability (shaded area).

Therefore, these results suggest that the smoothed transition probabilities for the variants of the regime-switching models capture a number of important events that have affected the state of the Ugandan economy, as described by the data-generating process for key macroeconomic variables. These events include the period of heightened domestic inflationary pressures during 2011, which was accompanied by higher policy interest rates. In addition, the smoothed transition probabilities of the shocks also appear to capture a number of significant shocks that have affected economic activity.

### 5.4.3 In-sample evaluation

The in-sample statistics for the three models – i.e. the no-switching model, the model that incorporates regime-switching in the monetary policy rule only, and the model that incorporates regime-switching in both the monetary policy rule and the volatility of shocks – are reported in Table 5.1. These results for the log-posterior, the log-likelihood, log-prior and log-MDD Laplace statistics may be used to identify the model that would provide a superior explanation of the macroeconomic data for Uganda. They suggest that the in-sample statistics for all three models are highly comparable and that there is only an extremely small difference in favour of the model that excludes regime-switching features, while the model that includes regime-switching in monetary policy only ranks second, with an identical log-likelihood statistic but with a slightly higher log-posterior statistic. Furthermore, the details of the in-sample statistics suggest that the model that includes regime-switching in both the monetary policy rule and the volatility of shocks is the least favourable, although the log-MDD Laplace statistic remains extremely close to that of the other two models.

Table 5.1: In-sample estimation statistics.

	log-post:	log-lik:	log-prior:	log-MDD
No-switching	<b>1564</b>	<b>1539</b>	<b>24.65</b>	<b>1466</b>
Switching in monetary policy rule	1571	1539	31.32	1463
Switching in monetary policy rule & volatility of shocks	1607	1560	46.75	1460

Note: The superior statistics are in boldface.

#### 5.4.4 Out-of-sample evaluation

Table 5.2 contains the results of the evaluation of the out-of-sample performance based on the RMSEs. The forecasts were generated by assuming that the in-sample periods for each of the models estimated initially ends in 2008Q4. Thereafter, one- to eight-step-ahead forecasts were generated by first updating the in-sample data to 2009Q1 for the subsequent re-estimation that was used to generate the second forecast. All the recursive forecasts were then used in the evaluation exercise for each step-ahead forecast, over the entire out-of-sample period for the three models that are described above.

When considering the results of the RMSEs, we noted that there are considerable differences in the respective out-of-sample statistics over the short-term horizon. However, the differences appear to be very small when we consider the forecasts that were generated for the longer horizons. More specifically, the results suggest that the model that does not incorporate regime-switching features has superior short-term out-of-sample forecasting properties for output and that over the long-term horizon, the out-of-sample output forecasts for the regime-switching models are somewhat superior. With regard to the forecasts for the rate of inflation, slightly superior forecasting performance is provided by the model that does not include regime-switching features over the longer horizon; however, over the shorter horizons, the variants of the regime-switching models provide superior results. Similarly, the interest rate forecasts for the model that does not include regime-switching features has slightly superior out-of-sample forecasting results over the longer horizon, whereas the two variants of the regime-switching models have somewhat superior measures for interest rate forecasts over the shorter horizons.

To consider whether the differences in the RMSEs are potentially significant, we tested the null hypothesis of equal predictive ability, where the model that does not include regime-switching behaviour was compared with the two regime-switching models using the criteria. This investigation makes use of the methodology that has been proposed by McCracken (2007) and Clark and West (2006, 2007), which are usually referred to as the MSE-F and CW tests, respectively.<sup>16</sup>

<sup>16</sup>As the model that does not include regime-switching is nested within the regime-switching alternatives, the use of the Diebold and Mariano (1995) and West (1996), equal predictive ability tests would tend to be severely undersized and would often lead to too few rejections of the null hypothesis.

Table 5.2: Root-mean squared-errors statistics (2009Q1-2015Q4).

	Forecast Horizon							
	1-step	2-step	3-step	4-step	5-step	6-step	7-step	8-step
<b>Output</b>								
No-switching	<b>0.0268</b>	0.0274	0.0243	<b>0.0236</b>	0.0220	0.0170	0.0168	0.0166
Switching in monetary policy rule	0.0274	0.0272	<b>0.0239</b>	0.0241	<b>0.0218</b>	<b>0.0170</b>	0.0168	0.0166
Switching in monetary policy rule & volatility of shocks	0.0272	<b>0.0266</b>	0.0241	0.0236	0.0222	0.0170	<b>0.0168</b>	<b>0.0165</b>
<b>Inflation</b>								
No-switching	0.0283	0.0258	0.0256	0.0254	<b>0.0253</b>	<b>0.0252</b>	<b>0.0251</b>	<b>0.0249</b>
Switching in monetary policy rule	<b>0.0278</b>	0.0257	<b>0.0246</b>	<b>0.0251</b>	0.0253	0.0253	0.0252	0.0250
Switching in monetary policy rule & volatility of shocks	0.0305	<b>0.0252</b>	0.0250	0.0253	0.0254	0.0253	0.0252	0.0250
<b>Interest rate</b>								
No-switching	0.0066	0.0088	0.0096	0.0098	0.0097	0.0094	<b>0.0091</b>	<b>0.0097</b>
Switching in monetary policy rule	<b>0.0065</b>	<b>0.0086</b>	<b>0.0093</b>	<b>0.0094</b>	<b>0.0094</b>	<b>0.0093</b>	0.0093	0.0100
Switching in monetary policy rule & volatility of shocks	0.0072	0.0091	0.0095	0.0096	0.0096	0.0094	0.0093	0.0099

Note: The minimum RMSEs are indicated by the boldface entries.

The CW test statistics are reported in Table 5.3, where the results for the output forecasts suggest that the model that includes regime-switching features in both the monetary policy rule and the volatility of shock processes significantly outperforms the model that excludes these features for the two- and eight-step-ahead horizons (at a 10% significance level).

For inflation forecasts, the regime-switching models significantly outperform the model that excludes these features over the one- to three-step-ahead horizons. More specifically, at the one-step-ahead horizon, the regime-switching model that incorporates these features in the monetary policy rule is superior at the 10% significance level, while the level of significance is 5% at the three-step-ahead horizon. Similarly, the model that includes regime switching in both the monetary policy rule and the volatility of shocks is superior at the two- and three-step-ahead horizons at 5% and 1% levels of significance, respectively.

