Monetary Policy and Macroeconomic Stabilization:

An Application of New Keynesian Framework for Forecasting and Policy Analysis in Ghana

By

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ABSTRACT

The role of monetary policy in macroeconomic stabilization remains an important research focus for central banks, particularly in frontier and developing economies where the institutional structure are not quite complete, integration with the world economy is partial and also just at the beginning of a process of growth and transformation. These economies are also confronted with relatively large and recurrent correlated shocks entirely different from their developed counterparts. Notwithstanding, there is paucity of studies on monetary policy making in frontier and developing economies as the bulk of the literature has concentrated on either advanced economies or emerging markets where there is stable institutional structure and relatively predictable economic linkages. One of such leading frontier markets is Ghana. The West African nation became the 28th economy in the world but second Africa country after South Africa to officially opt for inflation targeting framework of monetary policy in May 2007. Regardless of the well-formulated price stability objective and operational independence clearly preserved in the Bank of Ghana (BOG) Acts 2002 (Act 612) after the adoption of inflation targeting regime, inflationary pressures have lingered over the years in Ghana. Without a doubt, Ghana's consumer price inflation has been among the highest in sub-Saharan African economies, and the inflationary developments are often linked to large internal and external aggregate demand and supply-side shocks. The BOG has over the years adopted different policy stance in an attempt to steer inflation towards its medium term target of 8±2 percent, and hence, to ensure overall macroeconomic stability. The disinflationary process has often been short-lived, triggering controversy in policy and academic discourses regarding the appropriateness of the current monetary policy regime in Ghana. At the same time, some fast pace of GDP growth has recently been recorded, placing Ghana among the fastest growing economies in Africa. In the midst of these uneven macroeconomic outcomes, it is of paramount interest to comprehend the effectiveness and the dominant channel of monetary policy transmission mechanism in Ghana. Also given the fact that BOG currently follows a certain policy rule, it is necessary to ascertain how BOG has reacted to macroeconomic shocks over the years. Furthermore, available empirical literature is inconclusive on the extent of the policy pass-through (i.e. via interest rate) to the real economy in Ghana amid large segment of unbanked population (i.e. non-Ricardian consumers) and continuous fragile fiscal profile. Besides, the New Keynesian framework for monetary policy analysis and forecasting adopted in frontier and developing economies still follows the representative agents' approach - which assumes that all households have complete access to the financial system and hence, able to smooth consumption - even though a large segment of the population face acute financial constraints and are thus "hand-to-mouth" consumers. Given the pace

of financial integration and international trade dynamics, evidence of shock transmission and interdependence of macroeconomic variables could provide meaningful suggestions for monetary policy implementation in a small but highly opened economy like Ghana with underdeveloped financial market. This thesis addresses these gaps inherent in extant literature and offers empirical solutions for the Ghanaian case by investigating the monetary and business cycle dynamics, exploring interdependence (spillovers) between policy instruments and targeted macroeconomic variables, estimating monetary policy reaction function, developing a New Keynesian DSGE framework with and without non-Ricardian consumers for monetary policy forecasting and analysis as well as for consumption effects of monetary and fiscal policies.

On a whole, the thesis is methodically organized into six essential and interrelated empirical chapters, each significantly touching on peculiar theme(s) that form the crux of the problems or research questions on monetary policy and macroeconomic stability while employing advanced macroeconometric techniques and models that underpin monetary policy transmission mechanism in a leading frontier market, Ghana. The first four empirical chapters of the thesis judiciously use empirical macroeconometric methods to investigate four aspects of monetary policy making in Ghana. In particular, the first empirical chapter focuses mainly on the institutional and practical architecture of the current monetary policy framework in Ghana. In a sense, it comprehensively explores the level of transparency, accountability and credibility of Bank of Ghana, following much of the literature. The salient finding is that monetary policy framework is consistent with inflation forecast targeting and exhibits moderate levels of policy transparency and credibility. The second empirical chapter investigates the macroeconomic benefits of inflation targeting strategy in Ghana using business cycle analysis and standard econometric methods. This chapter shows significant interconnectedness with business cycle and that the inflation targeting strategy has been broadly beneficial in Ghana compare to the previous policy regimes. The third empirical chapter investigates monetary policy transmission mechanism and its overall effectiveness with particular focus on the macroeconomic interdependence or volatility spillovers among money market interest rate on one hand and among the policy (interest) rate, exchange rate and the real sector (i.e. inflation and output gap) on the other hand, over time and in multiscale domain. Using appropriate models such as three-dimensional continuous Morlet wavelet coherency technique, parametric and nonparametric Granger non-causality tests, as well as the generalized forecast error variance decomposition (GFEVD) methods, the chapter mainly suggests moderate levels of interconnectedness among money market interest rates across time and multiscale domains in Ghana. The third empirical chapter further reveals that the degree of interdependence

among the policy interest rate, exchange rate and the real macro-variables are scale-dependent, as strong interlinkages are observed at the longer time-scale. The fourth empirical chapter looks at macroeconomic policy reaction functions with the view to determining monetary policy preference across economic cycles and political regimes in Ghana using generalized least squares and quantile regression methods. The basic finding of the fourth empirical chapter is a clear evidence of an asymmetric monetary policy rule with vivid vacillation in the key policy parameters across business cycles and time, strong interest rate inertia and weak evidence of heterogeneous policy preference in different political regimes, surmising the exercise of monetary policy independence. Together, the findings of the preceding four chapter form the basis for the development of small-open economy general equilibrium model in the subsequent two empirical chapters. Notably, the fifth empirical chapter develops and estimates a small-open economy New Keynesian general equilibrium model with representative agent (i.e. RANK) for monetary policy analysis in Ghana. It empirically tests the RANK model with the view to analyzing and determining the optimal monetary policy rule for Ghana. The salient finding is that forward-looking monetary policy rule is optimal for Ghana. However, the impulse response function demonstrated that model is prone to price puzzle. Given the large proportion of unbanked population in Ghana, we further extend the analysis of the preceding chapter to accommodate heterogeneous household behaviour. Accordingly, the sixth empirical chapter develops a small-open economy New Keynesian general equilibrium model with heterogeneous agent (i.e. HANK) with the view to exploring the implications of the inclusion of non-Ricardian households on monetary and fiscal policy transmissions in Ghana. Thus, the empirical chapter six assesses the relative suitability of the HANK model for monetary policy analysis in Ghana. Though the findings corroborate the earlier support for forward-looking monetary policy rule for Ghana, the HANK model in chapter six rather generates meaningful impulse response functions and hence, more suitable for monetary policy investigations in Ghana.

Collectively, the findings of the thesis provide new and unique perspectives that extend current understanding of the monetary policy framework and its interconnectedness with the real sector within a frontier or developing economy saddled with underdeveloped financial markets as well as heterogeneous economic agents.

Keywords: Monetary policy, Transmission Mechanism, New Keynesian, Volatility Spillovers, Structural Shocks, Taylor Rule, Stabilisation, Fiscal Policy, Crowding-Out, DSGE, Heterogeneous Agents, Bayesian, Ghana.

JEL Classification: *B41, C5, C11, D11, D21, D41, D42, E2, E12, E43, E52, E58, F31, F41*.

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DECLARATION

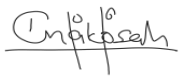
I, ***Nana Kwame Akosah***, hereby declare that this research report is my own work, except as indicated in the references and acknowledgements. It is submitted in fulfilment of the requirements for the award of Doctor of Philosophy degree in the field of Economics at the University of Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination in this or any other university.

Nana Kwame Akosah

Doctoral Research Candidate

November 9, 2020

Date



Signature

DEDICATION

To Victoria Acquaisie Danso-Sarpong, Dyamond Nana Adomah Danso-Sarpong, Ethan Akosah Danso-Sarpong, Eloy Akosah Danso-Sarpong & Elysa Nana Agyeiwaa Danso-Sarpong.

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List of Abbreviations

Abbreviation	Meaning
ADF	Augmented Dickey-Fuller
AIC	Akaike Information Criterion
AR	Autoregression
AWM	Area Wide Model
BML	Bayesian Maximum Likelihood
BOG	Bank of Ghana
BP	Band Pass
BQ	Bayesian Quantile
BVAR	Bayesian Vector Autoregression
CA	Current Account
CB	Central Bank
CER	Real Exchange Rate
CI	Credible Interval
CPI	Consumer Price Index
CTO	Contribution to Others
DAZ	Density around Zero
DCR	Direct Control Regime
DSGE	Dynamic Stochastic General Equilibrium
DW	Durbin-Watson
ECB	European Central Bank
EDO	Estimated Dynamic Optimization
E_GDDS	Enhanced General Data Dissemination System
ERP	Economic Recovery Programme
FC	Foreign Currency
FD	First Difference
FINSAP	Financial Sector Adjustment Program
FOC	First Order Conditions
FPAS	Forecasting and Policy Analysis System
FQ	Frequentist Quantile

FX	Foreign Exchange
G	Government
GDP	Gross Domestic Product
GFC	Global Financial Crises
GFEVD	Generalized Forecast Error Variance Decomposition
GMM	Generalised Method of Moments
GSS	Ghana Statistical Services
HAC	Heteroskedasticity Autocorrelation Consistent
HANK	Heterogeneous Agent's New Keynesian
HIPC	Highly Indebted Poor Countries
HP	Hodrick-Prescott
ICBF	Increasing central bank financing
IMF	International Monetary Fund
INFGAP	Inflation Gap
IFT	Inflation Forecasting Targeting
IT	Inflation Targeting
ITL	Inflation Targeting Lite
KF	Kalman Filter
KPSS	Kwiatkowski-Philips-Schmidt-Shin
LENDR	Average Lending Rate
LHS	Left Hand Side
LL	Log-Linear
LOOP	Law of One Price
LQ	Log-Quadratic
MA	Moving Average
MC	Marginal Cost
MCMC	Markov Chain Monte Carlo
MH	Metropolis-Hastings
WMC	Wavelet Multiple Correlation
WMCC	Wavelet Multiple Cross Correlation
MOFEP	Ministry of Finance and Economic Planning
MODWT	Maximal Overlap Discrete Wavelet Transforms

MPC	Monetary Policy Committee
MPIP	Marginal Posterior Inclusion Probability
MPR	Monetary Policy Rate
MPRF	Monetary Policy Reaction Function
MPTM	Monetary Policy Transmission Mechanism
MTR	Money (or Monetary) Targeting Regime
M2+	Broad Money Plus
NINFGAP	Negative Inflation Gap
NK	New Keynesian
NNS	New Neoclassical Synthesis
NPLs	Non-Performing Loans
NS	Net Spillovers
NSDP	National Summary Data Page
NYGAP	Negative Output Gap
OAC	Overall Average Contribution
OLG	Overlapping Generational
OLS	Ordinary Least Squares
PIH	Permanent Income Hypothesis
PCA	Principal Component Analysis
PINFGAP	Positive Inflation Gap
PP	Philips and Perron
PR	Political Regime
PSC	Private Sector Credit
PYGAP	Positive Output Gap
Q&A	Questions and Answers
QPM	Quarterly Projection Model
RANK	Representative Agent's New Keynesian
RBC	Real Business Cycles
REH	Ricardian Equivalence Hypothesis
RER	Real Exchange Rate
RHS	Right Hand Side
ROT	Rule-of-thumb

SDR	Saving Deposits Rate
SOE	Small Open Economy
SAP	Structural Adjustment Programme
SEFD	Summary of Economic and Financial Data
SSA	Sub-Saharan Africa
SSNK	Semi-Structured New Keynesian
TBILL	91-day Treasury Bill Rate
TEFC	Tighter external financing conditions
TEN	Tweneboa, Enyenra, Ntomme
ToTEM	Terms-of-Trade Economic Model
TPP	Transparency about Policy Processes
TSTL	Two Stage Least Squares
T-Y	Toda-Yamamoto
UIP	Uncovered Interest Parity
UNCTAD	United Nations Conference on Trade And Development
VAR	Vector Autoregression
VECM	Vector Error Correction Model
XDEP	Nominal Exchange Rate Depreciation
YGAP	Output Gap
1SBQ	One-Stage Bayesian Quantile
2SBQ	Two-Stage Bayesian Quantile

CHAPTER ONE

General Introduction

1.0 Background to the thesis

The primary objective of monetary policy across the globe is the maintenance and achievement of low and stable inflation, while keeping output at potential level. Certainly, both academics and policymakers generally concur, based on experience and strong empirical evidence, that high inflation and its associated high volatility distort the decision-making process of private agents regarding investment, consumption/savings, production and eventually result in sluggish economic growth (Croce and Khan, 2000; Purwanda and Rochana, 2017). To attain this policy goal, monetary policy provides a "nominal anchor" to the economy by stabilizing the business cycle during booms and bolstering it during downturns using policy instruments which are perceived to have adequate impact on both price and economic activity. For that reason, many central banks in developed, emerging and developing economies have shifted to inflation targeting (IT) framework since the late 1980s, with the short-term nominal interest rate as the main policy instrument, following the failure of the previous monetary framework (such as currency peg and monetary targeting regimes) to successfully rein in inflation. The nominal anchor for the IT framework is the inflation target communicated to the public. The central preconditions of IT regime are the primary objective of price stability, the announcement of numerical value for medium-term inflation target, monetary policy based on extensive information delivery and greater transparency of central bank's activities. The last two elements is regarded as a component underpinning a wide-ranging autonomy bestowed to central banks in recent decades[1]. In the IT framework, monetary policy is designed to target inflation through an inflation forecast (intermediate target as there are lags in the monetary transmission mechanism). And given that the inflation forecast is a function of many macroeconomic variables, policy reacts to a whole range of variables based on the premise that inflation is not solely a monetary phenomenon, but other factors do influence prices.

The theoretical underpinning of the IT framework is the recognition that a change in policy interest rate induces a number of mechanisms and heterogeneous reactions of agents in different sectors in the short run. This will ultimately affect aggregate economic variables such as output or prices via a process called the monetary policy transmission mechanism (MPTM). The crux of interest rate

[1] The core operation of central bank practicing IT strategy is comparable in many ways such as the preference for flexible exchange rate regime, disclosure of medium-term inflation and GDP forecasts to the public, or importance given to monetary policy communication and transparency. All the same, some notable differences exist across central banks particularly with respect to how inflation target is defined or how their levels are set.

transmission mechanism is thus the weight on the long-term real (instead of nominal short-term) interest rate as the main conduit of influence on consumer and business decisions. In view of this, the expectations of future short-term official interest-rate changes also influence medium and long-term interest rates (Beyer, Nicoletti, Papadopoulou and Others, 2017). This is because longer-term interest rates depend partly on market expectations about the future course of short-term rates. Therefore, monetary policy can also guide economic agents' expectations of future long term interest rate and thus influence current investment and consumption decisions and hence price developments. The direct interest rate channel via the user cost of capital is a standard feature of large scale macroeconometric model used for forecasting and policy analysis (FPAS) in the FRB/US model at the US Federal Reserve (Reifschneider, Tetlow and Williams, 1999), ECB's Area Wide Model (Fagan, Henry and Mestre, 2005) and Bank of England's Quarterly Model (Harrison et al, 2005).

However, this transmission channel is not without criticism. For instance, Bernanke and Gertler (1995) argued that empirical researches have struggled to establish quantitatively significant effects of interest rate via cost of capital. Besides, the monetarists object to this traditional channel with the view that it focuses only on one asset price, the interest rate, rather than on many asset prices (see, Meltzer 1995). This empirical failure of interest rate channel ignited the search for other channels of monetary policy transmission. But macroeconomic theory clearly illustrates that interest rate channel does not work in isolation but wrap around other channel of transmissions, such as the consumption-based channels, equity price channel, international-trade based channel and credit channel.

Theoretically, an increase in interest rate by monetary authority increases the returns on domestic assets relative to foreign assets, resulting in inflows of foreign capital and hence appreciated domestic currency. The higher value of domestic currency makes domestic goods expensive than foreign goods, leading to expenditure switching in favour of foreign goods with an adverse consequence on net exports and aggregate demand. The opposite is equally true for monetary policy easing. On the other hand, changes in the exchange rate can directly affect inflation, if imported goods are directly used in consumption. Nevertheless, the literature clearly posits that the effectiveness of the exchange rate channel depends on the degree to which exchange rate is sensitive to interest rate movements. For instance, studies such as Bryant, Hooper and Mann (1993), Taylor (1993) and Smets (1995) found the effects of the exchange rate channel to be larger for smaller but more open economies.

Another prominent channel in the literature is the "non-neoclassical transmission mechanism" or "credit view" (see, Boivin et al. 2010) that arise due to market imperfections other than those related to nominal wage and price rigidities. In general, banks play a very critical role in the financial system

as they cope well with the problem of information asymmetry in the credit market. Indeed, certain borrowers will not have access to credit market unless they borrow from banks. Given that there is no perfect substitute for bank deposits with other sources of funds, the traditional bank lending (or credit) channel of monetary policy transmission operates as follows. Contractionary monetary policy (for instance, an increase in reserves requirement) reduces bank reserves and deposits, leading to a decline in the size of bank loans available. This induces decline in investment and consumption spending since many borrowers depend on bank credit, thereby reflecting a fall of aggregate output. The convex is also true for monetary easing. But, this dynamics will be more prevalent with the smaller firms that are heavily dependent on bank credit than larger firms that can easily raise capital via the stock market. Yet, the practical relevance of the traditional bank lending channel remains unsettled in the literature, as diverse viewpoints have been raised by Romer and Romer (1989), Gertler and Gilchrist (1993, 1994), Edwards and Mishkin (1995), Lown and Morgan (2002) and, Iacoviello and Minetti (2008), Mishkin (2008)[2], and Gertler and Kiyotaki (2010).

The foregoing discussion clearly demonstrates that central banks, especially in frontier and developing economies, make policy decisions in environments of substantial and inescapable uncertainties (see Issing, 2002; Greenspan 2003; Feldstein, 2003) amid inadequate practical knowledge of monetary policy transmission mechanism (Mahadeva and Sinclair, 2001). It also reflects that monetary policy is limited in scope regarding what variables the central bank can directly control and to what extent, and the period with which the impact of monetary policy will last. The uncertain policy environment is driven by data flaws and delays (a protracted policy transmission lag), complexity in measuring the reactions of the economy to supply and demand shocks, continuous arrival of new shocks, structural changes and inaccurate estimation of the transmission channel from the policy instruments to the objectives. In addition, a number of critical monetary policy questions have remained unresolved especially when the official interest rate is changed. These include; by how much is inflation affected, and when; whether output is affected in the short-run and through which channel does this happen?

This notwithstanding, momentous theoretical and empirical advances have been made to enhance the understanding and effectiveness of monetary policy transmission[3]. The most outstanding perhaps is the recent generation of New Keynesian (NK) or Neoclassical Synthesis (NS) models since the 1980s which have become increasingly popular and standard workhorse models in monetary policy analysis (see, Goodfriend and King, 1997; Rotemberg and Woodford, 1997; Clarida et al., 1999; Woodford,

[2] The importance of bank lending channel in the recent global financial crisis has been emphasized by policymakers and popular accounts.
[3]See Almeida (2009) for detailed advances in literature.