Then, lastly, for the interest rate forecasts, the difference in the performance of the models is significant over the one- to five-step-ahead horizons, where the level of significance ranges between 1% and 10% for the model that incorporates regime-switching in the monetary policy rule. In addition, the differences in forecasting for the model that incorporates regime-switching in both the monetary policy rule and the volatility of shocks is significant at the three- to five-step-ahead horizons.

Table 5.4 includes the results for the MSE-F test for equal predictive ability between the null of no regime-switching and the alternative for the two regime-switching models. The results support those of the CW test, but would imply that there are more quarters in which the variants of the regime-switching model significantly outperform the model that excludes these features. For instance, in the case of output forecasts, the regime-switching models provide significant improvements over six of the total forecasting horizons. More specifically, for the model with regime-switching in the monetary policy rule, this arises at a 1% level of significance at all but the one- and four-step-ahead horizons.

With regard to the inflation rate forecasts, the regime-switching models significantly outperform the model that excludes these features over the one- to four-step-ahead horizons. This difference in forecasting performance arises at the 1% significance level in the second-step and fourth-step-ahead horizon for the model that incorporates regime-switching in the monetary policy rule. Similarly, when considering interest rate forecasts, the results suggest that the regime-switching models provide significant performance gains over the one- to six-step-ahead horizons. Many of these differences are at the 1% level of significance.

The out-of-sample evaluation for the forecast densities are performed with the aid of the probability integral transform (PIT).<sup>17</sup> These statistics are used to compare the distribution of the respective forecasts in relation to the underlying data-generating process.

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<sup>17</sup>More detailed discussions on the applications of the PIT methodology and how it may be applied to evaluate forecast densities can be found in Diebold et al. (1998) and Wolters (2015).

Table 5.3: Clark-West Test (2009Q1-2015Q4).

	Forecast Horizon							
	1-step	2-step	3-step	4-step	5-step	6-step	7-step	8-step
<b>Output</b>								
Switching in monetary policy rule	0.500	0.202	0.165	0.9400	0.145	0.412	0.179	0.298
Switching in monetary policy rule & volatility of shocks	0.310	0.095*	0.225	0.639	0.860	0.509	0.132	0.068*
<b>Inflation</b>								
Switching in monetary policy rule	0.051*	0.146	0.050**	0.133	0.676	0.983	0.958	0.921
Switching in monetary policy rule & volatility of shocks	0.802	0.043**	0.003***	0.304	0.886	0.940	0.970	0.938
<b>Interest rate</b>								
Switching in monetary policy rule	0.078*	0.088*	0.031**	0.008***	0.025**	0.294	0.719	0.836
Switching in monetary policy rule & volatility of shocks	0.512	0.553	0.082*	0.026**	0.061*	0.387	0.707	0.784

Notes: This table reports p-values for one-to-eight-steps ahead CW tests of equal predictive ability between the null of the no regime-switching model against the alternative for each regime-switching model. The alternative model is the model with regime-switching in the monetary policy rule only and the model with regime-switching in both the monetary policy rule and the volatility of shocks. A small p-value indicates a rejection of the hypothesis, and \*, \*\*, and \*\*\* indicate that the alternative model significantly outperforms the no regime-switching model at 10%, 5%, and 1% significance levels, based on a one-sided standard test.

As part of this analysis, we reported on the results of the histograms of the PITs at the one-, four-, and eight-step-ahead forecasting horizons. These are displayed for measures of output, inflation and interest rates in Figures 5.4, 5.5, and 5.6, respectively. To interpret these results, it is worth noting that the variants of the models that are responsible for superior predictive distributions would generate a density that approximates a uniform distribution. Overall, the results suggest that there is no single model that provides superior forecasting densities for all variables and forecasting horizons. However, there are a few instances where certain models generate forecast densities that are more representative of the features of the underlying data-generating process of the respective variables.

The results in Figure 5.4 suggest that the predictive densities for output are relatively uniform and that they fall within the confidence intervals for the entire forecasting horizon and for all the model variants. This would imply that the three variants of the model are able to generate for output reasonably accurate forecast densities that match the distribution of the true underlying data generation process. In terms of the relative performance of the three models, the results are fairly similar, with the model that includes regime-switching in both the policy rule and volatility of the shocks outperforming the others over the longer horizon.

Figure 5.4: Histogram of the probability integral transforms (PITs) for output with  $h = 1, 4 \& 8$ .

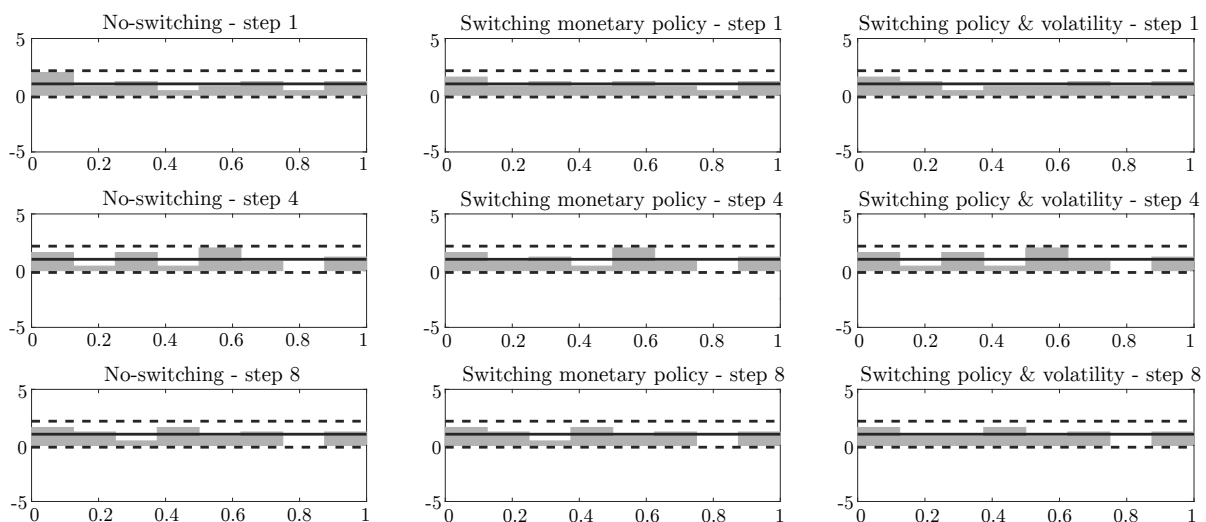


Figure 5.5, suggests that there is an absence of a uniform forecasting distribution at the four-step-ahead and eight-step-ahead forecasting horizons. This result is consistent across all models, where there is a concentration around the mean and a general scarcity of observations on the extreme left-hand side of the distribution. The results in Figure 5.6 suggest that all the distributions are relatively uniform at the one-step-ahead horizon. However, as in the case of inflation, there is a slight concentration around the mean over

Table 5.4: McCracken Mean square error (MSE-F) test (2009Q1-2015Q4).