2003). The NK models combine forward-looking and micro-founded dynamic stochastic general equilibrium (henceforth DSGE) with the assumption of monopolistic competition, nominal and real rigidities, alongside a set of random disturbances. Particularly, the methodological advances in NK-DSGE models have convincingly offered cogent answers to relevant policy questions in open macroeconomics (Uribe and Schmitt-Grohe, 2017), spreading their application from academia to policy-making institutions[4]. The NK-DSGE models are thus one of the most exciting and opportune fields in contemporary macroeconometric research. Unambiguously, the literature is mostly conclusive that the existing alternatives of the NK-DSGE models with sufficient amount of market rigidities (nominal and real) and relatively large amount of shocks have enriched their forecasting potential and have even outclassed most other multivariate models, especially when applied to macroeconomic data of advanced economies (see, Smets and Wouters, 2002). This notwithstanding, the suitability of these models in terms of forecasting performance in the case of developing and emerging economies has been fairly diverse. More so, while inflation stabilization was greatly accomplished in many inflation targeting (IT) countries, the recent global financial crisis and the "great recession" presented a massive challenge for monetary policy. The crisis revealed serious gaps in central banks' ability to accurately define, measure and manage financial sector activities that pose risks to the macroeconomy as a whole. It is also widely assented that the IT central banks generally did not anticipate the ballooning risks to financial systems that eventually exploded. Neither were they able to fully alleviate the knock-on effects on economic activity (Williams, 2014) and international contagion.

1.1 Motivation of the Thesis

Formal monetary policy in Ghana started with the introduction of credit control regulations in April 1964 following the promulgation of the Bank of Ghana Act 1963. This steered the epoch of monetary policy through direct controls[5] that was to last through the 1980s (Bawumia, 2010). The preference for the direct control regime at the time was largely due to governments' perception that it was more reliable, at least initially, in controlling credit aggregates or both the distribution and the cost of credit. As a result, the period was characterised by strict controls on interest rates, credit ceiling and directed lending at the behest of the authorities rather than for commercial reasons, as well as capital and exchange rate controls. However, rapid growth in monetary aggregates resulted in accelerated and volatile inflation in the late 1960s through to the early 1980s (see Figure 1.1). Monetary expansion

[4] The NK-DSGE models have been widely embraced by most central banks (particularly in inflation targeting (IT) economies) and the other large institutions such as the International Monetary Fund (IMF) for the conduct of policy analysis as well as systematic and consistent forecasts since the late 1980s.

[5]Direct controls refer to the one-to-one correspondence between the instrument (such as a credit ceiling) and the policy objective (such as specific amount of domestic credit outstanding). Direct instruments operate by setting or limiting either prices (interest rates) or quantities (amounts of credit outstanding) through regulation.

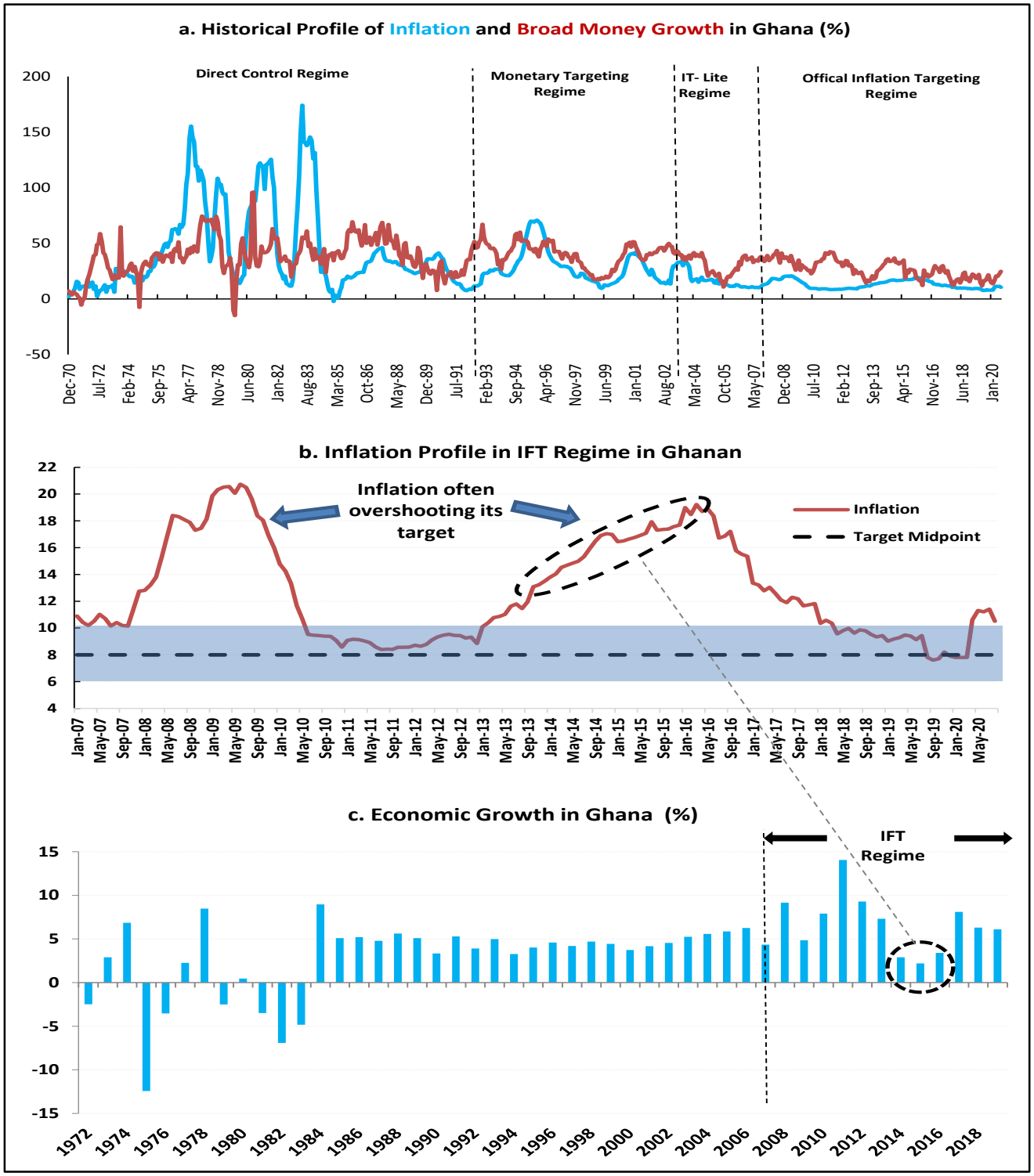
during the period was triggered by incessant monetary accommodation of fiscal expansion fuelled by significant political interference in the operations of the central bank (Ayensu, 2007). The monetary situation continued to worsen and inflation reached triple-digit by 1983[6] with attendant economic decline. This resulted in the implementation of a comprehensive stabilization programme (namely, Economic Recovery Programme, ERP), following a consultation with the IMF and the World Bank by October 1983. A key component of the program was the financial sector reforms (Financial Sector Adjustment Program, FINSAP)[7].

The FINSAP led to the era of Monetary Targeting Regime (i.e. MTR) which reflected the policy shift from credit ceilings, directed credit and credit controls towards the use of market-driven monetary policy instruments as well as the development of the money and capital markets. The MTR focuses on the growth rate of a chosen monetary aggregate based on the idea that inflation is everywhere a monetary phenomenon. This is grounded on the finding that in the long term, price growth is affected by money supply growth. Therefore, policy under MTR was designed to control broad money supply using growth in monetary aggregates (such as cash reserve requirement, growth in narrow money or high powered money, etc.) as intermediate targets. These market oriented programs led to a more dynamic financial system which encouraged rapid expansion of banking activities (Kovanen, 2011). However, the increasing pace of financial innovation, market computerization and globalisation also weakened the relationship between monetary aggregates and the price level (see Figure 1.1 for the seeming divergent movements in inflation and broad money growth especially from 2001). Although, the policy initiatives under FINSAP were envisioned to translate into improved monetary policy transmission mechanism, the general consensus was that inertia in inflation expectations became strongly embedded in the economy due to high inflation and acute exchange rate volatility. It was also asserted that fiscal dominance was undermining the effectiveness of monetary policy in Ghana, as persistent fiscal deficits were financed by monetary accommodation. In the midst of embedded inflation inertia, policy makers perceived that the MTR was not an appropriate framework for the achievement of price stability objective.

[6]Ghana recorded its highest inflation rate of 123% in 1983.

[7]FINSAP included the liberalization of interest rates and abolition of directed credit, restructuring of financially distressed banks, strengthening of the regulatory and supervisory framework, the establishment of the Ghana Stock Exchange (GSE), and promotion of non-bank financial institutions. The foreign exchange market also witnessed progressive reforms, culminating in the floating of the exchange rate and the establishment of forex bureaus to help eliminate the parallel markets.

Figure 1.1: Inflation, money supply and economic growth dynamics in Ghana



Source: Author's construct based on data from Bank of Ghana & Ghana Statistical Service.

In view of the lingering challenges, a second wave of financial sector reforms was launched in 2001, mainly to address regulatory impediments and its associated corporate governance issues. This reflected the passage of several laws which enhanced the institutional architecture of the financial system. Perhaps, the most significant landmark was the promulgation of the Bank of Ghana Act, 2002,

Act (612), which granted operational independence to Bank of Ghana and also established the Monetary Policy Committee (MPC) with the responsibility of formulation and implementation of monetary policy. Upon its inauguration in September 2002, the MPC began the processes that would eventually lead to the formal adoption of Inflation Targeting (IT) as a framework of monetary policy in May 2007[8].

The policy shift made Ghana the second African country (after South Africa) but the first developing economy in the world to fully adopt IT strategy. Like other IT central banks, the main policy instrument utilized by the BOG is the policy interest rate (known as the monetary policy rate, henceforth, MPR), while the operating target is the overnight money market interest rate (Interbank rate). And 'ultimate' intermediate target is the inflation forecast. The MPR thus signals the stance of monetary policy and anchors short-term market interest rates to achieve the primary objective of price stability (www.bog.gov.gh/monetary-policy). The MPR is the rate around which a policy corridor is defined for central bank's acceptance of deposit and granting of credit to commercial banks, reflecting a limited importance on monetary aggregates. However, for the monetary policy to have the desired impact on inflation (the prime objective) and the overall economy, it is critical that changes in policy interest rate affect the short run wholesale interest rate (e.g. overnight interbank rate) which in turn translates into changes in retail interest rates (e.g. lending and deposit rates) and ultimately influence the overall macroeconomy and inflation.

The broad consensus, however, is that the IT regime has generally improved inflation management in Ghana (see, Kyereboah-Coleman, 2014). Clearly, annual inflation has reduced remarkably to about 18% in the IT-lite regime (2002-2006) and further plummeted to an average of 13% over the period 2007-2019. Even though inflation appears to have broadly declined during the IT regime compared to the previous monetary policy framework, the Bank has struggled to successfully bring actual inflation (and inflation expectation) to the medium-term target of 8±2%. In fact, the Bank has only managed to tame inflation within the medium-term target in three (3) out of almost fifteen (15) years of official practice of IT strategy (2007-2020), raising fundamental concerns in policy cycles. The high and persistent inflation above the medium-target target band seems to run counter to the assertion that temporary price shocks should have less persistent effects on inflation if the formulation of monetary policy changes after the adoption of inflation targeting in such a way that the emphasis on fighting inflation increases (Kuttner and Posen 1999). The elevated inflation persistence would similarly

[8]While some authors refer to the official announcement to date the adoption of IT (see Kwakye, 2012), we support the position of Bawumia et al. (2008) that even though formal announcement was made in May 2007, Inflation Targeting was launched in the latter part of 2002.

indicate that the monetary policy credibility has not improved in Ghana and that inflation expectations are still backward-looking after the introduction of IT framework.

Unequivocally, Figures 1.1b & 1.1c give the impression that the inflation reduction program via the IT strategy has frequently been thumped by large domestic and external shocks (predominantly supply-side). These predominant and recurrent supply-side shocks concurrently generate output contraction and rising consumer prices, a serious policy quandary for the monetary authority in Ghana. The recurrent large macroeconomic shocks have reflected in frequent overshooting of inflation above the medium-term target of 8±2 percent, and hence placing Ghana among the top ten African economies with highest inflation (see Appendix 1Ai). The seeming frequent supply-side shocks raises the concern of whether the current IT framework adopted in Ghana is appropriate in dealing with the persistence in inflation. This hinges on the extant literature that when an economy faces important and acute supply-side shocks, strict inflation targeting exacerbates the business cycle and not the other way round. Frankel, Smit and Sturzenegger (2006) argued that inflation targeting is fine, but any increases in the consumer inflation attributable to negative supply shocks or increases in dollar price of imports, should not induce monetary tightening to prevent prices from rising. But this depends on the central bank's policy preferences. This notion has ignited research interests in the effectiveness of monetary policy transmission and various papers have applied varieties of standard time-domain econometric techniques. Notable recent works on the interest rate transmission in Ghana including Kovaren (2011), Fukac and Baldini (2014) and Akosah (2015) have reported diverse findings on monetary policy effectiveness in Ghana.

The relative frequent and larger supply-side or cost-push shocks (compared to demand-side shock) are driven by inherent structural weaknesses that the central bank has limited control of. For instance, a major headwind for monetary authority in Ghana has been the perennial twin (i.e. fiscal and current account) deficits problem over the past two and half decades (see figures at Appendix 1Aii and 1Aiii) especially during periods of enervated global commodity prices (Appendix 1Aiv). In addition, the large external imbalances expose the economy to exchange rate risk and the implication of the latter is clearly exemplified via imported inflation due to the sizeable share of imported items in the CPI basket (26.3%). Also prevalent is the frequent upward adjustments of utilities, transport and petroleum products prices mostly triggered by the rapid depreciation of domestic currency and rising international crude oil prices. Besides, there is notable headwind from the shallow and underdeveloped financial sector which together with large non-banked segment of the population tends to have considerable defect on monetary policy transmission in Ghana. What's more, the retail lending interest rate has

remained persistently high, an indication of weaker policy pass-through to the real sector and this is thoroughly investigated in this thesis using more robust methods.

Concomitantly, it is conspicuous from Figure 1.1c that economic activities (i.e. real GDP growth)[9] in Ghana has remained largely unsteady over the years, especially prior to mid-1980s and in the post-2006 era. Sundry of factors underpinned the seeming erratic economic growth pattern in Ghana. Notably, Ghana's economic growth momentum is very susceptible to the vagaries of global developments due to over-reliance of domestic economic activities on the importation of capital and intermediate inputs often financed via earnings from exports of few traditional (primary) export commodities (cocoa, gold and recently oil). More often than not, the era of large external imbalances, emanating from declines in global prices cocoa and gold or rises in crude oil prices (See Appendix 1Aiv), is often associated with weak economic growth momentum in Ghana. Markedly, the effects of the global financial crisis in 2008-2009 and domestic energy supply challenges in 2009 underpinned the sluggish economic growth momentum in 2009. The subsequent commencement of crude oil production[10] and exports in Ghana considerably boosted economic growth momentum in 2010-11, while the loss of investor confidence on account of successive large fiscal overruns amid tighter external financing conditions and the reemergence of energy supply challenges in 2014-15 largely led to a general slowdown in economic growth during 2014-16 epochs. The succeeding increase in economic growth momentum since 2017 is also attributable to increase in crude oil production at the back of additional liftings from the TEN (i.e. Tweneboa, Enyenra, Ntomme) offshore oilfields. Indeed, Ghana was classified among the fastest growing economies in the world, especially in 2018 and 2019 (Figure 2.1c) while macroeconomic volatilities (especially for both growth and inflation) have broadly diminished during the IT regime in Ghana. This perhaps provides an unequivocal supposition that Ghana has been practicing flexible rather than draconian IT strategy, given the inherent economic and structural constraints in order to minimize the variability in economic growth.

In line with other IT central banks and to consider a host of relevant information in monetary policy decision making, the Bank of Ghana (BOG) currently adopts a forecasting and policy analysis system (FPAS) which pivots around a core quarterly projection model (QPM) - a semi-structured New

[9] The sectorial analysis unveils that the Services sector remains the dominant contributor to economic growth in Ghana over the past three decades, while the industrial sector overtakes the agriculture sector for the second position, particularly since 2016.

[10] Ghana's Jubilee offshore oilfield was discovered in 2007 by Kosmos Energy and developed by Tullow Oil. Production began in 2010 but crude oil exports started in 2011.

Keynesian (SSNK)[11] model with representative agents (i.e. Ricardian consumers). By this approach, the Monetary Policy Committee (MPC) of the Bank of Ghana, like many IT countries, assesses the upside and downside risks to inflation and output and then positions the policy (official) interest rate, following a Taylor-type rule. But it is uncertain that policy rate is set according to this rule as little or nothing is known about the empirical business cycles in Ghana and its interplay with policy interest rate (and exchange rate). A proper understanding of Ghana's business cycle dynamics is highly germane for policy making due to the fact that adjustments in policy interest rate are expected to initially influence aggregate demand (i.e. real sector activities) before impacting inflation. Therefore, inadequate knowledge or assessment of the current state of the economy would potentially lead to deficient policy making and worse outcomes. In addition, several recent macro studies (including Kaplan and Violante, 2014; Cloyne and Surico 2016; Kaplan et al., 2018) point to considerable heterogeneity in consumption responses across the population, driven largely by the level of liquid wealth and the composition of household balance sheets. By the same token, Kaplan and Violante (2014) argued that the relative strength of monetary policy can be properly assessed within a framework that offers a better representation of household consumption and household finances than the economic models with representative agents. This lends support to the proposal by Mankiw (2000) that economic model should allow for the coexistence of optimizing and non-optimizing consumer behaviours.

The above deliberation adduces several policy questions. The foremost question is whether monetary policy adequately inures macroeconomic stability in Ghana, given the apparent persistent and high levels of prices? Relatedly, is there robust empirical relationship among inflation, economic growth, interest rate and exchange rates in Ghana? In other words, how has monetary policy cycle influenced (or been coerced by) the dynamics of real business cycles in Ghana? Another key question is whether the current NK model used by the central bank of Ghana is adequate to capture the various nuances of the transmission mechanism of monetary policy. What is/are the dominant channel(s) of monetary policy transmission mechanism in Ghana? Is the monetary policy rule symmetric or asymmetric with respect to variations in inflation and output gap? What is the most appropriate reaction function for monetary policy in Ghana? Does the exchange rate play a role in the empirical monetary policy rule in a small-opened economy such as Ghana? Is the version of representative agent's model (adopted by BOG) suitable for Ghana, given the extent of informal sector and a financial constraints faced by a sizeable proportion of the population? Are there significant global spill-over effects on Ghana's

[11] Berg, Karam and Laxton (2006) identified that most central banks have applied two main versions of "New Keynesian" Macroeconometric model within the FPAS process.

monetary policy given the recent pace of international financial and trade integration? To what extent is BOG able to anchor inflation expectation? To what extent is the current policy regime in Ghana credible and/or transparent to help anchor inflation expectation? These critical policy questions serve as a drive for this thesis.

1.2 Objectives of the thesis

The preceding critical policy questions require thorough empirical responses. The main objective of this thesis is to comprehend the extent of monetary policy influence on macroeconomic stabilization or outcomes in Ghana. However, the specific objectives for this thesis are as follows:

- Examine the institutional and practical architecture of the current monetary policy framework regarding the levels of policy transparency, accountability and credibility.
- Understand the macroeconomic impact of the current inflation targeting monetary policy strategy in Ghana.
- Examine the dependence structures of key macroeconomic policy and targeted variables so as to understanding the monetary policy transmission mechanism and its effectiveness in Ghana.
- Estimate monetary policy reaction function in order to understand policy preferences at different business cycles in both time and frequency domains, and at different political regimes.
- Evaluate the relative suitability of the recent generation of New Keynesian DSGE model with or without non-Ricardian consumers for monetary policy analysis in small-open developing economy, like Ghana.
- Examine the relevance and implications of external spillovers on monetary policy in Ghana.

1.3 Significance of the thesis

More often than not, research on monetary policy is focused on two main categories of countries. These are (1) the advanced economies - where monetary policy operates with a back drop of stable and well established institutional structures and relatively predictable economic relationships (however until the Global Financial crisis) and (2) the emerging markets – where the openness to global trade and financial markets inflict a sequence of challenges of upholding macroeconomic stability but are on a path of growth and transformation. Clearly, very scanty studies have focused on monetary policy making in frontier and developing economies, where the institutional structures are rather incomplete along with partial integration to the global economy, underdeveloped financial system, prevalent role of national distortions to markets and at the embryonic stage of economic growth and transformation. Despite the instutitional limitations, monetary stability equally matters in frontier and developing

markets. And surely, monetary authorities in frontier and developing economies pine for the same volume of specific research and forecasting tools than any other central bank in the world. The foregoing phenomenon underscores the novel contribution of this thesis to the growing literature on monetary policy making in the frontier and developing economies.

The expected contribution to existing literature accentuates the significance and justification for undertaking this research. Notably, the thesis offers both significant empirical and methodological contributions that are worth highlighting.

Most DSGE models are focused on large industrial economies and advanced emerging economies. Yet, these models offer exciting and opportune fields in contemporary macroeconometric research. Another important spur is that despite ample evidence of large unbanked population and underdeveloped financial systems in developing and emerging African economies, the extant literature primarily applies representative agent's DSGE model for monetary policy analysis in these economies. The empirical relevance of the thesis is that the IT central banks in developing economies operate in an entirely different policy environment than the research findings from DSGE model with representative agents (RANK-DSGE) that have focused on the advanced economies. Consequently, this thesis uniquely extents the literature by conducting an empirical assessment to ascertain whether or not the standard RANK-DSGE models are appropriate for small-open developing and frontier African economies. By developing and estimating a small-open economy HANK[12]-DSGE model, the thesis offer an important empirical perspective on the repercussions of non-Ricardian consumers on the effectiveness and transmission of monetary policy within the particular context of developing and frontier economies. Consequently, by comparing the relative forecasting performance of RANK vs. HANK-DSGE models, the thesis enhances the understanding of monetary policy transmission mechanism in developing economies as it encompasses key frictions that are often ignored in the traditional NK model for these economies.

In addition, existing studies for developing and emerging economies typically apply contemporaneous monetary policy (or Taylor rule) in their DSGE models for monetary policy analysis. There is however no empirical justification for the suitability of such adhoc monetary policy rule for small-open developing and emerging economies. Given the important role of exchange rate in small-open developing and emerging economies, other studies also explicitly include of exchange rate in their monetary policy rule based on theoretical persuasions without empirical validation. Accordingly, this

[12] HANK means Heterogeneous Agent's New Keynesian, while RANK denotes Representative Agent's New Keynesian.

thesis also provides a unique empirical contribution to the existing literature by determining the most appropriate empirical policy rule for Ghana using marginal likelihood estimates as yardsticks. Additionally, the thesis offers a notable perspective on the Ricardian Equivalence Hypothesis (REH) by providing a more comprehensive analysis of fiscal policy effects on consumption at different market structures (or rigidities) with heterogeneous household agents. Last but not the least, the determination of policy transparency index in Ghana using complementary approaches of Dincer and Eichengreen (2008) and Al-Mashat et al. (2018) is an empirical contribution worth mentioning. Particularly, the proposed new transparency index by Al-Mashat et al., (2018) (henceforth, CBT-IT index) for inflation-forecast-targeting central banks overcomes the shortcomings of Dincer and Eichengreen (2008) index. Based on the theoretical underpinnings of IFT framework, the CBT-IT index focuses on three broad categories: (1) transparency about policy objectives, (2) transparency about the Forecasting and Policy Analysis System (FPAS), and (3) transparency about the policy process. To the best of our knowledge, the thesis is the first to extend the Al-Mashat et al. (2018) technique to measure policy transparency index for developing and frontier African economies.

The novelty of this thesis is also demonstrated in the methodology employed. Principally, the use of different econometric estimation techniques and the development of DSGE models, which have relatively not seen substantial application for monetary policy analysis in developing African economies, signify a meaningful progress in the empirical studies on monetary policy transmission mechanism in Ghana and beyond. Precisely, the application of Bayesian maximum likelihood estimation for the DSGE model with heterogeneous consumers is a contribution worth-mentioning as it has received relatively very little attention in developing African economies. Only few studies have employed DSGE models in the case of Ghana, but virtually none has explored Bayesian HANK-DSGE technique for monetary policy analysis. Another methodological contribution is that, converse to the existing studies on monetary policy reaction function (henceforth, MPRF) that used standard time-domain econometric methods, the thesis applies Bayesian Quantile techniques to analyse MPRF at time-frequency domain. To the best of our knowledge, this is the first study to exclusively analyse MPRF using Bayesian Quantile techniques with wavelet multiple time-scale inferences. The policy relevance of frequency domain analysis is well acknowledged in the extant literature because macroeconomic data are time-varying and subject to structural change. Moreover, the application of a more innovative technique like Maximal Overlap Discrete Wavelet Transform (MODWT) with Debauches least asymmetric filter of length (LA8) to obtain wavelet time-scale coefficients for the analysis of MPRF at the short, medium and longer time horizons is a methodological contribution

worth mentioning. The thesis thus offers more encompassing analysis than the existing literature on monetary policy transmission in Ghana.

Furthermore, existing empirical studies on volatility spillovers and interconnectedness have predominantly focused on financial (and cryptocurrency) markets. The thesis thus supplements the growing empirical research on interconnectedness and volatility spillovers by providing a perspective from key macroeconomic policy variables, especially for the small-open frontier and developing economies. Another notable methodological milestone of the thesis is its parallel applications of both linear/nonlinear Granger non-causality tests and the generalized forecast error variance decomposition (GFEVD) methodologies to evaluate the dynamic linkages between monetary policy instruments and the policy targeted macro-variables at both historical time-interval and multiple timescales (frequency domain). In this context too, no existing study has explored spillovers dynamics among money market rates and also among key macroeconomic variables such as exchange rate, output gap, inflation gap and policy interest rate at time-frequency domain using complementary applications of nonlinear Granger non-causality test of Diks and Panchenko (2006), three dimensional wavelet analysis and the GFEVD techniques espoused by Diebold-Yilmaz (2012) and Barunik-Krehlik (2015). As a consequent, this thesis utilizes more encompassing and unparallel empirical methodologies worth accentuating.

Ultimately, it is anticipated that this thesis will offer deeper understandings of monetary policy transmission mechanism in developing African economies and particularly, the extent to which monetary policy facilitates macroeconomic stabilization or outcomes in Ghana. Above all, it is also the aspiration of the thesis to curiously embolden other researchers, especially in developing and frontier economies, to develop a rejuvenated enthusiasm to research in the area.

1.4 Structure of the thesis

In all, the contributions of the thesis to literature are organized in six empirical chapters. In the following paragraph, Chapters 2 – 7 are summarized, in turn highlighting briefly on each chapter's focus and the associated methodologies. Therefore, readers are encouraged to read the detailed findings and contribution to the literature from the main appended chapters.

Chapter two focuses on two main areas: first, it ascertains whether the current monetary policy framework in Ghana satisfies all the key tenets of Inflation Targeting (IT) central bank. The understanding of the practical architecture of current monetary policy and its compatibility with key tenets of IT regime is particularly motivated by the fact that Ghana is a second longest practicing IT

economy in Africa but faces high and persistent inflation. It is widely agreed that the IT tenets such as policy transparency and accountability are hard to accurately pin down. Yet, the literature strongly posits that greater transparency boosts policy credibility which in turn aligns economic agent's inflation expectation towards policy target. This, together with the notion that agent's expectation formation is a crucial channel of monetary policy transmission, motivates the chapter to compute policy transparency index and also credibility index for Ghana following the empirical literature. The investigations in this chapter are done in stages. Regarding the monetary policy framework, the chapter initially examines the practical institutional architecture of the current monetary policy framework using historical narratives and compare with the tenets of IT regime. Subsequently, we determine the index of policy transparency using both methodologies of Dincer-Eichengreen (DE, 2008) and Al-Mashat et al., (2018). The CBT-IT index offers more detailed scrutiny about the practice of central bank compare to the DE index. In the third stage, we follow Akosah et al (2017) to construct an aggregated policy credibility index which is a weighted average of symmetric index (e.g. De Mendonça and de Guimarães e Souza, 2009) and asymmetric index (of Levieuge et al., 2018). The collective finding is that monetary policy framework is consistent with inflation forecast targeting and exhibits moderate levels of policy transparency and credibility. In addition, a cursory analysis supports a negative relationship between central bank transparency score and inflation expectation established in the extant literature. This preliminary finding therefore remits a very important implication for current monetary policy implementation in Ghana that greater policy transparency by BOG would help tame inflation expectation to the medium term target and hence, accelerates the disinflation process.

Chapter three provides detailed insights on whether the inflation targeting regime has so far been beneficial to the Ghanaian economy. The investigation into the relative benefits of the IT regime in Ghana is also done in two stages. First, we quantify or derive monetary and real business cycle statistics to analysis the relative cyclical dynamics of more expansive datasets including as Real GDP and its (aggregate demand) components, consumer inflation, real and nominal interest rate (i.e. MPR and 91-day Treasury bill rate) and exchange rate (both nominal and real). The inclusion of monetary policy variable (i.e. MPR) and exchange rate is to ascertain whether monetary policy action underpins or is influenced by real business cycle dynamics in various regimes. In the second stage, we determine the precise size and the direction of impact utilizing several standard econometric techniques while accounting for other salient macroeconomic events and/or disasters that hit the Ghanaian economy. Collectively, the chapter reveals significant interconnectedness with business cycle and that the inflation targeting stategy has been broadly beneficial in Ghana compare to the previous policy regimes.

Chapter four broadly examines monetary policy transmission mechanism in Ghana and its overall effectiveness at time-frequency domain. In the empirical analysis, we specifically explore volatility spillovers and the lead/lag relationships among the macro-variables at both time- and frequency domains to ascertain: (i) the signalling ability of the policy interest rate in the money market as well as the most influential money market interest rate(s) in Ghana; (ii) the interest rate-real sector nexus (determining the extent of interest rate spillovers to the real sector (output gap) and consumer inflation); and (iii) the extent to which the exchange rate influences domestic interest rate settings and the overall monetary transmission mechanism (i.e. determining exchange rate volatility spillovers to interest rate and key policy targeted macro-variables, especially inflation and output gap). The investigations in this chapter are done in two stages. First, we examine in-sample interdependence among the macroeconomic variables at analytical domains and this is also done using two approaches. Initially, we employ the standard time-domain and three-dimensional continuous Morlet wavelet (i.e. wavelet coherency analysis) methodologies to determine co-movements of the macroeconomic variables. Next, we determine lead/lag relationships among the macroeconomic variables using both linear and nonlinear Granger non-causality tests based on the Diks and Panchenko (2006) approach at both levels and time-frequency domains. In the second stage, we examine the out-of-sample volatility spillovers among the macroeconomic variables by utilizing the generalized forecast error variance decomposition (GFEVD) approaches espoused by Diebold-Yilmaz (2012) and Barunik-Krehlik (2015) which are respective methodologies for time-domain and frequency-domain analyses. The chapter mainly suggests moderate levels of interconnectedness among money market interest rates across time and multiscale domains in Ghana. Another salient finding is that the degree of interdependence among the policy interest rate, exchange rate and the real macro-variables are scale-dependent, as strong interlinkages are observed at the longer time-scale.

Chapter five examines macroeconomic policy reaction functions to ascertain how the Central Bank of Ghana has reacted to deviations of inflation and output gap from their respective desired levels over the past one and half decades. Primarily, it ascertains whether monetary policy in Ghana can be more precisely described by either (i) the standard linear Taylor rule, or (ii) an augmented linear rule including exchange rate or (iii) a nonlinear augmented threshold rule. The chapter thus determines the relevance of the exchange rate in monetary policy rule in Ghana and whether monetary policy reactions to inflation and/or output gaps are symmetric and conforms to the Taylor principles. This is motivated by the persistently high inflationary environment amid recurrently large domestic and external shocks as well as the predominant volatility spillovers from exchange rate emphasized by the preceding

chapter. The analysis in the chapter is done in three stages based on three methodologies using both the actual and wavelet timescale datasets. Particularly, we generate a wavelet timescale dataset from each corresponding level (actual) dataset using MODWT with Debauches least asymmetric filter of length (LA8). In the first stage, we estimate monetary policy reaction function (MPRF) and also evaluate the relevance of exchange rate in the policy rule using the conventional two-stage least square (particularly, generalized methods of moment, GMM) which is able to avert potential endogeneity problems. In the second stage, both Frequentist and Bayesian quantile regression methods are utilized to examine MPRF at time-domain and multiple time-scales (frequency domain) for different business cycles. The rationale is that the conventional generalized linear models have been criticized to only focus on the mean part of the response distribution. Therefore, studies based on conditional mean regression model (like GMM) essentially provide an incomplete account of MPRF, exactly when the parameters diverge over the entire conditional distribution of interest rates. Consequently, the approach in stage three provides the full account of the linkages between the response variable and its predictors in MPRF for Ghana. In the third stage, the chapter investigates the evidence of asymmetric policy reaction to targeted macroeconomic variables using the standard threshold regression technique developed by Hansen (1999) which endogenously determines the threshold value of the chosen variable along with the other parameters in the model. Collectively, the chapter finds an asymmetric monetary policy rule with clear oscillation in the key policy parameters across business cycles and time. In addition, there is ample evidence of strong policy interest rate smoothing but weak evidence of heterogeneous policy preference in different political regimes, surmising the exercise of monetary policy independence. More so, the chapter uncovers that the exchange rate exerts an important influence on interest rate settings especially in the low inflation regime, supporting an augmented nonlinear (threshold) Taylor rule for Ghana in the latter regime.

Chapter six develops a small-open economy New Keynesian (NK) general equilibrium model for monetary policy analysis in Ghana. The specific objectives of this chapter are however threefold. First, we ascertain whether the standard NK workhorse model with representative optimizing consumers is appropriate for monetary policy analysis in economy like Ghana that is saddled with large unbanked population who are essentially "hand-to-mouth" consumers. Second, we seek to determine the optimal monetary policy rule for Ghana. This is driven by the fact that most of the empirical studies for developing and emerging economies either assume the standard or augmented Taylor rule with an exchange rate. There is however no clear consensus on the empirical validity of such specifications for small-open developing economies even though exchange rate plays crucial role for the macroeconomic outcomes of these economies. Third, the estimated NK-DSGE model with the most appropriate policy

rule is used to address a number of policy questions. The RANK DSGE model developed in this chapter shares the essential features of the standard New Keynesian models. The model has two economies (Home and Foreign) that interact in both goods and financial markets. The home economy is assumed to be insignificantly small in size relative to the foreign economy. Consequently, the foreign economy is assumed to be exogenous to developments in the domestic economy. The model consists of forward-looking agents who are made up of households, firms and government. Households maximize their expected lifetime utility by consuming goods (domestically produced and foreign imports) and supplying labour and capital to firms. Households are able to smooth consumption via external habit formation in consumption. The firm, in turn, produces goods and set prices so as to maximize expected profit. Government comprises a fiscal authority that ensures a balanced budget at all times but undertakes only consumption spending (no public investment), and a monetary authority that sets the short-term interest rate based on the level of expected future inflation and current output gaps. In line with the literature, the model also introduces a relatively large number of additional frictions that are essential to mirror the empirical persistence and covariance in the main macroeconomic data of Ghana. In addition to habit formation in consumption, the model assumes that both price and wages are sticky a la Calvo. The model also incorporates a full set of structural shocks that are standard in recent New Keynesian DSGE models. We use six (6) macroeconomic variables over the period 2000Q1-2017Q4 while utilizing period 2000Q1-2007Q2 as training data. The variables are real GDP, private consumption, government consumption spending, private investment, consumer inflation and nominal interest rate for the home economy. The Euro Area is chosen as a representative foreign economy mainly due to their sizeable share (about 34.61%) of Ghana's external trade (see, Akosah et al., 2018). The salient finding is that forward-looking monetary policy rule - where the monetary authority responds to one-quarter-ahead inflation deviation from target together with contemporary output gap - is optimal for Ghana. Nonetheless, the standard New Keynesian model with representative agent (RANK) appears not to be appropriate for monetary policy analysis in Ghana as the model is found to be prone to the price puzzle.

Chapter seven develops and assesses the suitability of a small-open economy DSGE model with heterogeneous agents (i.e. HANK) for macroeconomic policy investigations (i.e. monetary and fiscal policies as well as foreign spillover effects) in Ghana. This is motivated by the realization that the RANK model developed in Chapter Six is prone to price puzzle. This observation consequently calls for a more robust model that captures other salient characteristics of developing economies. A notable characteristic, among others, is the evidence that not all households are able to smooth consumption (Kaplan et al., 2018, 2014) as they face some form of financial constraint and such households are

sizeable in developing economies (see Dagher et al, 2012). Besides, several studies (notably, Mankiw, 2000; Swarbrick, 2012; Kaplan et al., 2018, 2014) have underscored the necessity for economic models to permit the cohabitation of optimizing and non-optimizing households. An enormous empirical literature also accentuates that the presence of heterogeneous household behaviours has important implications for optimal monetary and fiscal policies. It also alters the effect on fiscal policy on private consumption. This is because non-Ricardian or ROT consumers do not even out consumption and hence, they do not response to various shocks (e.g. interest rate or inflation shocks). It is thus argued that non-Ricardian consumers are the source of misalignment between movements in the interest rate and aggregate consumption growth since the Euler equation does not hold with equality for such consumers (Kaplan et al., 2018, 2014). Besides, such consumers find it necessary to spend every windfall (either via tax cut or increased government spending) as they have no savings opportunities. In line with the empirical literature, this chapter develops a HANK-DSGE model that has the same essential features and frictions as the RANK-DSGE model except for the coexistence of both non-Ricardian and Ricardian consumers. The chapter also has the objectives as in the preceding chapter since it is just an extension of the latter. However, an additional objective here is to examine the relative performance of the HANK-DSGE model against the RANK-DSGE model in order to determine the best suited model for monetary policy analysis in Ghana. In the empirical analysis, the investigations are similarly done in stages. First, it is important to stress that earlier empirical studies on Ghana (for example Dagher et al., 2010, 2012) assumed a prior mean of 0.4 for the share of non-Ricardian consumers along with a certain policy rule. In contrast, this chapter rather empirically determines both the share of non-Ricardian consumer and the appropriate monetary policy rule for Ghana. Following the extant literature, we initially estimate possible range of shares of non-Ricardian consumers based on the theoretical Euler consumption equation that is augmented with output (income) using two stage least squares technique (particularly, the Generalized Method of Moments, GMM). Next, the estimated possible range of shares for non-Ricardian consumers are then used as prior means in our HANK DSGE model along with alternative specifications of monetary policy rules and different prior distributions for the Calvo parameters. Finally, the appropriate share of non-Ricardian and the monetary policy rule are gauged by the model that generates the highest marginal likelihood. The rationale is that the marginal likelihood, which can be interpreted as a summary statistic for the model's out-of-sample prediction performance, forms a natural benchmark for comparing DSGE model with other alternative specifications and other statistical models (see, Smet and Wouters, 2002; Landon-Lane, 1998; Geweke, 1999). In the second stage, the forecasting performance of the preferred HANK-DSGE is then compared with that of RANK-DSGE. In the third stage, the preferred HANK-DSGE model along with alternative scenarios (based on different market structure or rigidities) is used to

address the foregoing policy questions. The chapter uses the same nine macro-datasets as in the preceding chapter.