	Forecast Horizon							
	1-step	2-step	3-step	4-step	5-step	6-step	7-step	8-step
<b>Output</b>								
Switching in monetary policy rule	-0.787	0.296***	0.604***	-0.855	0.324***	0.004***	0.132***	0.181***
Switching in monetary policy rule & volatility of shocks	-0.512	1.175**	0.320***	-0.133	-0.371	-0.025	0.135***	0.342***
<b>Inflation</b>								
Switching in monetary policy rule	0.835**	0.180***	1.623**	0.462***	-0.038	-0.174	-0.205	-0.131
Switching in monetary policy rule & volatility of shocks	-2.754	0.839***	0.879***	0.051***	-0.103	-0.146	-0.214	-0.145
<b>Interest rate</b>								
Switching in monetary policy rule	0.461***	0.730***	1.230**	1.634*	1.048**	0.222***	-0.868	-1.159
Switching in monetary policy rule & volatility of shocks	-3.125	-1.180	0.687***	0.923***	0.544***	0.001***	-0.752	-0.923

Notes: This table reports the calculated test statistics for the one-to-eight-step-ahead MSE-F tests of equal predictive ability between the null of the no regime-switching model against the alternative regime-switching models. The alternative model is the model with regime-switching in the monetary policy rule only and the model with regime-switching in both the monetary policy rule and the volatility of shocks. \*, \*\*, and \*\*\* indicates that the alternative model significantly outperforms the no regime-switching model at 10%, 5%, and 1% significance levels, respectively.

longer horizons, where there is also a scarcity of observations on the left-hand side.

Figure 5.5: Histogram of the probability integral transforms (PITs) for inflation with  $h = 1, 4 \& 8$ .

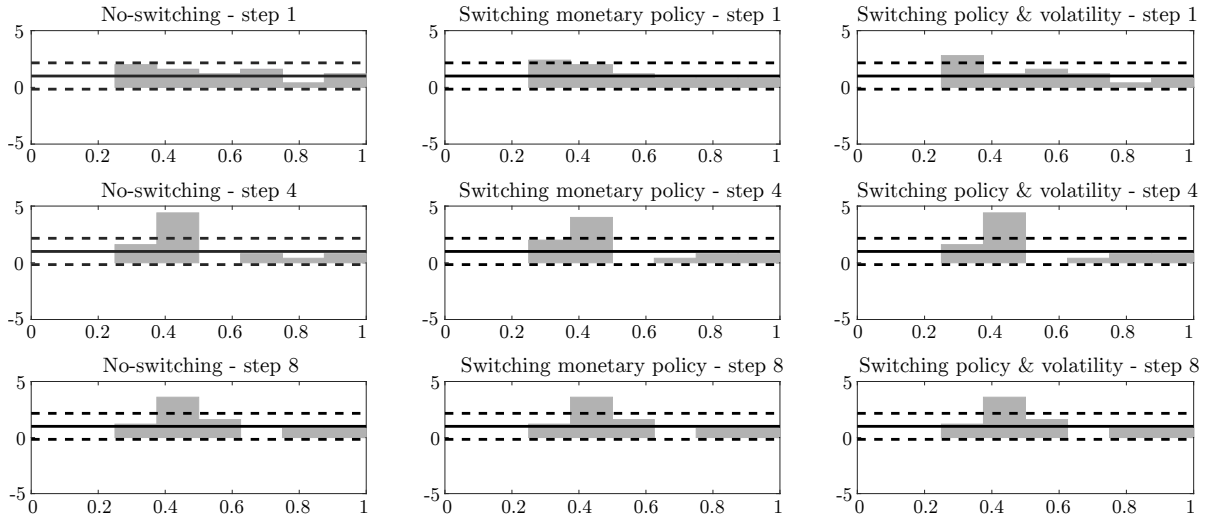
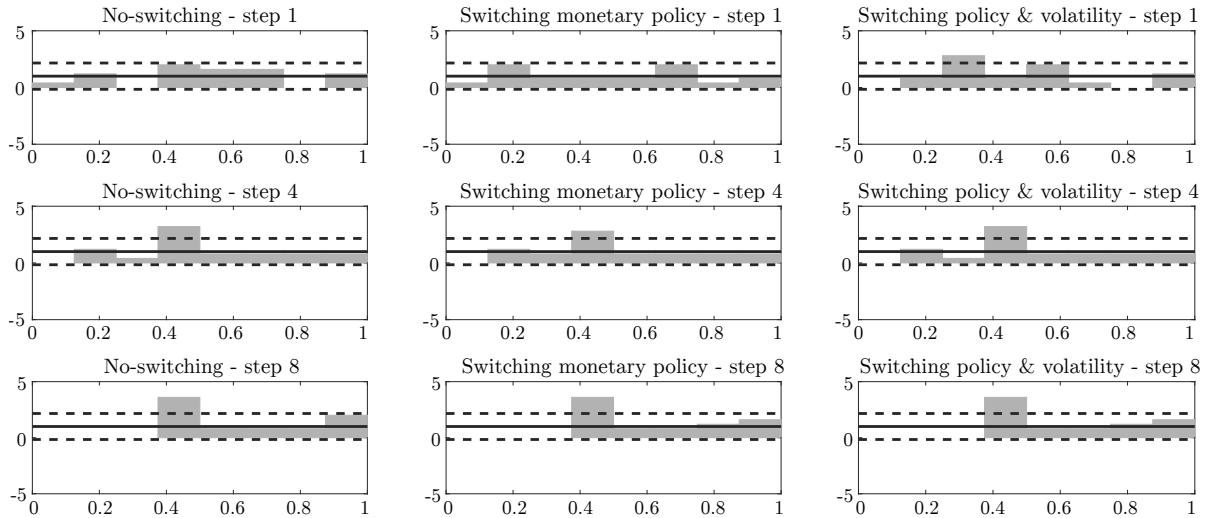


Figure 5.6: Histogram of the probability integral transforms (PITs) for interest rate with  $h = 1, 4 \& 8$ .



In summary, the evaluation of the out-of-sample point-forecasting results suggest that the variants of the regime-switching model may exhibit superior predictive ability for the three key macroeconomic variables (output, inflation rate and interest rate) over certain forecasting horizons. When considering the forecasting densities of the three models, we noted that in most cases they are comparable and appear to provide a fairly reasonable characterisation of the higher moments of the underlying data.

## 5.5 Conclusion

This chapter considers the use of regime-switching dynamic macroeconomic models that may be used for monetary policy analysis and forecasting purposes in Uganda. The motivation for this study is based on the premise that many low-income countries, such as Uganda, face several large domestic and external shocks that may alter the data generation process in these economies. We considered two variants of regime-switching models: one that incorporates regime-switching features in the monetary policy rule only and another that incorporates regime-switching in both the monetary policy rule and in the volatility of shock processes.

After estimating most of the parameters in the models that incorporate regime-switching, we noted that there are significant differences in application of monetary policy when comparing the estimation results for the two regimes. In addition, the transition probabilities provide little evidence of a level shift in the central bank rule, which would suggest that the change in monetary policy framework has had little effect on the general behaviour of the central bank. These transition probabilities also suggest that there are only a number of instances where the central bank response was particularly aggressive, where there was less interest rate smoothing and a much stronger response to changes in inflation and output. Such behaviour is consistent with the underlying events that affected the Ugandan economy at particular points in time.

In terms of the volatility of the shock processes, the model that incorporates these features appears to suggest that there have been only a few instances where there were extremely large shocks. These may have impacted on the observed values of the exchange rate, the interest rate, and possibly output. The results would also appear to suggest that when the volatility of the risk premium, technology, cost-push and foreign inflation is particularly high, the volatility for shocks relating to the interest rate, interest rate spread, preferences in consumption, foreign output and the foreign interest rate is relatively low.

The relative performance of the respective models was subsequently evaluated with the aid of in-sample and out-of-sample statistics. While the in-sample results suggest that the two variants of the regime-switching model are largely comparable to the model that excludes these features, the out-of-sample results suggest that the regime-switching models could be responsible for more accurate forecasts over particular horizons. For example, the regime-switching models provide superior out-of-sample statistics for inflation and interest rates over short and medium horizons, while they also provide improved forecasting results for output over the longer horizon. When considering the results of the out-of-sample forecasting distributions, all of the models appear to provide predictive densities that are highly comparable.

# Chapter 6

## Summary and Conclusion

### 6.1 Summary of Findings

This dissertation contributes to the literature on monetary policy in low-income countries. It discusses the fact that monetary policy models used for policy analysis and forecasting in LICs are applied to a more challenging economic environment, than that of developed and advanced emerging market economies. The economic environments in LICs are characterised by: i) fragility with few supporting mechanisms or institutions; ii) underdeveloped financial and capital markets that are usually dominated by commercial banks, while other markets such as those for fixed- incomes securities and equities are ineffective; iii) interaction with other economies, where the effect of shocks from advanced emerging and developed economies could be dramatic; and iv) high volatility in the data generating processes, arising from both supply and demand shocks. To address some of these features, this thesis considers the time-varying nature of inflation persistence, the role of financial frictions in small open-economy models, and the role of nonlinearities in such a model. Our studies use macroeconomic data on Uganda. This country is a useful case study, as the economic data for this economy is fairly extensive (compared to that of other LICs) and the central bank follows a modern monetary policy regime (i.e. inflation-targeting). Uganda also has several features that are consistent with many other LICs, such as inefficient capital and financial markets.

Chapter 3 covers research that makes use of a quantile regression framework to probe the speed of adjustment of the rate of headline and core inflation in response to macroeconomic shocks. This technique allows for the identification and measurement of the mean-reverting properties in the inflation quantiles. The study employs a 10-year rolling-window, together with 95% bootstrap confidence interval, to investigate time-varying persistence in the two measures of inflation, at both monthly and quarterly frequency. In addition, the study considers the application of the wavelets decomposition to provide an alternative measure of core inflation (Core-Wavelet).

The results suggest that, for the entire sample, the QKS test rejects the null hypothesis of a unit root, which indicates evidence of mean reversion. However, for some subsamples, the core inflation rates show evidence of a unit root, which suggests an absence of mean reversion within these subsamples. Furthermore, the results suggest that there is evidence of asymmetry in the inflationary process, as the unit roots are contained to the upper quantiles, and there is no evidence of a unit root for the bottom quantiles. This suggests that the persistence in Ugandan inflation is not constant, as the persistence in the top quantiles is consistently higher than the bottom quantiles. In addition, persistence increased after 2006 and during the period under inflation targeting (July 2011 to December 2015). This could mean that inflationary expectations in Uganda have recently stabilised. Lastly, the results show that the Core-Wavelet is a much smoother, and more persistent measure than both headline and core inflation measures, which are currently used by UBOS. The persistence in the Core-Wavelet measure seems to be asymmetric, while for the period under inflation targeting the persistence results from the Core-Wavelet measure are somewhat mixed.