With a total of 40 HANK-DSGE models estimated, the chapter finds the most appropriate prior mean for the share of non-Ricardian consumer to be 0.425 for Ghana which in turn yields a corresponding posterior mean of 0.464 with a 95% confidence interval of [0.429 0.501] in the preferred baseline HANK-DSGE model. This suggests that about 46.4% of consumers are classified as non-Ricardian, given the Ghanaian macro-dataset. Though the findings also corroborate the earlier support for forward-looking monetary policy rule for Ghana, the HANK model rather generates meaningful impulse response functions and hence, more suitable for monetary policy investigations in Ghana. There is also ample evidence of crowding-out effect of positive government spending shock on aggregate private consumption in the baseline HANK-DSGE model with Calvo price and wage rigidities, despite low or high fraction of non-Ricardian consumers. Consistent with RANK model, the exchange rate remains an important channel through which both domestic and foreign spillovers affect the Ghanaian macroeconomy.

CHAPTER TWO

Institutional Architecture of Monetary Policy in Ghana:

Measuring the Extent of Policy Transparency and Credibility

2.0 Introduction

Increasing number of central banks in developed, emerging and developing economies (including Ghana) have adopted to inflation targeting (IT) framework since the late 1980s as a new monetary policy nominal anchor to tie down the general level of prices[13]. The essential prerequisites of IT regime are the primary objective of price stability, the announcement of numerical value for medium-term inflation target, monetary policy based on extensive information delivery and greater transparency of central bank's activities. The last two elements can be regarded as a component accentuating a wide-ranging autonomy conferred on central banks in recent decades.

Clearly, central bank transparency, accountability and communication have come a long way. The shift in transparency and communication practices indeed took time. Even up to the early 1990s, opacity and mystique had been deeply imbedded in central banks' psyche (Haldane, 2017) as they appeared to have kept their public utterance to a minimum. Conversely, monetary policies have seen dramatic changes globally since the late 1990s with a conscious move towards greater policy transparency and communication[14], particularly following the inception of inflation targeting (IT) regime. This epoch has witnessed increasing number of speeches and public appearances by governors and their deputies as well as eclectic publications of policy documents by central banks. The central banks in advanced economies have been very impressive in pioneering these sharp changes in transparency and communication strategies. Outstanding examples are found in the Federal Reserve System in the US, The European Central Bank (ECB), the Bank of England and the Central Banks of

[13] In the IT framework, the nominal anchor for inflation expectation is the inflation target communicated to the public.

[14] Geraats (2008) simply defines transparency as the absence of information asymmetry. According to Little and Romano (2009), the institutional elements contributing to transparency range from central bank independence to the makeup of the policy-setting body. Amato and Shin (2003) asserts that the actions of central bank and the information it publicly provides create a common powerful focal point for the information processing decisions of economic agents. Therefore, a central bank must not only be a heedful observer of outcomes but also be able to shape the outcomes, and hence greater policy transparency is key to achieving this dual monetary policy role.

Canada, New Zealand and Sweden. These notable central banks have deplored several ways to boost policy transparency, such as publication of inflation forecasts, far-reaching explanations of the reasoning behind their decisions, and publication of voting records on policy decisions or a discussion of the 'bias' in those decisions. Nonetheless, this sea-change in policy transparency is unequivocally a global phenomenon as increasing number of central banks in emerging and developing economies have also echoed similar trends towards ensuring greater transparent policy environment.

The ballooning trend towards greater policy transparency and communication is driven by a number of factors. First, it is grounded on the recognition that increased policy transparency does not only enhance monetary policy effectiveness, flexibility and credibility[15] but is also perceived as a crucial component of accountability in the era of central bank independence (see Haldane, 2017; Al-Mashat et al., 2018). Second, it is widely articulated that central bank independence is a means of shielding monetary authority from short-term political pressures. Central bank independence is thus recognized as an efficient way of dealing with the time-consistency problems that are often associated with discretionary policy (Dincer and Eichengreen, 2014). Policy transparency is acknowledged as a best means through which the public can judge whether the actions and tactics of independent central bankers are consistent with their mandate. Thirdly, transparency is perhaps part of a broader trend to make government more responsive to the public – boosting the transparency and efficiency of government operations in general. Last but not the least, transparency enables markets to react quite easily to policy decisions. This is because policy decision from a more transparent central bank is less probable to come as a surprise to market participants (investors) [16]. Consequently, such policy changes are less prone to induce sharp oscillations in asset prices that cause financial distress.[17]

[15]Gonzalez-Paramo (2007) professed credibility as a fundamental issue in modern central banking, while Blinder (1998, 2000) also deemed credibility as a treasurable asset that need to be seriously upheld by central banks.

[16] According to Amato and Shin (2003), the actions of central bank and the information it publicly provides create a common powerful focal point for the information processing decisions of economic agents. Using a panel of emerging economies, Papadamou et al. (2015) find monetary policy transmission mechanism to be more effective under high policy transparency.

[17] Another strand of the literature however considers that certain restrictions on transparency are important for operational reasons (notably, Issing, 1999, 2014; Morris and Shin, 2002; Faust and Svensson, 2001; Geraats, 2002; etc.)

From the preceding discourse, the chapter covers two focal areas. First, we establish whether the current monetary policy framework in Ghana satisfies all the key tenets of Inflation Targeting (IT) central bank. The understanding the practical architecture of current monetary policy and its compatibility with key tenets of IT regime is particularly motivated by the fact that Ghana is a second longest practicing IT economy in Africa but faces high and persistent inflation. This investigation is carried out by using historical narratives and compare the practical design of monetary policy in Ghana with the tenets of IT regime. The second focus of the chapter is to determine the extent of policy transparency and credibility in Ghana by computing policy transparency and credibility indices following the empirical literature. This is mainly driven by the general recognition that greater transparency boosts policy credibility which in turn aligns economic agent's expectation towards policy target, a crucial channel of monetary policy transmission. Quantitatively, the index of policy transparency is computed using both methodologies of Dincer-Eichengreen (DE, 2008) and Al-Mashat et al., (2018). The CBT-IT index offers more detailed scrutiny about the practice of central bank compare to the DE index. After computing the policy transparency index, the chapter cursorily analyses the empirical link between monetary policy transparency and inflation expectation in the context of Ghana. Subsequently, we follow Akosah et al. (2017) to construct an aggregate policy credibility index for Ghana which is a weighted average of symmetric index (e.g. De Mendonça and de Guimarães e Souza, 2009) and asymmetric index (of Levieuge et al., 2018).

In terms of contribution, the chapter expands the literature by extending the application of the newly espoused CBT-IT index for gauging the extent of policy transparency in IFT central banks as the index is currently only applied to the Czech Republic. Thus, to best of our knowledge, the thesis is the first to apply the newly espoused CBT-IT index to IFT central bank in African continent.

2.1 Practical Architecture of Inflation Targeting Regime in Ghana

The Bank of Ghana was not operationally independent from government prior to early 2000s. During this era, the Bank had a very poor track record for inflation, and the key drivers for the high and pervasive inflation pressures were excessive governments spending, supported by generally loose monetary policy and low credibility to effectively anchor inflation

expectation. Accordingly, the annual inflation averaged 53% and 29% for the periods 1975-1991 (i.e. direct control regime) and 1992-2002 (i.e. monetary targeting regime) respectively.

To tackle the entrenched inflation inertia, the Bank of Ghana Act 2002 (Act 612) was enacted in November 2002 and initiated the transition to IT regime. Ghana in May 2007 officially became the 28th country in the world but the second African economy (after South Africa) to adopt IT framework. The fundamental requirements of inflation targeting regime are the primary objective of price stability, the announcement of numerical value for medium-term inflation target, monetary policy based on extensive information delivery and greater transparency of central bank's activities. The last two elements can be regarded as a component underpinning a wide-ranging autonomy bestowed to central banks in recent decades. On the whole, the core operation of central bank practicing inflation targeting strategy is comparable in many ways such as the preference for flexible exchange rate regime, disclosure of medium-term inflation and GDP forecasts to the public, or importance given to monetary policy communication and transparency. All the same, some notable differences exist across central banks particularly with respect to how inflation target is defined or how their levels are set.

Like most IT central banks, the primary objective of Bank of Ghana (BOG) is price stability (see Table 2.1), as enshrined in the Bank of Ghana Act 2002 (Act 612). The Act 2002, as amended, also charges the Bank to support economic growth and to guarantee financial stability using available macroprudential tools. The Bank of Ghana Act 2002 established the Monetary Policy Committee (MPC) and granted operational independence to the central bank. The main policy instrument of BOG is short term interest rate and the intermediate target is the forecast inflation rate. The MPC meets six (6) times in a year (bi-monthly) and the meeting dates are communicated to the public far in advance following the international best practices. After careful evaluation a host of relevant and recent information, including the global economy, the real sector, the monetary sector, the fiscal sector, the external sector, consumer and business sentiments, developments in inflation and inflation expectations as well as the latest BOG forecasts, the MPC determines the looming (upside and downside) risks to inflation and output growth over the medium-term and hence, position the short-term interest rate.

To effectively anchor inflation expectation, the BOG has intensified its information delivery to the general public (see Table 2.2) based on the general acknowledgement of a close connection between monetary policy transparency and the anchoring of inflation expectations (e.g. Al-Mashat et al., 2018; Cruijsen and Demertzis, 2007). So far, the milestones achieved by the Bank since the investiture of MPC in November 2002 (as in Table 2.2) can broadly be clearly summarized as follows:

- Gained operational (but not legal) independence
- Precision of target – declaration of medium-term inflation target;
- Transparency of instrument – clarity of the policy interest rate setting;
- Unambiguous communication on policy implementation; and
- Clarity of the intermediate target - publication of the inflation forecast (fan chart) constructed under the assumption of an endogenous interest rate

Table 2.3 however shows the Bank of Ghana has so far not provided a number of documents to the general public compared to the recent trends in most IT central banks in advanced and emerging economies. Particularly, the minutes of the MPC meetings are not yet made available to the general public. The literature (notably, El-Shagi and Jung, 2015) strongly suggests that published MPC minutes helps markets form expectation on future monetary policy decisions and hence, shape economic agent's formation of inflation expectation. In addition, the BOG is known to have developed a core quarterly projection model for its forecasting and policy analysis system (FPAS) with the help from Bank of England and the IMF. In the same vein, the bank is yet to provide the detailed documentation of its forecasting and policy analysis system (FPAS) along with the policy loss (reaction) function to the general public. The loss function shows how a central bank is dealing with the trade-off between inflation and output.

In addition, BOG is yet to disclose the forecasting performance of its quarterly projection model (QPM-Gap model). Only the fan chart for CPI inflation is published by BOG while most IT central banks also publish the endogenous policy interest rate alongside output gap and exchange rate. While the MPR provides the imminent risks to inflation and output over

the short-to-medium term, no fan charts were published during the IT-Lite period (pre-2007 era).

The history of IT and the transition from IT-Lite to IFT and then to fully-fledged IFT provides a line of transparency or accountability. Therefore, even though BOG announced the official adoption of IT regime in May 2007, the critical question is to what extent the non-disclosure of some of these important policy documents affects the transition of its policy regime from IT-Lite to IFT and then to fully-fledged IFT. Given the above milestones and the classification by Al-Mashat et al (2018), we can classify BOG as an IFT (but not fully-fledged IFT) central bank (see Table 2.4). This is because BOG first published inflation forecast series in 2007 (based on a combination of Autoregressive, Error Correction Forecast and Calibration methods) following the official announcement of IT regime in May 2007. The publication of fan chart for inflation constructed under the assumption of an endogenous interest rate within a QPM-Gap model started in 2008 but only consistently after 2010.

To leapfrog to a fully-fledged IFT status, the BOG has to follow the international best practices of major central banks to publish the conditional numerical forecast path of the endogenous short-term interest rate within its core quarterly projection model in order to illustrate how it has been dealing with the short-run output-inflation trade-off in Ghana. Besides, lucid communication regarding the uncertainties surrounding the forecast path of the endogenous policy interest rate and the rational for policy actions should be provided to the general public.

Table 2.1: Degree of central bank autonomy for selected emerging IT economies

Countries	Approximate Date of Official Adoption	Goal Autonomy	Target Autonomy	Instrument Autonomy		Target Level
		Legal Objective	Specification of Target	Credit to Government	Participation of Government	
Brazil	1999M6	Price Stability	G	No	No	4% +/-1.5%
Chile	1999M9	Price + Financial Stability	CB	Yes	Member to vote	3%+/-1.0%
Colombia	1999M9	Price Stability	CB	Non	Member to vote	3%+/-1.0%
Czech Republic	1997M12	Price Stability	G+CB	No	No	2%+/-1.0%
Ghana	**2007M5**	**Price Stability**	**G + CB**	**Yes**	**No**	**8% +/-2%**
Hungary	2001M6	Price Stability	G+CB	No	No	3%+/-1.0%
Indonesia	2005M7	Price Stability	G+CB	No	No	4%+/-1.0%

Israel	1997M6	Price Stability	G	No	No	1.0%-3.0%
Mexico	2001M1	Price Stability	CB	Yes	Yes	3%+/-1.0%
Peru	2002M1	Monetary Stability	CB	No	Member to vote	2%+/-1.0%
Philippines	2002M1	Price Stability	G+CB	limited	Member to vote	3%+/-1.0%
Poland	1999M10	Price Stability	CB	No	No	2.5%+/-1.0%
Romania	2005M8	Price Stability	G+CB	No	No	2.5%+/-1.0%
Slovakia	2005M1[18]	Price Stability	CB	No	No	3%+/-1.0%
South Africa	2000M2	Price Stability	G + CB	Yes	No	3.0%-6.0%
South Korea	2001M1	Price Stability	G+CB	Yes	Yes	2.0%^
Thailand	2000M5	Monetary Stability	CB	Yes	No	2.5%+/-1.5%
Turkey	2006M1	Price Stability	G+CB	No	No	5%+/-2.0%

Note: G is Government; CB is Central Bank; ^ denotes target for 2016-18. Source: Central Banks' website, Svensson (2010) and Aguir (2018)

Based on the foregoing discussions, the chapter follows the extant empirical literature to quantitatively determine the extent of monetary policy transparency and credibility in Ghana. This is motivated by the notion that greater transparency boosts policy credibility which in turn aligns economic agent's expectation towards policy target. Even though agent's expectation formation is a crucial channel of monetary policy transmission, it is empirically cumbersome to accurately pin down degree of policy transparency and accountability.

[18] But according to Krusec (2011), Slovakia was an implicit inflation targeter in beginning of 1999.

Table 2.2: Timelines of Communications and Transparency Innovation for Bank of Ghana (2002-2019 era)

2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017-19
Establishment of MPC					Official announcement of Inflation Targeting Regime	Publish Fan charts for Inflation & GDP	No Fan charts published	Publish Fan charts for inflation					Publish Economic & Financial Data	Add Financial Stability Objective	
Operational Independence															
Price Stability Objective															
Annual Inflation Target					Publish a 2-year Inflation Outlook							Medium-Term Inflation Target			
Pre-announced MPC dates															
Press Conferences															
Announce rate change or no change & the rational in Press Releases											Publish Transcripts				
Inflation Outlook & Monetary Aggregates.													Monetary Policy Report		
WEO & ESD Report.															
Financial Stability Report.													Banking Sector Report		
Money Mkt. & Financial Development Report															

Note: WEO is world economic outlook; ESD is external sector developments. Financial stability mandate was explicitly included in BOG's mandate following the BOG (amendment) Act, 2016 (Act 918). Source: Authors' construct based on information at Bank of Ghana's website.

Table 2.3: How BOG's Communications and Transparency Innovation compares with other IT central banks

Countries	Date of Official Adoption	Historical Data/Chart	FPAS	Loss Function	Forecast Variables: I, Y, R, X	Fan Charts: I, Y, R, X	Forecast Assumptions	Alternative Scenarios	Minutes of MPC	MPC Voting Pattern/ Records	Press Release	Press Conference
Brazil	1999M6	Yes	Yes	Yes	All	I,Y,R	Yes	Yes	Yes	No	Yes	Yes
Chile	1999M9	Yes	Yes	Yes	All	I,Y,R	Yes	Yes	Yes	Yes	Yes	Yes
Colombia	1999M9	Yes	Yes	Yes	All	I,Y	Yes	Yes	Yes	Yes	Yes	Yes
Czech Rep.	1997M12	Yes	Yes	Yes	All	All	Yes	Yes	Yes	Yes	Yes	Yes
Ghana	**2007M5**	**Yes**	**No**	**No**	**No**	**I**	**Yes**	**Yes**	**No**	**No**	**Yes**	**Yes**
Georgia	2009M1	Yes	Yes	Yes	I,Y	I,Y,R	Yes	Yes	No	No	Yes	Yes
Hungary	2005M8	Yes	Yes	Yes	I,Y	I,Y	Yes	Yes	Yes	Yes	Yes	Yes
Indonesia	2005M7	Yes	Yes	Yes	No	I,Y	Yes	Yes	No	No	Yes	Yes
Israel	1997M6	Yes	Yes	Yes	I,Y	I	Yes	Yes	Yes	No	Yes	Yes
India	2016M8	Yes	Yes	Yes	I,Y,R	No	Yes	Yes	Yes	Yes	Yes	Yes
Mexico	2001M1	Yes	Yes	Yes	All	No	Yes	Yes	Yes	Yes	Yes	Yes
Paraguay	**2011M5**	Yes	Yes	Yes	All	I	Yes	Yes	Yes	No	Yes	Yes
Peru	2002M1	Yes	Yes	Yes	All	I, Y	Yes	Yes	No	No	Yes	Yes
Philippines	2002M1	Yes	Yes	Yes	I	I	Yes	Yes	Yes	No	Yes	Yes
Poland	1999M10	Yes	Yes	Yes	I,Y,R	I, Y	Yes	Yes	Yes	Yes	Yes	Yes
Romania	2005M8	Yes	Yes	Yes	I	I	Yes	Yes	No	No	Yes	Yes
Serbia	2009M1	Yes	Yes	Yes	I,Y	I, Y	Yes	Yes	No	No	Yes	Yes
Slovakia	2005M1	Yes	Yes	Yes	I,Y	No	Yes	Yes	No	No	Yes	Yes
South Africa	2000M2	Yes	Yes	Yes	All	R	Yes	Yes	No	No	Yes	Yes
South Korea	2001M1	Yes	Yes	Yes	I,Y,R	No	Yes	Yes	Yes	Yes	Yes	Yes
Thailand	2000M5	Yes	Yes	Yes	All	No	Yes	Yes	Yes	No	Yes	Yes
Turkey	2006M1	Yes	Yes	Yes	I	I	Yes	Yes	No	No	Yes	Yes
Uganda	2011M6	Yes	No	No	No	I	Yes	Yes	No	No	Yes	Yes

Note: I, Y, R and X denote inflation, output, (endogenous) policy interest rate and exchange rate respectively.