In the fourth chapter, we make use of a small open-economy DSGE model that incorporates financial frictions, to consider the role of these frictions and the implementation of monetary policy in Uganda. In this case, financial frictions are introduced through the activities of heterogeneous households (savers and borrowers). The other elements that are included in the model are: A continuum of monopolistically competitive firms that produce intermediate goods, perfectly competitive firms that produce final goods, monopolistically competitive foreign good producing firms, financial intermediaries that link savers and borrowers, a government sector that incorporates a central bank, and a foreign economy, represented by the trade-weighted average of key trading partners. The model also includes a number of real and nominal rigidities, habit formation in consumption, and incomplete asset markets. The Bayesian technique is used to estimate most of the parameters in the model using quarterly macroeconomic data from 2000Q1 to 2015Q4. The results suggest that the key posterior parameter estimates are largely consistent with the values that are found in the general literature. The dynamics of the model suggest that the central bank currently responds to changes in interest rate spread, even though capital and financial markets are fairly inefficient in Uganda.<sup>1</sup>

The effect of a monetary policy innovation in the model with financial frictions shows that the response of the variables is broadly consistent with the monetary policy transmission literature. For example, a monetary policy shock leads to an increase in the lending rate, an increase in non-performing loans, a decrease in borrowing, a decline in the output gap, a fall in the rate of inflation, and an appreciation of the exchange rate. The results from the investigation into the optimal monetary policy rule suggest that the estimated

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<sup>1</sup>This is despite the fact that the current rule (that is employed in the central models) does not expressly include the interest rate spread in the reaction function.

coefficients are comparable with the optimal counterparts, where the value of the coefficient for the response to changes in the interest rate spread is substantially different from zero.

Lastly, in the chapter five, we investigate macroeconomic dynamics in Uganda, using a Markov-switching small open-economy DSGE model that incorporates financial frictions. All the elements of a small open-economy dynamic model that were included in the previous chapter are maintained in the structure of this model. The main difference between the model in this chapter and the model in the previous chapter relates to the structural parameters in the central bank's reaction function, and the shock processes that are able to change in accordance with the stochastic regime-switching process. The Markov-switching models are estimated using a solution approach that is based on a higher-order perturbation strategy, and most of the parameters are estimated with the aid of Bayesian techniques. Two variants of the regime-switching models are considered. One variant incorporates regime-switching features in the monetary policy rule only. The other incorporates regime-switching in both the monetary policy rule and the volatility of shock processes.

The results of the parameter estimation for the two model variants suggest that there are significant differences between the first regime and the second regime, as the estimated parameters are not constant over the entire sample. In the model that incorporates regime-switching in monetary policy only, the central bank response in the first regime is characterised as a high response regime. That is, where there is less interest rate smoothing and a much stronger response to changes in inflation, output, the exchange rate, and the interest rate spread. For the model that incorporates regime-switching in both the monetary policy rule and the volatility of shocks, the central bank response in the first regime may be characterised as a low response regime. That is, where there is more interest rate smoothing and a less stronger response to changes in inflation, output, exchange rate and interest rate spread. In terms of the volatility of the shock processes, the model that incorporates these features may be characterised as a high volatility regime in the risk premium, technology, cost-push and foreign inflation in the first regime and a low volatility regime in the interest rate, interest rate spread, preferences in consumption, foreign output and foreign interest rate in the second regime.

The results that relate to the transition probabilities provide little evidence of a level shift in the central bank rule. However, there is evidence of a pulse effect around the time of the introduction of the inflation targeting regime. When considering the in-sample results, it is noted that the two variants of the regime switching model are largely comparable to the model that excludes regime-switching features. In addition, the out-of-sample forecast evaluation results suggest that the fit of the regime-switching models is possibly superior to that of the model that excludes these features.

## 6.2 Policy implications

Several important policy considerations can be drawn from the three investigations in this study. Our findings show high persistence in headline inflation in recent samples and evidence of asymmetric persistence in the different inflation quantiles. In addition, the results show that the core inflation rate (Core-UBOS) might not be the most appropriate inflation rate to target, because it has a high degree of volatility. The monetary policy response may therefore be volatile, which could weaken the effectiveness of the inflation targeting monetary policy regime as a tool to anchor inflation expectations. The wavelet generated measures of core inflation (Core-Wavelet) could be an alternative, since it tracks headline inflation with greater precision and is less volatile. Lastly, to keep inflation under control, policy-makers in the central bank should constantly monitor inflation pressures, and proactively employ monetary policy tools to anchor inflation expectations, as measures of inflation show persistence in recent periods (after 2006).

The findings discussed in chapter four reaffirm the view that has been expressed by [Baldini et al. \(2015\)](#), that the application of DSGE models provide useful insights for quantitative macroeconomic analysis for LICs. The BoU could use these techniques in their macroeconomic management framework. Our findings suggest that, to reduce macroeconomic volatility, the central bank should consider formally including financial sector frictions in the monetary policy rule. Another policy implication that can be drawn from the results discussed in this chapter is that the central bank could consider adopting slightly more aggressive responses to changes in output and inflation, as this could decrease macroeconomic volatility and lead to a more favourable sacrifice ratio.

The findings covered in chapter five suggest that the incorporation of Markov-switching in these structural models may improve their out-of-sample fit and render them useful for forecasting. For example, regime switching models provide superior forecasts for inflation over the short-term. They also provide and superior forecasts of the interest rate over both the short- and long-term, superior output forecasts over the medium- to long-term. Therefore, policymakers at the BoU could consider including various MS-DSGE models in their suite of tools for quantitative monetary policy analysis and forecasting.

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# Appendix A

## Monetary policy and Financial Frictions in a Small Open-Economy model for Uganda

### A.1 Log-linearised model

1. Law of one price gap

$$\psi_{F,t} = q_t - (1 - \alpha) s_t \quad (\text{A.1})$$

2. Terms of trade

$$s_t - s_{t-1} = \pi_{F,t} - \pi_{H,t} \quad (\text{A.2})$$

3. Change in the nominal exchange rate

$$\Delta e_t = q_t - q_{t-1} + \pi_t - \pi_t^* \quad (\text{A.3})$$

4. Uncovered interest rate parity condition

$$E_t q_{t+1} - q_t = (R_t - E_t \pi_{t+1}) - (R_t^* - E_t \pi_{t+1}^*) + \phi_{uip} a_t + \varepsilon_t^{rp} \quad (\text{A.4})$$

5. Flow budget constraint

$$c_t + a_t = \beta^{-1} a_{t-1} - \alpha (s_t + \psi_{F,t}) + y_t \quad (\text{A.5})$$