Table 2.4: Stages of BOG's inflation Targeting

Inflation Targeting Lite (ITL)	Inflation-Forecast Targeting (IFT)	Fully-Fledged Inflation-Forecast Targeting
2003-2006	**2007-2019**	**Not Yet**

2.2 Quantitative Assessment of Policy Transparency in Ghana

In this section, we compute policy transparency index for Ghana following the empirical literature. We however begin the analysis with the proposed measures in the literature and proceed with the presentation of empirical result for the Ghanaian context.

2.2.1 Brief Literature and Methodology

Empirical literature on the measurement of central bank transparency is replete. For instance, Geraats (2002) provides a structured review of the theoretical and empirical literature on the consequences of transparency of monetary policy. She also proposed a distinction between uncertainty and incentive effects of transparency. Several theoretical and empirical approaches have also been proposed to quantify the degree of central bank policy transparency. Notable studies that have developed indices for policy transparency include Fry et al. (2000), Siklos (2002), Eijffinger and Geraats (2006), Dincer and Eichengreen (2008, 2010, 2014), Naszodi et al (2016) and Al-Mashat et al., (2018). Notably, Fry et al. (2000) gauged central bank transparency of ninety-four (94) countries using an evenly weighted average of three sub-indicators: (1) whether the central bank provides prompt public explanations of its policy decisions; (2) the frequency and form of forward-looking analysis offered to the public; and (3) the frequency of bulletins, speeches, and research papers. Siklos (2002) also provided comparable measures for twenty OECD countries but again for only one point in time, the late 1990s. The main limitation of both studies is the crude definition of transparency.

In view of this limitation, Eijffinger and Geraats (2006), henceforth EG, provided a much broader definition of transparency by focusing on disclosure of information pertinent to monetary policymaking. They categorize transparency into the following five dimensions: (1)

political transparency (openness about policy objectives); (2) economic transparency (openness about data, models, and forecasts); (3) procedural transparency (openness about the way decisions are made, achieved mainly through the release of minutes and votes); (4) policy transparency (openness about the policy implications, achieved through prompt announcement and explanation of decisions); and (5) operational transparency (openness about the implementation of those decisions—in other words, about control errors and macroeconomic disturbances affecting their magnitude). Their index covered 9 major central banks from 1998 to 2002. They found that although significant increases are observed for all monetary policy regimes, the inflation targeting central banks are by far the most transparent.

Dincer and Eichengreen (2008, henceforth DE) further extended the EG (2006) transparency index to 100 central banks. According to DE (2014), political transparency relates to formal policy objective, quantification of objective and central bank independence, while economic transparency borders on disclosure of the model used for policy analysis, regular publication of central bank's forecast and easy access to basic economic data relevant for the conduct of monetary policy. The Procedural transparency pertains to the Bank's explicit disclosure of policy rule, provision of a comprehensive account of policy deliberation and how each decision on policy instrument or target are attained. Policy Transparency relates to prompt public notification and explanation of policy decision and the likely future policy action. Lastly, Operational transparency also pertains to regular evaluation of policy target, provision of information on macroeconomic shocks that affect the policy transmission process as well as evaluation of policy outcome vis-à-vis its macroeconomic objectives. Applying similar classification of transparency, a number of empirical studies (notably, Chortareas, Stasavage, and Sterne 2002; Swanson, 2004; Eijffinger and Geraats, 2006; Demertzis and Hallett, 2007; Crowe and Meade, 2008; Middeldorp, 2011; Ehrmann, Eijffinger, and Fratzscher, 2012; Dincer and Eichengreen, 2014; Naszodi et al., 2016); inter alia) claim that central bank transparency has a favorable effect on the economy. In contrast, some other papers (notably, van der Cruijsen, Eijffinger, and Hoogduin, 2010; Demertzis and Hoeberichts, 2007; Kool, Middeldorp, and Rosenkranz, 2011; Morris and Shin, 2002; Neuenkirch, 2013; and Walsh 2003) find either that higher transparency is unfavourable or has a nebulous effect on mitigating macroeconomic uncertainty.

Another prominent contribution is the study by Naszodi et al (2016) which proposed composite EG transparency index to 99 central banks (including Ghana) over the period 1998-2009. They rank the countries according to the degree of policy transparency using both the standard EG-DE index and a proposed composite EG index which aggregates the same fifteen components of the EG-DE method. The composite transparency index is obtained by regressing standard deviation of the individual CPI forecasts on each of the 15 components of EG index. They also determine which of dimension of transparency that exerts significant impact on macroeconomic variable (forecast inflation dispersion). Among others, they derive an index of 5.5 and 0.67 for Ghana based on the standard and weighted EG transparency measures respectively, ranking the latter economy as the 44 position (out of 97 countries considered). They also find that economic transparency has the robust favourable effect on inflation forecast dispersion.

The EG (2006) and DE (2007, 2014) transparency measures have however been criticized for lacking sufficient depth on advanced forms of communications, especially for the inflation-forecasting-targeting (IFT) countries. First, it becomes practically cumbersome to discriminate between different IFT countries and between IFT and non-IFT countries, since all IFT countries attain near maximum score of the EG-DE index. In addition, the EG-DE questions do not capture transparent communication of monetary and macro-prudential policy interactions despite the increasing importance of financial stability and macro-prudential policies after the global financial crisis (see, Al-Mashat et al., 2018). Consequently, Al-Mashat et al., (2018) proposed new transparency index (henceforth, CBT-IT index) for inflation-forecast-targeting central banks which overcomes the shortcomings of EG-DE index. Based on the theoretical underpinnings of IFT framework, the CBT-IT index focuses on three broad categories: (1) transparency about policy objectives (henceforth TAPO); (2) transparency about the Forecasting and Policy Analysis System (henceforth, FPAS); and (3) transparency about the policy process (henceforth, TAPP). The CBT-IT index offers more detailed scrutiny about the practice of central bank compare to the EG-DE index.

The TAPO explores central bank transparency along the following 4 dimensions:

I. Clear statement of monetary policy objective
II. Clearly defined inflation target
III. The role of financial stability in monetary policy communication
IV. Whether the central bank uses loss function evaluation to show how well it has been doing in managing the short-run tradeoffs between output and inflation (sacrifice ratio)

The questions related to the FPAS category appraise the robustness and public awareness of the FPAS process adopted by the central bank. This is based on the following nine (9) dimensions:

I. Public access to basic economic data relevant for the conduct of monetary policy.
II. Core quarterly projection model in downloadable format and updated within the last 5-years.
III. How transparent is the CB about the loss/reaction function (with the coefficients) that are used and communicating the judgment that has been involved on the forecast.
IV. Publishing quarterly (time series) forecasts of key macroeconomic variables over a horizon of at least two years
V. Fan charts for key macroeconomic variables to communicate forecast uncertainty
VI. Underlying methodology for the construction of fan charts as it increases the value of the information for the users.
VII. Whether the central bank regularly publishes its assessment of forecast revisions (decomposition of forecast changes vis-à-vis the previous forecast).
VIII. Publish alternative scenarios in the MPR, as it helps users to decipher a couple of potential risks in the baseline forecast.
IX. Including historical data and forecast for financial variables in the MPR.

Lastly, the TAPP category examines the central bank policy process along the following seven (7) aspects:

I. Holding press conference soon after every policy meeting and at pre-announced date and time.

II. Webcasting Press conference and Q&A session and the transcripts (in English) made available at the bank's website

III. Regular presentation of forecast update (including Q&A sessions) to journalist, market analyst and participants & the presentation should be available in English.

IV. Publication of policy deliberations (minutes) in less than one month after each meeting.

V. Clearly communicated role of staff and policymakers in the decision-making process

VI. Review of the forecasting performance of CB at least once a year and publishing it in the MPR or in a separate documents.

VII. External and independent evaluation of the policy framework and the FPAS every 5 years and made the result publicly available.

For brevity, readers are referred to Al-Mashat et al (2018)[19] for the justification of each question under the broad categories of the CBT-IT index.

2.2.2 Empirical Analysis

2.2.2.1 Transparency Index for BOG: DE-EG Approach

The DE-EG measure of central bank transparency focuses on five thematic areas: Political, Economic, Procedural, Policy and Operations (henceforth, PEPPO). Table 2.5 summarizes our transparency score for BOG according to the DE-EG methodology (Appendix 2A also presents the detailed questions for DE-EG measure).

Table 2.5: BOG Transparency Score as at end-2019 under the DE-EG Methodology

Questions	Perfect Score	BOG Score	Percentage score
Category I: Political Transparency			
1	1.0	1.0	
2	1.0	1.0	
3	1.0	1.0	
Sub-Total	**3.0**	**3.0**	**100.0**
Category II: Economic Transparency			
1	1.0	0.5	
2	1.0	0.0	
3	1.0	0.5	

[19] Al-Mashat et al., 2018 applied the proposed CBT-IT index to Czech National Bank (CNB) and derived a policy transparency index of 11.5 for CNB in 2018. Their study also finds that the transparency of CNB is growing over the years but there are areas that should be improved.

Sub-Total	**3.0**	**1.0**	**33.3**
Category III: Procedural Transparency			
1	1.0	0.0	
2	1.0	0.0	
3	1.0	0.0	
Sub-Total	**3.0**	**0.0**	**0.0**
Category IV: Policy Transparency			
1	1.0	1.0	
2	1.0	1.0	
3	1.0	1.0	
Sub-Total	**3.0**	**3.0**	**100.0**
Category V: Operational Transparency			
1	1.0	0.5	
2	1.0	0.0	
3	1.0	0.0	
Sub-Total	**3.0**	**0.5**	**16.7**
Overall Score	**15.0**	**7.5**	**50.0**

Source: Authors' construct

The DE-EG score for BOG is based on the information provided at the Bank's website and statutes, annual reports, other published documents and the routine procedures during and after MPC meetings. On the whole, the Bank performs creditably well in 2 out of 5 thematic areas. Particularly, the Bank secures a perfect score of 3/3 each for the Political and Policy Transparency categories. This is underpinned by the fact that the central bank has clear policy objectives and quantified inflation target well communicated at its website which reinforce political transparency. On the other hand, the publications of press releases and transcripts of press briefing which buttress the rationale for policy actions and a clear indication of future course of action by the MPC when necessary also strengthens the policy transparency of BOG. The score for the Bank's Economic Transparency is quite low as well (scored 1/3) driven by the publication of (i) fan chart for inflation and (ii) summary of economic and financial dataset.

However, the lack of publication of the core QPM for policy decision considerably affected the score for BOG in this category. In contrast, the Bank performed very poor in both Operational and Procedural thematic areas of EG-DE transparency measures with values of 0.5/3 and 0/3 respectively. The low policy adherence to procedural and economic transparency by BOG is largely consistent with the low score for the transparency about the

FPAS process in CBT-IT methodology. On aggregate, we find an overall EG-DE transparency score of 7.5 out of 15 for BOG. This suggests 50% transparency score for BOG as at end-2019, an improvement from a score of 5.5 (36.7%) reported by Nascodi et al., (2016) for the year 2009. Given the limitation of the DE-EG measure mentioned in Section 2.2.1, we proceed further to determine the level of policy transparency for BOG using the CBT-IT approach.

2.2.2.2 Transparency Index for BOG: CBT-IT Approach

Next, we determine the degree of monetary policy transparency in Ghana using the newly developed transparency index for inflation-targeting central banks (CBT-IT index) developed by Al-Mashat et al., (2018) which overcomes the shortcomings of DE index. As aforementioned, the CBT-IT index covers three main categories. In this paper, Category A denotes transparency about policy objectives (TAPO). Category B represents transparency about the forecasting and policy analysis system (FPAS), while Category C characterizes transparency about the policy process (TAPP). Appendix 2B provides the detailed questions and corresponding scoring systems for the CBT-IT approach. Table 2.6 summarizes the score assigned to BOG for each CBT-IT question as at end-2019 while Figures 2.1 and 2.2 report the historical evolution of the overall and the three components of CBT-IT index respectively for BOG from 2002 to 2019.

Table 2.6: BOG score for CBT-IT Transparency Index as at end-2019

Questions	Perfect Score	BOG Score	Percentage score
Category A: Transparency about policy objectives			
1	1.0	1.0	
2	1.0	1.0	
3	1.0	1.0	
4	1.0	0.0	
Sub-Total	**4.0**	**3.0**	**75.0**
Category B: Transparency about the FPAS			
1	1.0	0.2	
2	1.0	0.0	
3	1.0	0.0	
4	1.0	0.0	
5	1.0	0.2	
6	1.0	0.0	
7	1.0	0.0	
8	1.0	0.0	
9	1.0	0.2	
Sub-Total	**9.0**	**0.6**	**6.7**

Category C: Transparency about Policy Process			
1	1.0	1.0	
2	1.0	1.0	
3	1.0	0.0	
4	1.0	0.0	
5	1.0	0.0	
6	1.0	0.0	
7	1.0	0.5	
Sub-Total	**7.0**	**2.5**	**35.7**
Overall Score	**20.0**	**6.1**	**30.5**

Source: Authors' construct

2.2.2.2.1 Transparency about policy objectives (TAPO)

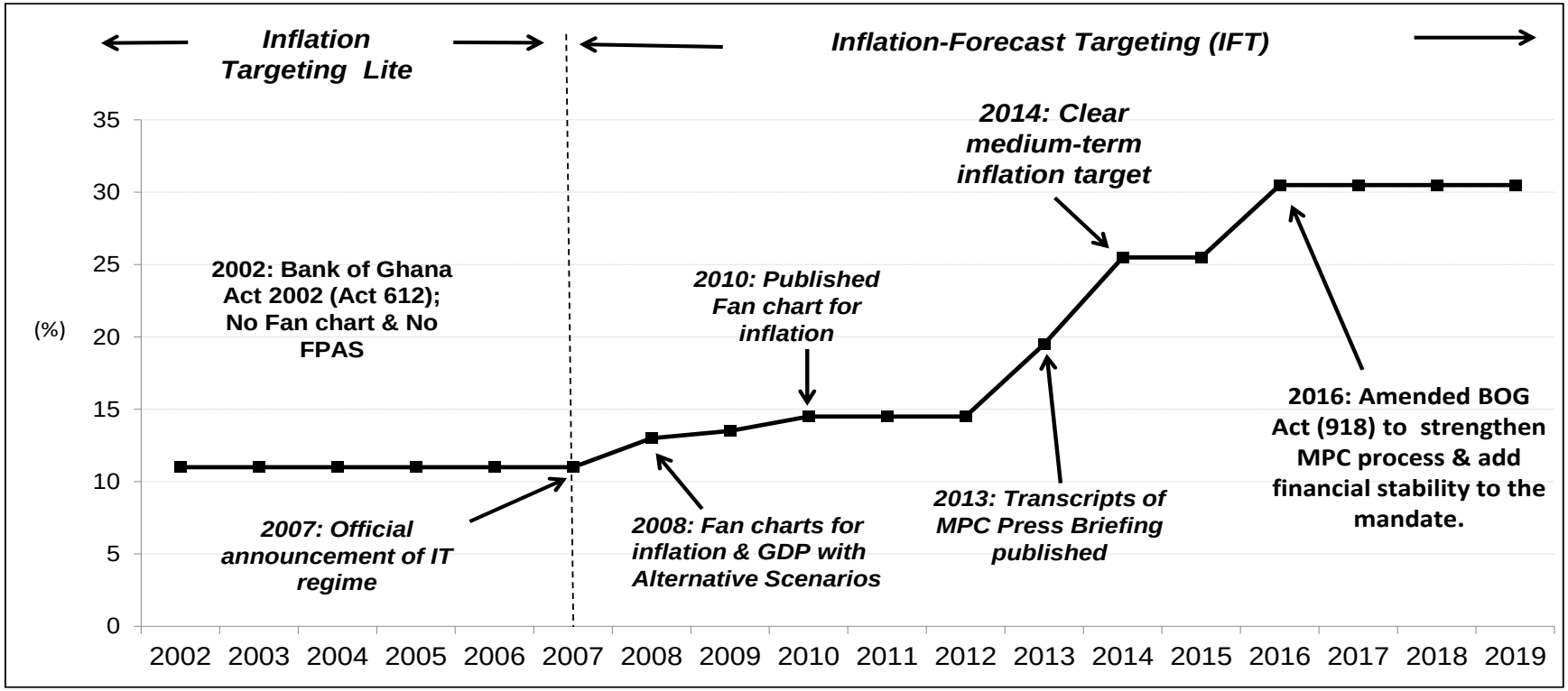
The transparency about policy objectives (Category A) has 4 dimensions. On aggregate, BOG had a total score of **3/4** score for transparency about the policy objectives (i.e. Category A) since 2016. The high (75%) score for BOG with regards to TAPO was however occurred over time. From the onset, and as clearly indicated in the Table 3, BOG has a clearly defined policy objective of price, facilitated by the promulgation of BOG Act 612 in 2002. This declaration by BOG is in agreement with the first pillar (i.e. A1) of TAPO which borders on clear statement of monetary policy objective(s). In this case, a perfect score is attained for A1 if inflation is declared as the primary objective such that any other objective (output, etc.) cannot be inconsistent with the primary objective of anchoring inflation and inflation expectations. Consequently, for post-2002 era, BOG secures a perfect score for A1 because the Act 612 clearly stipulates price stability as its primary objective and it can easily be found at the bank's website. However, a thorough examination of the various press statements/releases unveils that BOG adopted a yearly inflation target for the 2002-2013 period[20]. A medium-term inflation target (of 8±2%) was first mentioned in the 2014 MPC press statement/release. As a result, BOG's score for TAPO increased from 1 to 2 in 2014 as it satisfied the 2nd pillar of TAPO (i.e. A2), which emphasizes a clearly defined medium-term inflation target in an IT regime. Furthermore, the enactment of BOG (Amendment) Act, 2016 (Act 918) also articulated that added financial stability mandate of BOG from the year 2016 (See Table 2).

[20] Consistently, the staff report for the June 2013 Article IV consultation conclude that "*Credibility of BOG's IT framework could be also be enhanced by setting a medium-term inflation target to better anchor expectation*." (see, IMF Country Report No 13/187, page 21)

> *"We formulate and implement monetary policy to achieve price stability, contribute to the promotion and maintenance of financial stability, and ensure a sound payment system"* (https://www.bog.gov.gh/).