6. Domestic price inflation

$$\pi_{H,t} = \delta_H \pi_{H,t-1} + \theta_H^{-1} (1 - \theta_H) (1 - \beta \theta_H) m c_t + \beta E_t (\pi_{H,t+1} - \delta_H \pi_{H,t}) \quad (\text{A.6})$$

7. Firms marginal cost

$$mc_t = \frac{\sigma}{1 - h_\tau} (c_t^\tau - h_\tau c_{t-1}^\tau) + \varphi y_t + \alpha s_t - (1 + \varphi) z_t \quad (\text{A.7})$$

8. Import price inflation

$$\pi_{F,t} = \delta_F \pi_{F,t-1} + \theta_F^{-1} (1 - \theta_F) (1 - \beta \theta_F) \psi_{F,t} + \beta E_t (\pi_{F,t+1} - \delta_F \pi_{F,t}) + \varepsilon_t^{cp} \quad (\text{A.8})$$

where,  $\varepsilon_{c,p}$  is the cost-push shock that evolves as an AR(1) process.

9. Domestic CPI inflation

$$\pi_t = (1 - \alpha) \pi_{H,t} + \alpha \pi_{F,t} \quad (\text{A.9})$$

10. Consumption Euler Equation

$$c_t^\tau = \frac{1}{1 + h_\tau} E_t (c_{t+1}^\tau) + \frac{h_\tau}{1 + h_\tau} c_{t-1}^\tau - \frac{1 - h_\tau}{\sigma_\tau (1 + h_\tau)} (R_t - E_t \pi_{t+1} - \varepsilon_t^c) \quad (\text{A.10})$$

where  $\varepsilon^c$  is the exogenous demand shock, whose natural logarithm evolves as an AR(1) process, and  $\tau \in [b, s]$ .

11. Goods market clearing

$$(1 - \alpha) c_t = y_t - \alpha \eta (2 - \alpha) s_t - \alpha \eta \psi_t - \alpha y_t^* \quad (\text{A.11})$$

12. Borrowing

$$l_t = \lambda_r (R_{t-1} - \pi_t) + \lambda_y y_t + \lambda_\Omega \Omega + \lambda_\omega \omega_t + \lambda_b (l_{t-1} + \omega_{t-1}) \\ + \lambda_\xi [\pi_b (1 - \pi_b) \eta_t^c - s_\Omega \bar{\sigma}^{-1} (g_t + \chi_t)] \quad (\text{A.12})$$

13. Lending rate:

$$R_t^b = R_t + \omega_t \quad (\text{A.13})$$

14. Lending spread

$$\omega_t = \omega^{-1} [(1 + \eta_\chi) \chi_t^{\eta_\chi}] (\chi_t + \eta_\chi l_t) \quad (\text{A.14})$$

15. Non-performing loans

$$\chi_t = \rho_\chi \chi_{t-1} - \theta_\chi y_t + \eta_t^\chi \quad (\text{A.15})$$

16. Monetary policy rule

$$R_t = \rho_R R_{t-1} + (1 - \rho_R) [\rho_\pi \pi_t + \rho_y y_t + \rho_e e_t + \rho_\omega \omega] + \varepsilon_t^R \quad (\text{A.16})$$

17. Government spending

$$g_t = \rho_g g_{t-1} + \eta_t^g \quad (\text{A.17})$$

18. Foreign Output

$$y_t^* = \rho_{y^*} y_{t-1}^* + \eta_t^{y^*} \quad (\text{A.18})$$

19. Foreign Inflation

$$\pi_t^* = \rho_{\pi^*} \pi_{t-1}^* + \eta_t^{\pi^*} \quad (\text{A.19})$$

20. Foreign Interest Rate

$$R^* = \rho_{R^*} R_{t-1}^* + \eta_t^{R^*} \quad (\text{A.20})$$

21. Risk premium shock

$$\varepsilon_t^{rp} = \rho_{\varepsilon_t^{rp}} \varepsilon_{t-1}^{rp} + \eta_t^{rp} \quad (\text{A.21})$$

22. Cost-push shock

$$\varepsilon_t^{cp} = \rho_{\varepsilon_t^{cp}} \varepsilon_{t-1}^{cp} + \eta_t^{cp} \quad (\text{A.22})$$

23. Preference shock

$$\varepsilon_t^c = \rho_{\varepsilon_t^c} \varepsilon_{t-1}^c + \eta_t^c \quad (\text{A.23})$$

24. Technology shock

$$z_t = \rho_{z_t} z_{t-1} + \eta_t^z \quad (\text{A.24})$$

25. Interest rate spread shock

$$\varepsilon_t^x = \rho_{\varepsilon_t^x} \varepsilon_{t-1}^x + \eta_t^x \quad (\text{A.25})$$

Figure A.1: Prior and posterior density plots

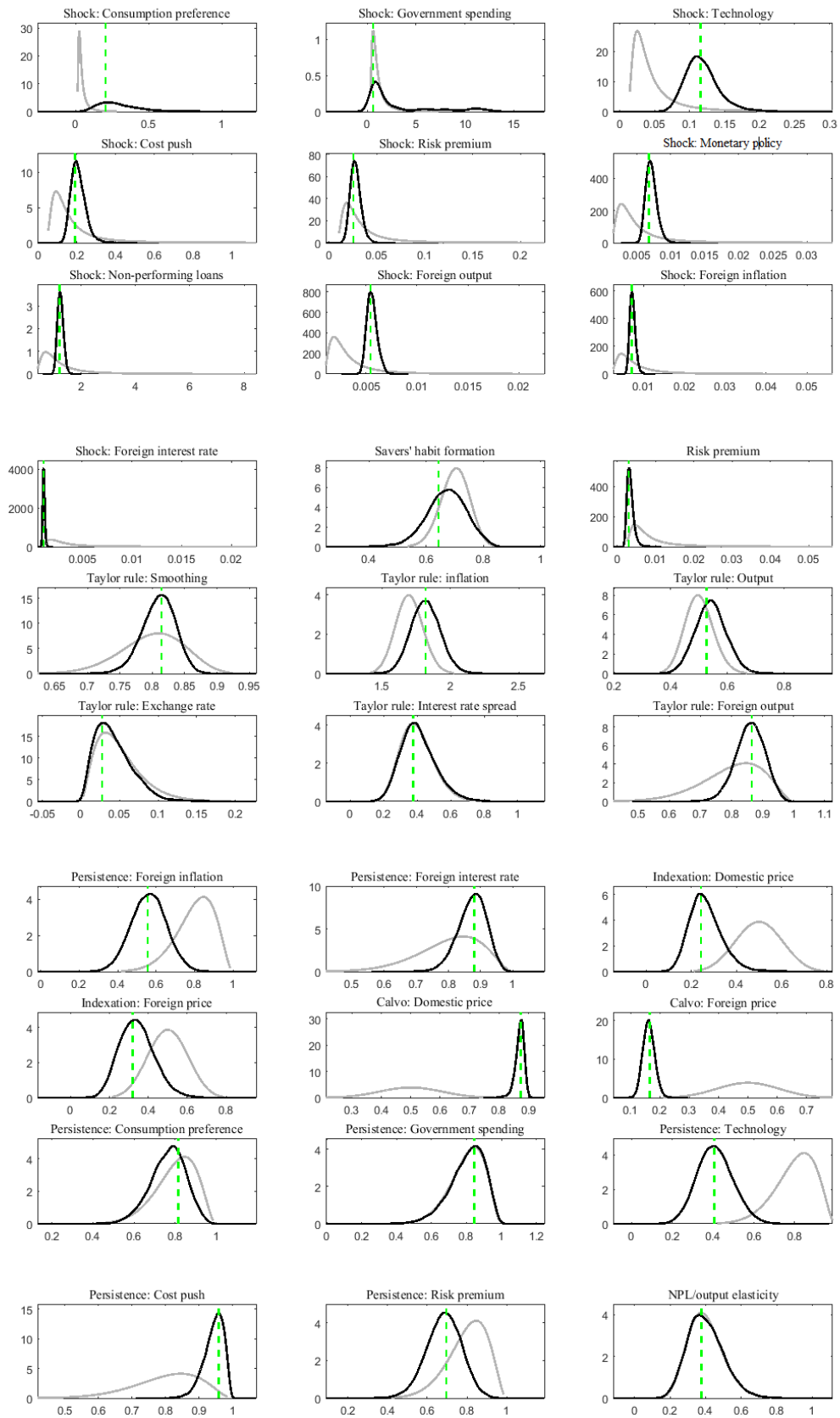


Figure A.2: MCMC multivariate diagnostics.

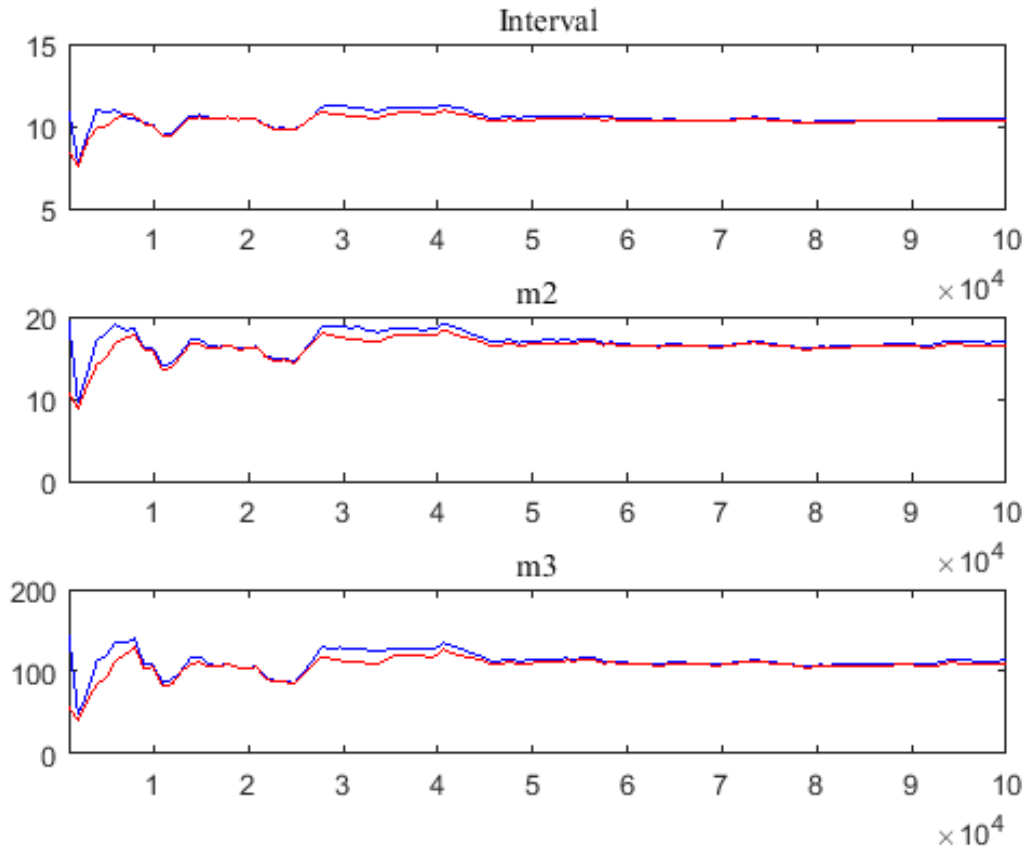


Figure A.3: Bayesian impulse response of a monetary policy shock with financial frictions

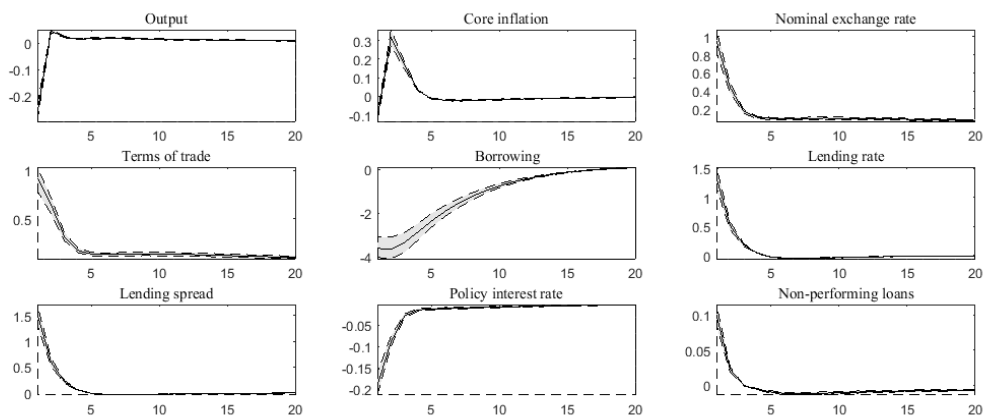


Figure A.4: Bayesian impulse response functions of a monetary policy shock without financial frictions