Such enactment or declaration also satisfies the 3rd pillar of TAPO (i.e. A3) which focuses on the role of financial stability in monetary policy communication. In particular, A3 ascertains whether another institution is responsible for financial stability or the central bank is at least partly responsible for financial stability. A perfect score is attained when central bank cares about financial stability to the extent that it affects stabilization objectives (output and unemployment), and makes it clear that inflation is the primary objective. Besides, central banks with a formal financial stability mandate should have the authority to use macro-prudential tools to tame or prevent financial imbalances. The Act 918 declares BOG as the sole regulator of the banking system to ensure financial stability in Ghana. Various macro-prudential benchmarks for each segment of the banking system are also provided and systemic stress tests are carried out by relevant departments of the Bank. Consequently, BOG score for TAPO increased from 2 in 2014-15 periods to 3 in 2016-19 epochs. For the last pillar of TAPO (i.e. A4), the IFT central banks are required to communicate the achievement of policy objectives to the public. A common approach in the literature (see, Al-Mashat et al 2018) is to compute the historical values of a quadratic loss function (or sacrifice ratio) which panelizes inflation deviation from target, output deviation from potential level and variations in policy interest rate.

Figure 2.1: Historical Trend in BOG's Policy Transparency (2002-2019)

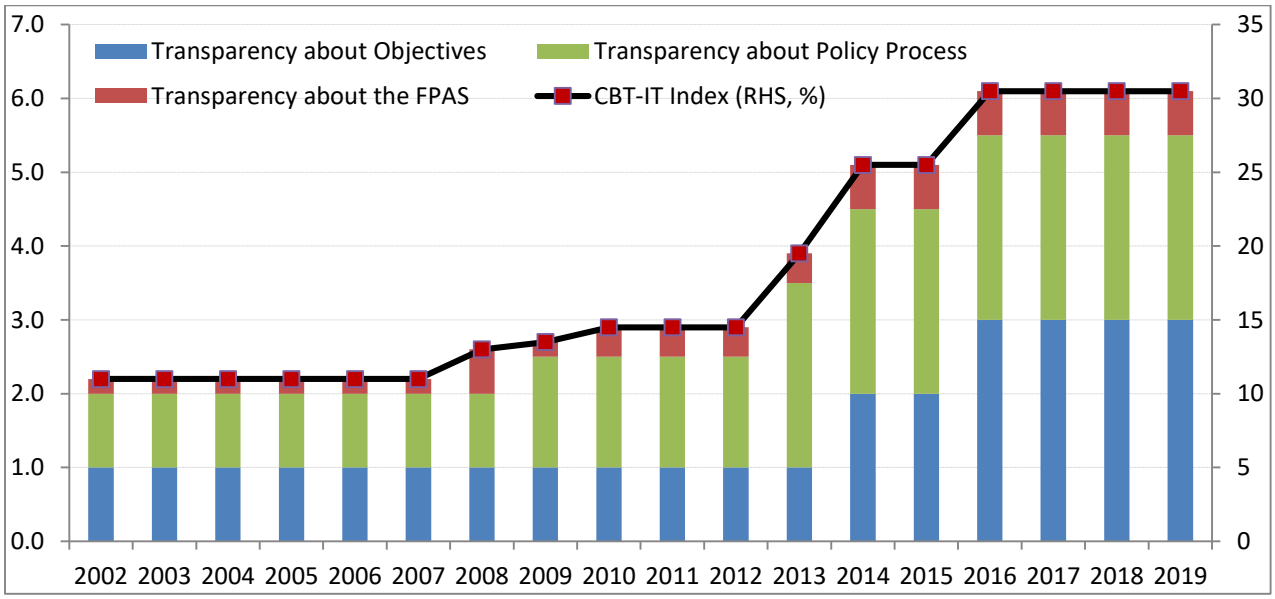


Note: NSDP denotes National Summary Data Page; e-GDDS represents the Enhanced General Data Dissemination System.

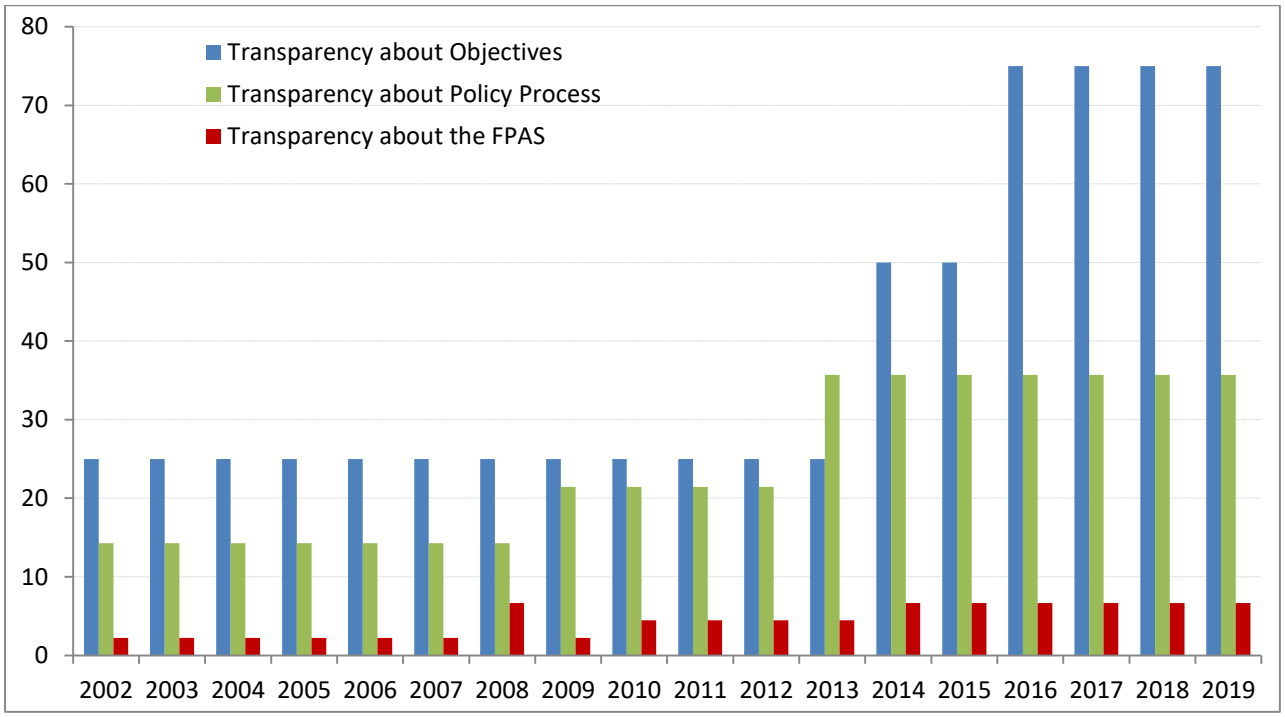
Source: Authors' construct.

Figure 2.2: Evolution of the Three Components of the CBT-IT Index for Bank of Ghana 2002-2019

Panel A: Aggregate and Component Values



Panel B: Percent of Each Component's Maximum Score



In this context of A4, BOG had a zero score is assigned to BOG as Table 2.3 clearly shows that no policy reaction function (i.e. the short-run trade-offs between output and inflation) has been made available to the general public since 2002. Besides, none of the press releases and transcripts at the bank's website provides any official information on BOG's policy loss function nor there is any suggested official linked to a working paper document. In sum, we note that BOG has done pretty well with respect to TAPO. Nonetheless, BOG should follow the best international practices to further its compliance with TAPO by communicating its policy achievement to the general public via the disclosure of policy loss function.

2.2.2.2.2 **Transparency about the Forecasting and Policy Analysis System (FPAS)**

The FPAS, in which forecast is carried out using a core quarterly projection model (QPM-Gap) is a prerequisite framework for the implementation of IFT. As an organizational structure through which macroeconomic information flows to policymakers, the FPAS serves as a crucial medium that facilitates the decision making process of central banks and hence, helps achieve their policy objectives. The rationale is that the FPAS entails the system of communication between policymakers and model builders, between policymakers and forecasters before and after forecast production, and a monetary policy reaction function (Al-Mashat et al., 2018). Besides, the FPAS projection - baseline forecast and alternative scenarios - encompasses: (i) an inflation rate forecast that indicates a return to the long-run target within a medium-term horizon; and (ii) a coherent projection for important endogenous macroeconomic variables (such as short-term policy interest rate, output and exchange rate, etc.). The transparent communication of FPAS forecast is thus a crucial medium to enhance central bank policy credibility.

The transparency about the FPAS (i.e. Category B) has nine (9) pillars and the overall score for BOG is 0.6/9. This surmises a 7% compliance of BOG to the international best practices of IT central bank regarding transparency about the FPAS framework. The detailed analysis indicates that the awful score for BOG in Category B is mainly driven by the lack of disclosure (publication) of the underlying model(s) for its FPAS framework as well as the inadequate dissemination of relevant macroeconomic historical and forecast data to the general public since the inception of the IFT regime. Specifically, BOG in 2014 started providing relevant historical economic and financial data pack (that includes inflation, GDP growth, monetary and financial aggregates, balance of payment, fiscal profile, etc.) to

the general public after each MPC meeting.[21] Nevertheless, the data pack or the monetary policy reports do not provide either historical or forecast series for output gap, wages and unemployment data. As clearly indicated in Appendix 2B, the pillar B1 lays emphasis on public access to at least the seven basic economic data (including output gap, inflation, inflation expectations, wages, unemployment, and GDP growth) relevant for the conduct of monetary policy in a downloadable format. In this case, only the historical time series on inflation and GDP growth are currently provided in the data pack. In addition to the minimal dissemination of relevant historical data, the non-publication of the quarterly projection model (i.e. B2) and non-disclosure of the policy loss function (i.e. B3) underpinning the FPAS framework also inhibit BOG's progress in category B. Consequently, we assigned a cumulative score of 0.2/9 to BOG based on the first three pillars (B1-B3) of Category B as only two (i.e. inflation and GDP growth) out of the seven relevant historical time series are provided to the general public since 2002 (in the case of B1). BOG's score for category B however increased to 0.6/9 in 2008 following the inclusion of fan charts for inflation and output gap in the monetary policy (MP) report. Accordingly, fan charts for inflation and output gap led to a gain of 0.4/1 for pillar B5 which pertains to the provision of forecast densities (fan charts) to communicate forecast uncertainty. The relatively low score for B5 is due to BOG's non-publication of the forecast densities and fan charts for particularly the endogenous policy interest rate (alongside the output gap and exchange rate), contrary to the international best practices of IFT central banks. The score for category B however dropped to 0.2/9 in 2009 as BOG excludes fan charts in the MP report during the 2nd half of 2009. Since 2010, BOG resumed the fan chart for inflation in the MP report[22] which inched up its score by 0.2 points. Subsequently, there is a routine enclosure of inflation fan chart in the MP report, inching up BOG's score for category B to 0.4/9 in the post-2009 era. But contrary to requirement of B6, the central bank still does not disclose the underlying methodology for the construction of the fan chart in the MP report. Consequently, a scored zero is assigned to BOG for B6.

[21] According to the IMF (November 13, 2018), Ghana in 2018 implemented the IMF's Enhanced General Data Dissemination System (e-GDDS) by establishing a National Summary Data Page (NSDP) which is linked to e-GDDS. The NSDP is a one-stop national data portal to publish crucial macroeconomic data on the national accounts, government operations and debt, monetary and financial sector, and BOP, among others. Utilizing the Statistical Data and Metadata Exchange, the NSDP is in both human and machine-readable formats. Hosted by the Ghana's Minister of Finance and Economic Development (MOFEP), the NSDP contains links to statistics published by Bank of Ghana, Ghana Statistical Services and MOFEP. The establishment of NSDP would help inure greater data transparency as it proffers simultaneous access to timely information critical for monitoring economic conditions and policies by domestic and international policymakers and shareholders including investors and rating agencies (see, IMF Press Release No. 18/421).

[22] Available at: https://www.bog.gov.gh/monetary_policy_rpts/

Over the years, BOG has not made available to the general public its forecast revisions (i.e. focus of B7) neither has it satisfied the requirement of pillar B8 by publishing the alternative forecast scenarios in the MP reports to illustrate key risk(s) in the baseline forecast. Unlike other IFT central banks, the MP report of BOG only highlights the imminent risks to the baseline forecast without accompanying alternative forecast output(s). Consequently, BOG has a zero score for both B7 and B8. The final pillar of Category B (i.e. B9) determines whether the MP reports include historical data and forecasts for financial variables such as long-term government bond yields, consumer lending rates, mortgage rates, equity prices, property prices, credit aggregates, corporate risky spreads (e.g., BAA-AAA bond yields), and credit standards (e.g., loan officer surveys). It has been well articulated in the extant literature that measures of financial conditions can significantly improve forecasting performance of models (see, Adrian, Laxton and Obstfeld, 2018). In the case of B9, a perfect score is attained if historical data on 5 or more policy variables are available, and forecasts for 5 or more of the policy variables are available. In the context of Ghana, we find that only the historical time series for consumer lending rates and credit aggregates are reported in the summary of economic and financial data pack at the bank's website[23], implying a score of 0.2/1 for B9 since 2014 and hence, 0.6/9 for category B. More so, even though BOG's Banking Sector report also embodied the survey on credit standards, no historical data for such survey is available to the general public[24]. Our analysis therefore emphasizes the exigency for BOG to follow the international best practices of IFT central banks to enhance its policy openness about the FPAS framework. Notable measures should include the provision of the FPAS documentation (with the core model), policy loss function, fan charts (with the underlying methodologies) for key policy variable aside inflations (particularly, endogenous interest rate, the output gap and exchange rate), increased data dissemination and the provision of alternative forecast scenarios to help shaped agent's inflation expectation formation towards the target.

2.2.2.2.3 Transparency about policy process (TAPP)

As aforementioned, the TAPP **(i.e.** Category C) has seven (7) dimensions. A review of these seven dimensions indicates that BOG has unfortunately satisfies only few of these dimensions. In the first place, Table 2.2 reveals that BOG has a pre-announced date and time for the six MPC meetings of the year along with a routine publication of press statements in English immediately after every press conference since 2002. This implies that BOG attained a perfect score (i.e. 1/1) for the first pillar of

[23]This information can be found at: https://www.bog.gov.gh/monetary-policy/press-releases/3871-summary-of-economic-and-financial-data-november-2018

[24] This report can be assessed at https://www.bog.gov.gh/banking_sect_report/.

TAPP (i.e. C1) which focuses on the routine immediate release of MPC press statement in English[25] to the general public. In addition, even though there has been routine press conference with the Q&A session since ITL regime, only a section of the conference is webcasted while BOG only started publishing the transcript of the press briefing with the Q&A session in 2013. It is realized that this activity by BOG is broadly in line with the second pillar of TAPP (i.e. C2) and hence, a perfect score of 1/1 is assigned to BOG for C2 particularly since 2013[26]. That is, BOG score for TAPP increased to 2/9 for the year 2013 and beyond.

The next category of TAPP (i.e. C3) emphasizes the important of regular central bank interactions with the market analysts and investors and the deliberations from such meetings made available to the general public. Since the discussion between the central bank and journalists, analysts, and market participants are not published, it is therefore uncertain that the deliberations with market analysts include forecast updates and a Q&A session. Consequently, we assigned a zero score (0/1) to BOG for dimension C3. The publication of MPC minutes is also seen as an international best practice of IFT central banks and such as, the question C4 emphasizes the publication of policy deliberations ("minutes") in less than one month after the meeting. This question seeks to determine whether policy decisions are made by a (i) monetary policy committee (MPC) or (ii) single policymaker. In this case, a perfect score is assigned if the response is affirmative for either (i) or (ii) along with detailed contributions by individual MPC members and the voting results on the main policy instrument. Unfortunately, and as illustrated in Table 2.3, the MPC minutes are so far not published by BOG, implying a zero score (0/1) for C4 since 2002. In line with the non-publication of the FPAS framework, the role of staff and policymakers in the baseline forecast process is not communicated clearly to the general public. Similarly, the forecasting performance of the central bank has never been disclosed to the general public since the inception of IT regime in Ghana. Consequently, BOG attains zero CBT-IT scores for both the 5th and 6th pillars of Category C (i.e. C5 and C6).

The final pillar of TAPP (i.e. C7) focuses on the last time the central bank held or invited an external evaluation of the policy framework and the FPAS, and whether the results were made publicly available. Particularly, a full score is given if the central bank allows an external and independent evaluation of the policy framework and FPAS every five years. We identify that the IMF's team has numerously visited BOG (particularly since 2003) as part of the IMF's extended credit facility

[25] It is easily accessible at https://www.bog.gov.gh/monetary-policy/press-releases.
[26] This information is readily available at https://www.bog.gov.gh/mpc_press_release/transcript-of-mpc-press-briefing-held-on-november-25-2019/

programs for Ghana. In most cases, the findings and recommendations of the IMF's staff missions to Ghana pertaining to BOG's policy stance are included in their communiqué. For instance, Ms. Annalisa Fedelino, the lead of the IMF team that visited Ghana from June 20-26, 2018 concluded that: "*The monetary policy stance remains appropriate and inflation is expected to continue to decline to the 8 percent target before the end of the year*"[27]. Nevertheless, BOG has not officially provided on its website the discussions with the IMF team concerning the external evaluation of its policy framework (or FPAS). Consequently, since a somewhat partial report on the evaluation of the policy framework or FPAS is provided to general public by the IMF rather than from BOG, we assign a score of 0.5/1 for BOG in this category of question (i.e. C7). On a whole, BOG secured a total score of 2.5/7 for TAPP, implying the need for rapid improvement by BOG in this category.

Our analysis accentuate that out of 20 CBT-IT questions (based on the three broad categories), BOG attains an overall transparency score of 6.1 (30.5%), indicating a relatively lower degree of monetary policy transparency in Ghana as at end-2019.