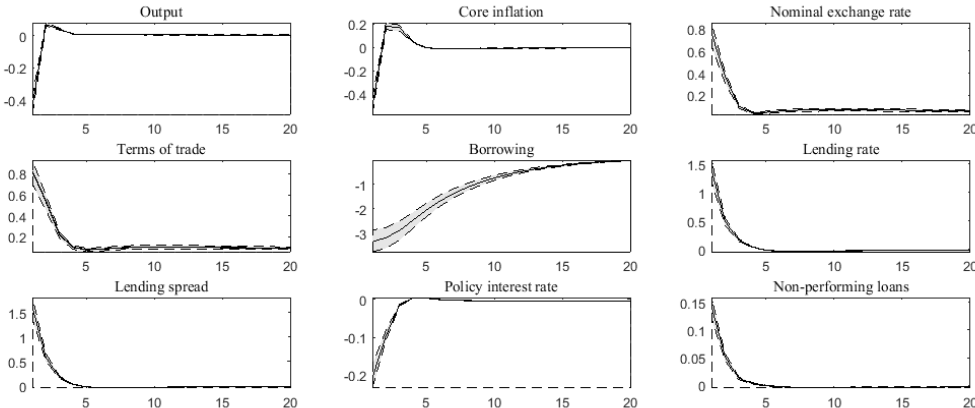
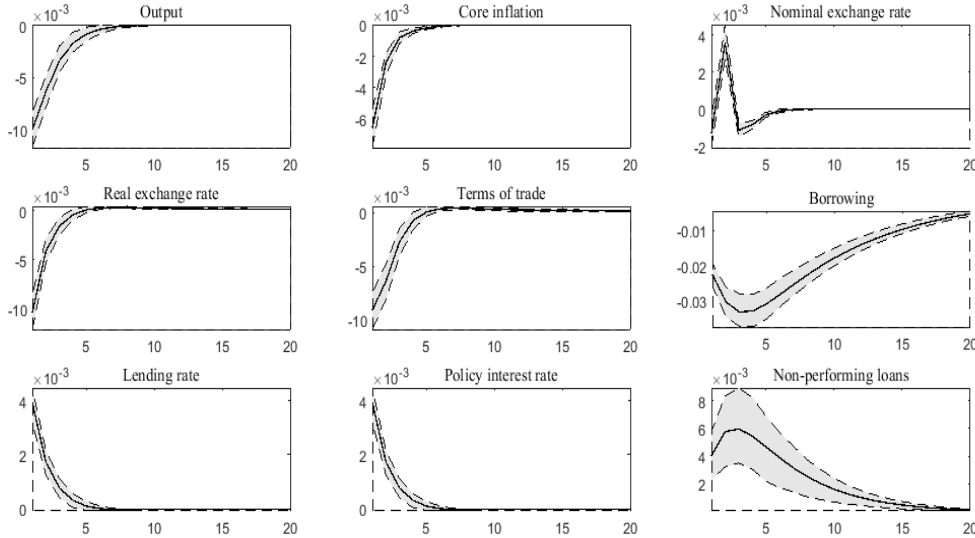


Figure A.5: Bayesian impulse response of a monetary policy shock



Note: The solid line corresponds to the mean values of the posterior distribution, and the dashed lines correspond to the 90% confidence interval.

Figure A.6: Output decomposition

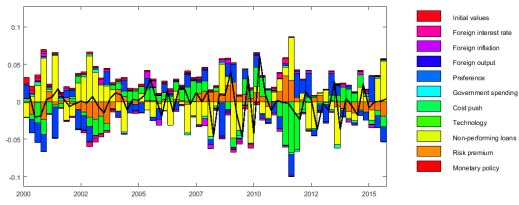


Figure A.7: Inflation decomposition

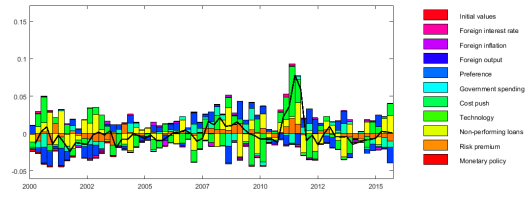


Figure A.8: Nominal exchange rate decomposition

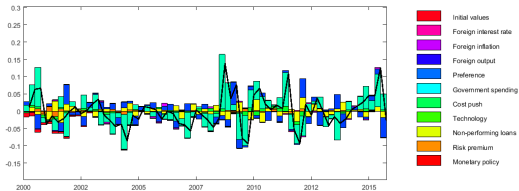


Figure A.9: Real exchange rate decomposition

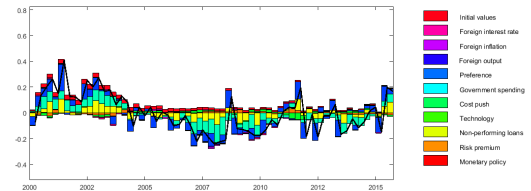


Figure A.10: Terms of trade decomposition

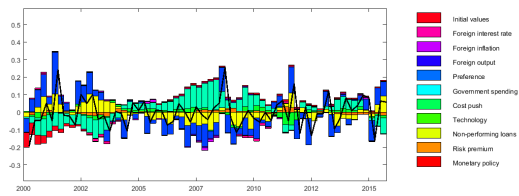


Figure A.11: Policy rate decomposition

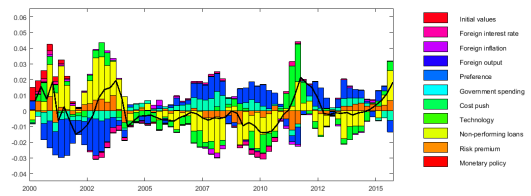


Figure A.12: Lending rate decomposition