2.2.2.3 **Discussion for Transparency Score for Ghana**

Collectively, the estimated transparency score for BOG as at the end of 2019 is 30.5% and 50% based on the CBT-IT and EG-DE measures respectively, implying a low-to-moderate degree of monetary policy transparency in Ghana. However, the estimated EG-DE transparency score for Ghana suggests a slight improvement from the 37% score reported by Naszodi et al. (2016) over a decade ago (i.e. for 2009). Yet, the estimated score strengthens the findings by Dincer and Eichengreen (2014) and Naszodi et al., (2016) that the Bank of Ghana is less transparent. By extension, the moderate transparency score is also an indication that the central bank may be perceived to be incredible by private agents. As a result, economic agents' formation of inflation expectation will continue to be backward-looking, as alluded to by Kovanen (2011), which does not bode well for realizing the core policy objective of price stability in Ghana. Another basic finding is that the Bank of Ghana Acts 2002 (Act 612) and the Amendment Act 2016 (Act 918) which provide legal framework (in terms of clarity in policy objectives and central bank independence, etc.) for BOG's operations is broadly consistent with the requirement of IT strategy. Nevertheless, the predominant areas of concern of policy transparency in Ghana include non-disclosure of policy analysis and forecasting framework used by the MPC for decision making, non-publication of minutes of MPC meetings and non-disclosure of the

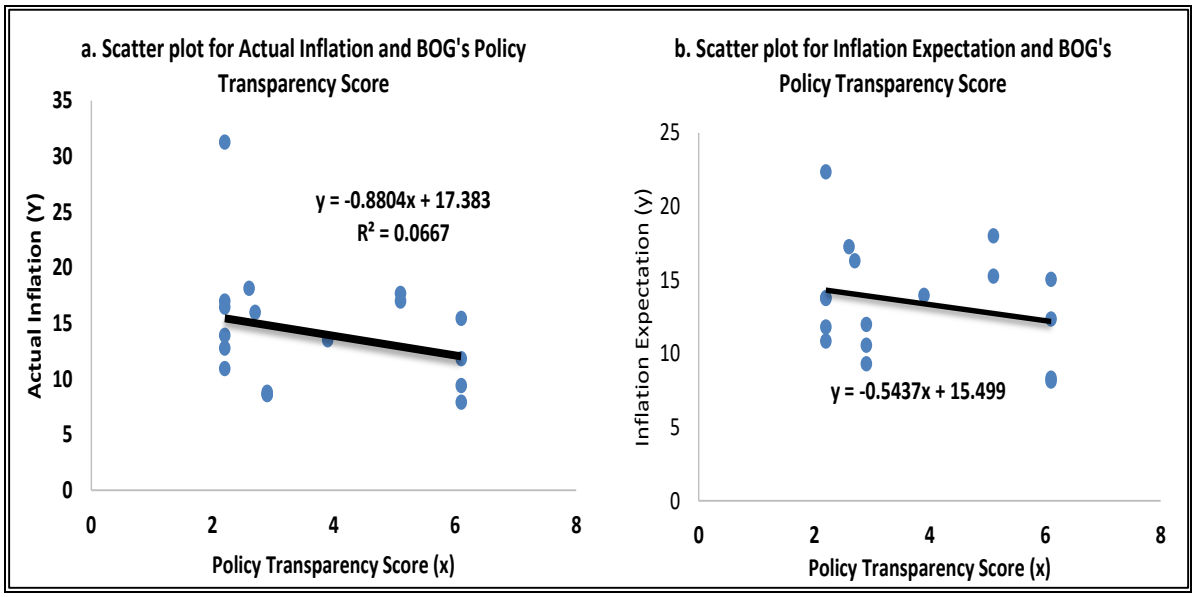
[27] Available at: https://www.imf.org/en/News/Articles/2018/06/26/pr18256-imf-staff-concludes-visit-to-ghana

forecast of the key macroeconomic variable (such as endogenous policy interest rate) aside fan chart for inflation.

2.2.2.4 Cursory Analysis of Policy Transparency and Inflation Expectation

Following the literature (e.g. Al-Mashat et al 2018; Cruijsen and Demertzis, 2007), we proceed to examination the empirical link between policy transparency and inflation and inflation expectation in the context of Ghana over the period 2003-2019. Figure 2.3 displays the scatter plot with a trendline[28] which illustrates the impact of greater policy transparency on inflation expectation (and actual inflation) in Ghana. Persuasively, our pilot investigation (in Figure 2.3) clearly demonstrates a negative correlation between BOG's transparency score and actual inflation (or inflation expectation). Specifically, the cursory analysis unequivocally demonstrates the proclivity for greater central bank transparency to hasten the disinflation process and also help anchor inflation expectation around the target in Ghana, which is in line with empirical findings Cruijsen and Demertzis (2007). Although this requires further investigation, the observed negative linkages between BOG's policy transparency score and inflation expectation (and actual) still offers critical implications for monetary policy implementation in Ghana, regarding the enhancement of central bank transparency in order to adequately diminish the high inertia in inflation expectation and to boost policy credibility.

Figure 2.3: Impact of Policy Transparency on Actual Inflation and inflation expectation



[28] The focus on scatter plot is mainly due to smaller sample size (2003-2019) which would make the use of more standard econometric estimation less tenable for meaningful economic inference.

2.3 Measuring Monetary Policy Credibility

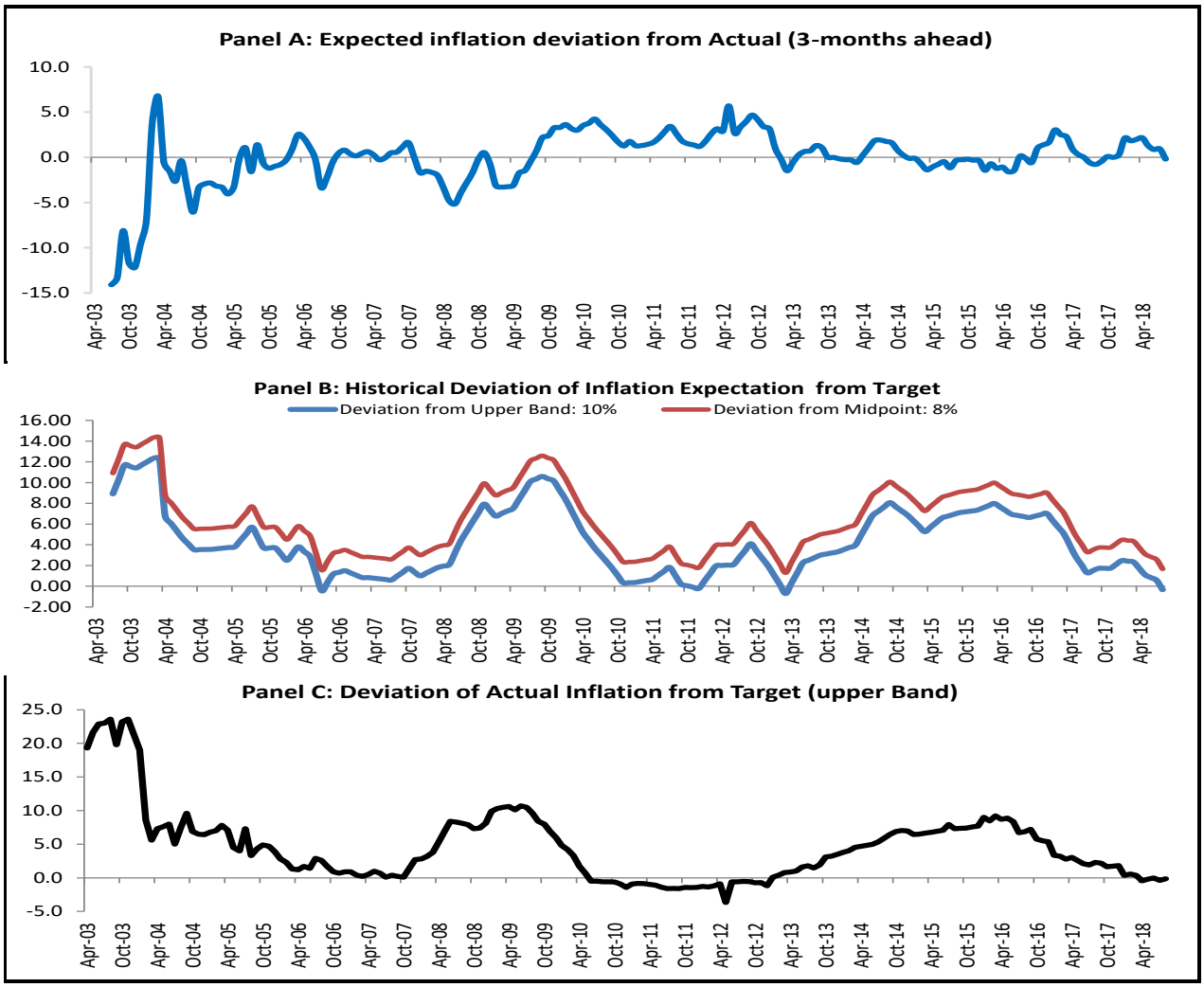
Policy credibility is a fundamental issue in modern central banking (Gonzalez-Paramo, 2007). For instance, Blinder (1998, 2000) deemed credibility as a treasurable asset that needs to be seriously upheld by central banks. A central bank is classified as credible if economic agents' formation of inflation expectation is substantially contingent on the announced inflation target (Bomfim and Rudebusch, 2000). That is, a credible monetary authority is able to well-anchor inflation expectation at or below the target point or within the target band. This notion is largely premised on the fact that increased (diminished) policy credibility lowers (heightens) uncertainty in the economy and hence boosts (damages) planning capacity of economic agents. Greater policy transparency is also recognized to boost central bank's credibility (see Al-Mashat et al., 2018). Therefore, given the level of monetary policy transparency in Ghana, it is of paramount interest to quantitatively determine how it has shaped policy credibility and agent's formation of inflation expectations over the years. As part of its IT implementation process, the BOG conducts bimonthly inflation expectation surveys for businesses, consumers and financial system. But this analysis focuses on business inflation expectation due to its larger data coverage (since April 2003).

Figure 2.4 displays the dynamic deviations of inflation expectation from a 3-month-ahead actual inflation and target. A quick look at the figure reveals that agent's expectation has generally been close to the 3-month ahead actual inflation in Ghana (see Panel A) as the mean deviation is -0.09 with a standard deviation of 3.05. Notably, however, agents' expectations seem to have initially been underestimated the pass-through of exchange rate vulnerability on domestic inflation especially during the early part of the recent global financial and debt crisis (2008/9). This consequently reflected in agents' over-expectation of inflation between late 2009 and December 2012, although the period recorded an unprecedented 31 months of single digit inflation in Ghana (see Panel C). Since then, however, agents' inflation expectation was close to actual inflation, with the exception of an apparent positive gap for November 2016 –March 2017 (largely linked to election cycle effect and fiscal uncertainties) and January to April 2018 (also connected to considerable exchange rate pressures).

Another important observation in Panels B and C of Figure 2.4 is the persistent and rising positive deviation of actual/expected inflation from the target especially since April 2013 with a peak in March 2016. This broadly reflects the era of significant exchange rate pressures, successive upward adjustments of administrative prices of petroleum, utilities and transports amid surge in international crude oil prices and domestic energy supply challenges. The subsequent general stabilization of the domestic currency, normalization of domestic energy supply conditions as well as stringent fiscal and

monetary policy measures contributed to the downward trajectory of actual and expected inflation towards the target level since March 2016.

Figure 2.4: Inflation Expectation and Inflation Dynamics



Note: in Panel A, the deviation is computed as: Expected Inflation minus 3-month ahead actual inflation; in Panel B, the deviation is computed as: Expected Inflation minus medium-term target (midpoint or upper band); In Panel C, the deviation is computed as: Actual Inflation minus Target inflation

Although one can crudely deduce from the preceding figure the extent of monetary policy incredibility in Ghana, we proceed to quantify the latter based on the direct measurement indicators espoused by the extant literature. Prior to that, we provide brief theoretical underpinnings for the credibility indicators. Using single target point, Cecchetti and Krause (2002), henceforth CK, gauge central bank policy credibility as an inverse function of the gap between agent's inflation expectation and the inflation target. The CK credibility index is specified as:

$$cred_{CK} = \begin{cases} 1 & if \quad \pi^e \leq \pi_t^* \\ 1 - \left(\dfrac{\pi^e - \pi_t^*}{20\% - \pi_t^*} \right) & if \quad \pi_t^* < \pi^e < 20\% \\ 0 & if \quad \pi^e \geq 20\% \end{cases}, \qquad (2.1)$$

where π^e is private sector inflation expectation; π_t^* is the inflation target (or the midpoint). From equation (2.1), the central bank is fully credible (cred_{CK}=1) if expected inflation is at most equal to the inflation target but it is incredible ($\text{cred}_{\text{CK}} = 0$) if expected inflation is at least 20%. The index takes values from 0 (no credibility) to 1 (full credibility).

De Mendonça, (2007), henceforth DM, extended the CK index by using target range rather than a single point. This was based on the notion that negative deviation of inflation expectation from target can equally surmise loss of policy credibility. The credibility index for DM is specified as:

$$Cred_{DM} = \begin{cases} 1 & if \quad \pi^e = \pi_t^* \\ 1 - \left(\dfrac{\pi^e - \pi_t^*}{\pi_t^{\blacksquare} - \pi_t^*}\right) & if \quad \pi_t^{min} < \pi^e < \pi_t^{max} \\ 0 & if \quad \pi^e \geq \pi_t^{max} or \quad \pi^e \leq \pi_t^{min} \end{cases} \tag{2.2}$$

where π_t^{min} is the lower bound of inflation target; π_t^{max} is the upper bound of inflation target; $\pi_t^{\blacksquare} \in \left(\pi_t^{min}, \pi_t^{max}\right)$ denotes the inflation target bound, which corresponds to the lower bound (π_t^{min}) if $\pi^e < \pi_t^*$ and to the upper bound (π_t^{max}), if $\pi^e > \pi_t^*$. Notwithstanding, both CK and DM indices are based on the notion that full credibility is obtained when the expected inflation is exactly equal to the midpoint of the inflation target, but declines proportionally and linearly when expectations deviate from target point.

However, De Mendonça and de Guimarães e Souza (2009), henceforth DMGS, criticized the CK and DM approaches as too restrictive and therefore could engender misleading conclusions. They therefore assert that full credibility is also attained when inflation expectations are within the target range but not necessarily at the midpoint. Accordingly, the DMGS proposed the following credibility index:

$$Cred_{DMGS} = \begin{cases} 1 & if \quad \pi_t^{min} \leq \pi^e \leq \pi_t^{max} \\ 1 - \left(\dfrac{\pi^e - \pi_t^{max}}{20\% - \pi_t^{max}}\right) & if \quad \pi_t^{max} < \pi^e < 20\% \\ 1 - \left(\dfrac{\pi^e - \pi_t^{min}}{-\pi_t^{min}}\right) & if \quad 0 < \pi^e < \pi_t^{min} \\ 0 & if \quad \pi^e \geq 20\% \, or \quad \pi^e \leq 0 \end{cases} \tag{2.3}$$

The preceding indices imposed symmetric (linear) policy credibility loss function which has been questioned by several practitioners at central banks on the ground that it has little support beyond analytical flexibility. Particularly, Levieuge, Lucotte and Ringuede (2015), henceforth LLR, argued that a credibility indicator should not necessarily be linear and as such classified the CK, DM and DMGS approaches to be too restrictive. LLR therefore proposed a policy credibility index that is based on asymmetric linear exponential (LINEX) approach. The LLR approach considers only positive

deviations of inflation expectations from target as a loss of central bank credibility. They perceive negative deviations to exert less serious impact (if any) on central bank credibility than that emanating from positive deviations. The LLR policy credibility index is specified as follows;

$$Cred_{LLR} = \begin{cases} \dfrac{1}{exp\left(\pi^e - \pi_t^{min}\right) - \left(\pi^e - \pi_t^{min}\right)} & for\ \pi^e < \pi_t^{min} \\ 1 & for \quad \pi_t^{min} < \pi^e < \pi_t^{max}, \\ \dfrac{1}{exp\left(\pi^e - \pi_t^{max}\right) - \left(\pi^e - \pi_t^{max}\right)} & for \quad \pi^e > \pi_t^{max} \end{cases} \quad (2.4)$$

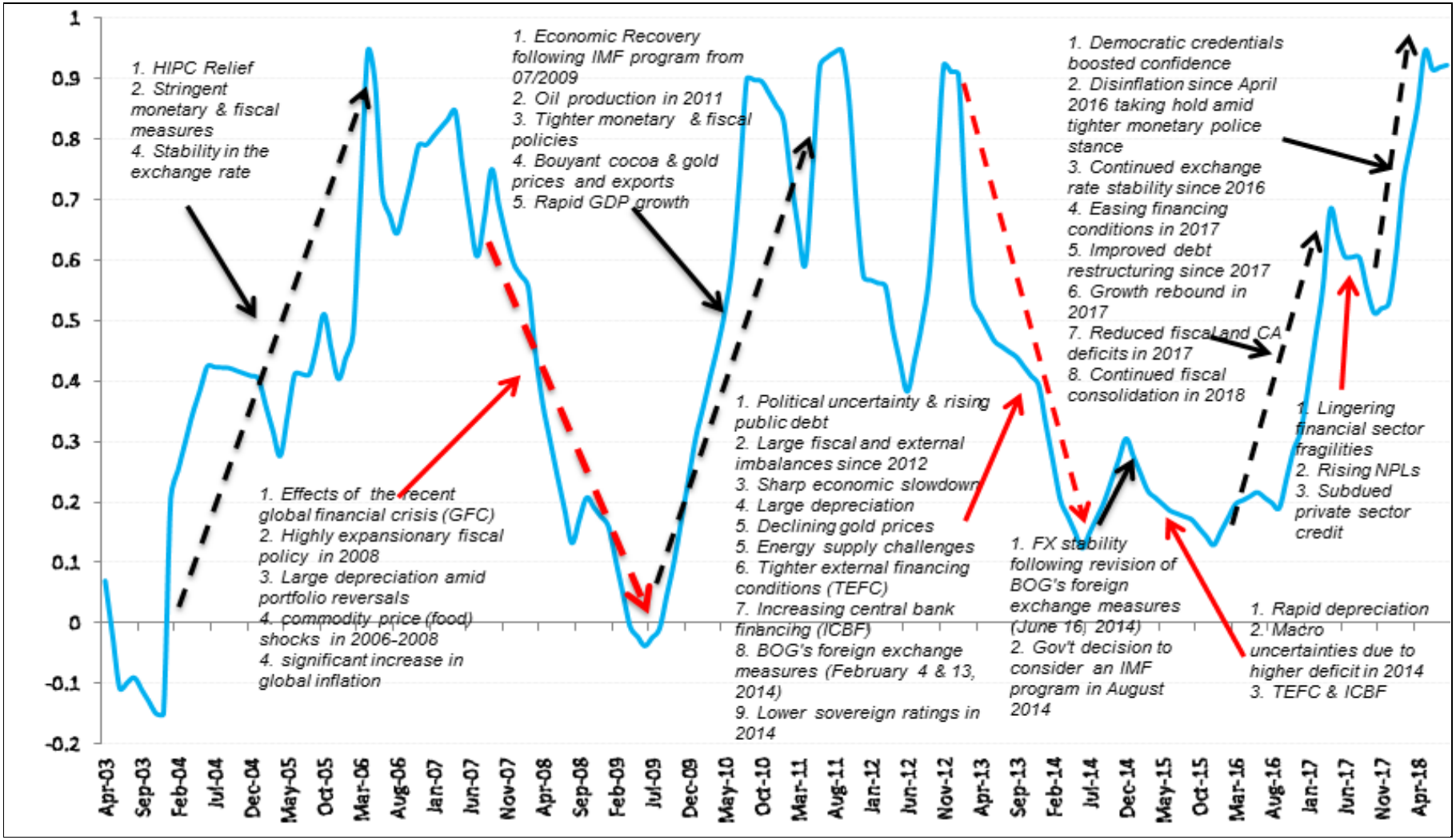
For robustness, the chapter develops a consolidated credibility index for Bank of Ghana which captures both the symmetric and asymmetric approaches as:

$$Cred_{BOG} = \theta_1 Cred_{CK} + \theta_2 Cred_{DMGS} + \theta_3 Cred_{LLR} \quad (2.5)$$

where θ_i denotes normalized average weights, computed as an arithmetic average of the weight generated via principal component analysis (PCA) and an inverse of a standard deviation of the respective index. Although this approach is similar to Akosah et al (2017), this paper applied weights that were only computed as an inverse of a standard deviation. Therefore, the thesis differs as it provides more robust weights with less subjectivity. Besides, the thesis provides high frequency analysis which is more informative for quick policy decision-making.

Figure 2.5 provides the policy credibility index for Bank of Ghana between April 2013 and August 2018 with the associated influencing macroeconomic developments. A quick glance at the figure largely illustrates monetary policy credibility over the years has been mixed due to frequent policy slippages that have resulted in significant external and domestic imbalances and consequently compounded adverse impact of shocks to the economy. Nonetheless, there is ample evidence of two-to-three-year cycles of high and low central bank credibility in Ghana. As illustrated by the insertions in the figure, the principal drivers that influence economic agents' perception about the extent of BOG's policy credibility include exchange rate dynamics, fiscal policy profile, and external trade and/or financing conditions. Essentially, periods with favourable (unfavourable) outcomes from these macroeconomic factors with resultant implication on inflation have largely raised (dwindled) BOG's policy credibility.

Figure 2.5: BOG's Policy Credibility Profile and the influencing Macro-Developments



Note: the black (red) broken arrows indicate increase (slowdown) in economic growth, while the black (red) solid arrows provide factors that underpin the slowdown (pickup) in economic growth respectively. **Source: Own construct**

Particularly, BOG's policy credibility has improved remarkably over the past two years, as the index picked up from a trough in December 2015 (0.12) to a peak of 0.946 in May 2018. The significant boost in monetary policy credibility particularly since 2017 can largely be linked to the peaceful election and transition of power to new political administration which renewed investor confidence, continuous exchange rate stability and disinflation since 2016 on the back tighter monetary policy stance, rigorous fiscal consolidation efforts alongside improved debt restructuring (which lengthened maturity profile and hence minimized rollover risks) with lower deficit outturn for 2017, remarkable rebound in economic growth momentum since early 2017 as well as favourable (or eased) external financing conditions and good sovereign ratings in 2017. However, the subsequent decline in credibility for the period June-August 2018 is broadly associated to tighter external financing conditions amid successive Fed rate hikes, lingering trade war and stronger US dollar which have adversely affected both emerging and developing economies.

2.4 Conclusion

This chapter determines the degree of both policy transparency and credibility in Ghana, given the high level of inflation persistence despite over a decade of practicing IT regime by the Bank of Ghana. For the transparency measure, we employ the methodologies proposed by Dincer and Eichengreen (DE, 2014) and Al-Mashat et al. (2018). Prior to that, we assess the institutional and structural framework of Bank of Ghana (BOG) vis-à-vis the tenets of inflation targeting regime with regards to clarity of policy objective, extent of central bank independence and policy communication and accountability. The chapter classifies Ghana as an inflation-forecast-targeter (IFT) but not yet reach the status of a fully-fledged IFT economy as it has so far not satisfied certain key transparency requirements of the latter category of countries. To advance to a fully-fledged IFT status, the central bank has to follow the best practices of major central banks to, among others, disclose the conditional numerical forecast path of the endogenous policy interest rate within its core quarterly projection model. This facilitates the understanding of how the monetary authority in Ghana has been addressing the short-run output-inflation trade-offs.

Collectively, both transparency approaches adopted in this chapter point to relatively moderate transparency score for BOG and this hampered by the low transparency score attained for the questions relating to the FPAS and the policy processes. Consequently, our transparency measures for BOG consistently suggest that several areas of policy communications need to be improved in order to boost transparency, and ultimately enhance the effectiveness and credibility of the IT regime. Compared to the estimate by Naszodi et al (2016), our estimates strongly suggest that monetary policy transparency

has certainly improved since 2009, albeit marginally. More importantly, our cursory analysis also supports the negative relationships between central bank transparency score and inflation expectation established in the extant literature. This preliminary finding thus remits a very important implication for current monetary policy implementation in Ghana that greater policy transparency by BOG would help tame inflation expectation to the medium term target and hence, accelerates the disinflation process.

What's more, the established low-to-moderate transparency score for BOG in this chapter consistently suggest that several areas of policy communications need to be improved in order to boost transparency, and ultimately enhance the effectiveness and credibility of the IT regime. Notable areas that required policy attention to boost transparency are: (1) the documentation and publication of the Bank's core quarterly projection model (FPAS) with key equations (especially the loss function); (2) the provision of more information about how BOG is dealing with the short-run sacrifice ratio (i.e. tradeoffs between output and inflation); (3) public access to the minutes from the MPC meetings with or without detailed contributions by MPC members; (4) evaluating and publishing how each decision on policy instrument or target are attained; (5) in addition to regular publication of fan chart for inflation in the monetary policy report, BOG should also consider publishing other core macroeconomic variables that are included in their baseline forecasts with confidence bands, risk assessments, and decomposition of forecast revisions; (6) the underlying methodology for the construction of forecast confidence bands should also be clearly explained; (7) there is the need for regular review of forecasting performance of the central bank and this should be made accessible to the public; (8) Continuous external evaluation of the policy framework and the FPAS at least every 5 years even when not under IMF program, and publishing the findings.

Consistent with a moderate level of policy transparency, we find that monetary policy credibility over the years has been mixed. There is ample evidence of two-to-three-year cycles of high and low central bank credibility in Ghana. The principal influencing drivers of economic agents' perception about the extent of BOG's policy credibility are exchange rate dynamics, fiscal policy profile, and external trade and/or financing conditions. Essentially, periods with favourable (unfavourable) outcomes from these macroeconomic factors with resultant implication on inflation have largely raised (dwindled) BOG's policy credibility. For instance, period of rapid exchange rate vulnerability generates very low policy credibility. This suggests that the deliberate policy attempt to weaken the domestic currency to gain international trade competitiveness may rather be counterproductive for monetary policy credibility.

CHAPTER THREE

Has Inflation Targeting Strategy Made A Difference in Ghanaian Macroeconomic Management?

Analysis of Business Cycle Fluctuations and Econometric Estimates

3.0 Introduction

The role of monetary policy in business cycles is palpably buttressed in macroeconomic literature. Since economic expansions and contractions are intrinsic in economic systems, monetary policy efficiency is generally defined by its capacity to produce price and financial stability or to dwindle cyclical economic oscillations[29]. DeLong and Summers (1986) assert that the gap between actual and potential output is always nonnegative and a successful stabilization policy is expected to close this gap. For that reason, socio-economic welfare is said to have improved if the stabilization policy successfully reverses economic downturns. Oftentimes, the ability of monetary policy to promote long term economic growth is overlooked due to the standard macroeconomic argument of monetary neutrality in the long run. Yet, recent studies generally regard monetary policy as the first line of defense against economic downturns in the short run as price and wages usually do not adjust immediately (Mathai, 2020). Another reason is that monetary authorities devote substantial resources to monitoring and analyzing the economy. Therefore, adjustments in interest rates and/or the money supply can be made more quickly to keep the economy humming or combat downturns while fiscal policy responds slowly to changes in economic conditions. In the short run, monetary authority can stimulate or slow down aggregate spending in the following ways. On one hand, central bank can influence interest rates to affect interest-sensitive spending, such as household spending on consumer durables, residential investment and business capital spending on plant and equipment. On the other hand, when interest rates differ between countries, it triggers capital flows that impact the exchange rate between domestic and foreign currencies, and in turn affects spending on exports and imports. Conversely, monetary policy predominantly affects inflation in the long run and a low and stable rate of inflation is generally acknowledged to boost price transparency and hence, ensure better decision making by economic agents (Labonte, 2015).

[29] The term business or economic cycle refers to a change in the economic activity of a country during a particular period. The recent Great Recession has particularly put more emphasis on the inevitability for experts in economics discipline to identify the turning points in the economy (Skare and Stjepanovic, 2016).

With the failure of monetary targeting and exchange rate targeting regimes to provide effective nominal anchor to the economy (Mishkin, 2008), inflation targeting strategy, after its first adoption by New Zealand, has emerged as one of the most extensively used monetary policy regimes for over three decades. In the latter framework, the nominal anchor for inflation expectation is the inflation target communicated to the public.

The increasing adoption of inflation targeting monetary policy strategy has concomitantly incited debate on the macroeconomic performance in the wake of this new policy strategy. It is acknowledged that for the monetary policy to have the strong impact on the real economy inflation, adjustments in policy interest rate must significantly influence the short-run wholesale interest rate (e.g. overnight interbank rate) which in turn leads to changes in retail interest rates (e.g. lending and deposit rates) and ultimately impact the overall economy and inflation. The scope of impact of the monetary policy adjustments on the wholesale and retail market rates however remains a contemporary issue for central banking, as it had implications on monetary policy credibility and effectiveness. Be that as it may, the supporters of the IT strategy are clearly convinced that there is no better way to conduct monetary policy that could be considered an actual alternative to the IT framework. They argued that the IT strategy for monetary policy increases transparency and strengthens the credibility of the central bank, which allows it to address the problem of time inconsistency (Svensson, 1997; Mishkin, 1999; and Bernanke et al. 1999a). Therefore, the supporters of the new framework for monetary policy argued that the merit of the IT strategy lies in its ability to attain, among others, superior macroeconomic performance (see, Corbe, Landerrache and Schmide-Hebbel, 2002; Mishkin and Schmidt-Hebbel, 2007).

Notwithstanding, the empirical evidence of IT impact on the macroeconomy has so far not reached a clear consensus. A strand of the literature explores the impact of IT strategy on inflation rate and its volatilities. Several studies, such as Ducker & Fisher, 1996; Cecchetti and Ehrmann, 2002; Da Silva and Portugal (2002), Wu (2004), Vega and Winkelried (2005), Batini and Laxton (2007), Goncalves and Salles (2008), Brito and Bystedt (2010), Lin and Ye (2010) and Daboussi (2014), found that the IT strategy significantly reduced both inflation and inflation volatility in OECD countries[30]. Another important study is by Lin and Ye (2009) which evaluated the treatment effects of inflation targeting in thirteen developing countries (excluding Ghana) that have adopted IT policy since the end of 2004. By

[30] It is however argued that inflation forecast errors reduced gradually over time for the countries that adopted an inflation-targeting regime (see, Almeida & Goodhart, 1998; and Bernanke et al. 1999b), while inflation persistence has equally declined sharply for targeters countries during the 1990s (Lin and Ye, 2010).

utilizing a variety of propensity score matching, they show that the IT strategy, on average, has large and substantial effect on subsiding both inflation and inflation volatility in these economies. Nevertheless, they found that the potency of the IT strategy in reducing inflation in these economies is rather heterogeneous. Notably, they further revealed that the performance of an IT regime can be affected by country-specific features such as government's fiscal position, central bank's desire to constraint the movements of exchange rate, its readiness to meet the prerequisites of policy adoption and the time length since the policy adoption. However, there is an enormous body of contrasting empirical evidences in the literature, notably that provided by Ball & Sheridan (2005), Petursson (2004), Genc et al. (2007), Lin and Ye, 2007; Angeriz & Arestis, 2008; Goncalves & Carvalho (2009). These latter studies argued differently that the evidence of beneficial impacts of the IT strategy on the macroeconomy is not unambiguous. For instance, Ftiti and Essadi (2013) assert that the IT regime could not control nor stabilize inflation in New Zealand and Canada during 1990s.

The other segment of the literature has also evaluated the macroeconomic impact of the IT regime on output behaviour (i.e. its average growth and volatilities). For example, studies (such as Friedman and Kuttner, 1996; Friedman, 2002; Cecchetti and Ehrmann, 2002; Ball and Sheridan, 2005; Mishkin and Schmidt-Hebbel, 2007; Ftiti, 2010) found that inflation targeting does not negatively affect output growth and its volatility. By examining a sample of 30 OECD countries, Goncalves and Carvalho (2009) also found that inflation targeters suffer a much higher output loss than the non-targeters. Petursson (2004) and Genc et al (2007) also conclude that empirical validations are unable to justify the targeting inflation impact significantly on the behaviour of macroeconomic variable such as economic growth and inflation. In contrast, other studies (including Batini and Laxton, 2007; Goncalves and Salles, 2008; among others) found that the IT strategy reduces output volatility in emerging economies although the impact on the average output growth is negligible in this group of countries. Lin & Ye (2010) also found that output volatility is reduced for both emerging and industrialized countries. Furthermore, studies (such as Goncalves and Salles, 2008; Lin and Ye, 2010) concluded that inflation targeting strategy stabilized average short-term interest rates for targeters than non-targeters emerging economies over the period 1980 -2005. Using difference-in-difference method for a panel of 53 developing countries of which 20 had adopted the IT strategy by the end of 2007, Daboussi (2014) found that the IT regime effectively boosts economic performance. Batini and Laxton (2007) also found positive of the IT regime on economic performance.

Another important aspect of the debate regards the potential role of the IT strategy in reducing sovereign risk premium (including, Fouejieu & Roger, 2013; Thornton & Vasilakis, 2016; Balima,

Combes & Minea, 2017, among others) which in turn results in lower interest rate (such as, Mishkin & Schmidt-Hebbel, 2007; Goncalves & Salles, 2008; Lin & Ye, 2010; Fouejieu & Roger, 2013; Lanzafame & Nogueira, 2013; Lanzafame, 2016). But the empirical relationship between the IT regime and interest rate is equally inconclusive. For instance, Ball & Sheridan (2005) and Lin & Ye, (2007) found no significant impact of the IT strategy on interest rate based respectively on difference-in-difference and propensity score matching approaches. However, Lanzafame & Nogueira (2013) contested the findings of Ball & Sheridan (2005) and Lin & Ye, (2007) on grounds that both latter studies had methodological flaws. Particularly, they asserted that the methodology in Lin & Ye (2007) does not account for time trends and possible unobservable characteristics of the countries investigated while the approach by Ball & Sheridan (2005) also failed to account for endogeneity problem and to control for time or country fixed effects.

Predominantly, studies on the role of the IT regime in macroeconomic performance are typically based on cross-section estimations (e.g. Ball & Sheridan, 2005) or standard panel techniques (Mishkin & Schmidt-Hebbel, 2007; Fouejieu & Roger, 2013; among others) to control for variable endogeneity. Even though parameter heterogeneity and cross-section dependence among panel groups are of particular importance, the standard panel techniques (i.e. pooled, fixed-effects or GMM estimators) impose a high degree of parameter homogeneity. In addition, the literature clearly articulates that the implementation of the IT strategy in emerging and developing economies face numerous teething troubles as these economies are more prone to large diverse shocks (some face mostly supply-side shocks while others have largely demand-side shocks), have a history of high and variable inflation as well as weaker policy transmission mechanisms (see, Alichi, Clinton and Others, 2009). Giving difference in economic structure and other characteristics, the effects of the IT regime are likely to be heterogeneous across countries. Besides, an implementation of inflation reduction program via a stringent IT strategy in a bid to maintaining policy credibility may rather have a destabilizing impact on such economies.

This chapter primarily ascertains whether adoption of inflation targeting strategy for monetary policy has beneficial or improved economic management and performance in Ghana. This objective is chiefly motivated by the fact that Ghana in May 2007 emerged as the first low-income (developing) country but the second African economy (after South Africa) to adopt IT strategy. But the inflation reduction program in Ghana via the IT strategy has frequently been thumped by shocks (predominantly supply-side), placing it among the top ten African economies with higher inflation. Unequivocally, Ghana has managed to bring inflation within the medium-term target in only two (2) out of the eleven (11) years

of official practice of the IT strategy. At the same time, however, Ghana is classified among the fastest growing economies in the world, especially in 2018 and 2019. Perhaps, an unambiguous conjecture is that Ghana has been practicing flexible rather than draconian IT strategy, given the inherent economic and structural constraints in order to minimize the variability in economic growth.

Unlike the previous studies, this chapter investigates the macroeconomic impacts of the IT strategy in Ghana in two-fold. First, we focus on cyclical analysis by quantifying or deriving monetary and real business cycle statistics using more expansive datasets such as Real GDP and its (aggregate demand) components, consumer inflation, real and nominal interest rate (i.e. MPR and 91-day Treasury bill rate) and exchange rate (both nominal and real). This approach is germane as it facilitates our understanding of the economic business cycle frequencies across monetary policy regimes in Ghana. This is because little is known about the business cycle dynamics in Ghana. There are a number of underlying factors that motivate the analysis of Ghana's business cycle. First, it helps to ascertain whether the components of aggregate demand (including consumption, investment, government spending, and exports) move pro or countercyclical in the context of Ghana. It also facilitates our understanding of the degree of persistence of the movement in aggregate activity across regimes. The answers to these questions form a basic set of empirical facts about business cycles that can be used to validate our open economy DSGE model. Besides, the great ratios based on the national income accounting are used as prior information in the calibration of the Bayesian DSGE model (in Chapters 6 & 7).

Furthermore, the literature justifies the low inflation in industrialized and emerging economies by a favourable global environment and the stability of inflation is observed in countries with and without IT regime (see, Fisher, 1996; Cecchetti and Ehrmann, 2002). Therefore, the second approach estimates the precise impact of the IT strategy on inflation and output growth using a number of standard econometric techniques while controlling for other salient global and domestic macroeconomic events and/or disasters. The inclusion of other variables as well as domestic and external economic and/or natural events helps to precisely pin down the effect of the IT strategy on the aforementioned variables in Ghana.

3.1 IT Regime and Real Business Cycles in Ghana

3.1.1 **Extracting the Business Cycles**

Important steps in business cycle analysis are the determination of trend and the execution of detrending processes. Nevertheless, there is neither a precise definition of "trend" nor any logical

algorithm for extracting it. As a result, various methods have been used to determine trend and to facilitate a detrending procedure (Wu, Haung, Long & Peng, 2007). The practice of separating the trend and cyclical components using linear time series methods are well established. The literature is replete with several methods for de-trending economic time series. A key method is the linear de-trending approach with the presumption that the observed series has a deterministic time trend. To extract a log-linear trend, consider natural logarithm of real GDP or output (y_t) in year t defined as

$$y_t = \bar{y}_t + \hat{y}_t \tag{3.1}$$

where $\bar{y}_t$ denotes the trend (secular) component of y_t, and $\hat{y}_t$ denotes the transitory (cyclical) component of y_t. The components $\bar{y}_t$ and $\hat{y}_t$ are estimated by running the regression

$$y_t = \alpha + \beta t + v_t \tag{3.2}$$

setting

$$\bar{y}_t = \alpha + \beta t \tag{3.3}$$

and

$$\hat{y}_t = v_t \tag{3.4}$$

The parameters α and β can be estimated via ordinary least squares (OLS). For example, this is how King, Plosser, and Rebelo (1988) define the cyclical component of U.S. time series in their seminal real business cycle paper.

Other studies, also adopted a log-quadratic approach to extract the cyclical components for business cycles. In the case of log-quadratic detrending method, the components $\bar{y}_t$ and $\hat{y}_t$ are estimated by running the regression

$$y_t = \alpha + \beta t + \gamma t^2 + v_t \tag{3.5}$$

setting

$$\bar{y}_t = \alpha + \beta t + \gamma t^2 \tag{3.6}$$

and

$$\hat{y}_t = v_t \tag{3.7}$$

The parameters α and β can be estimated via ordinary least squares (OLS). The log-quadratic detrending is similar to linear detrending with one major difference, as the former technique assumes the data follows an exponential pattern. For example, this is how Mendoza (1991) defines the cyclical component of Canadian time series in his small-open-economy real business cycle model for Argentine. In addition, Uribe and Schmidt-Grobe (2017) also applied similar approach to analyse the comparative business cycle dynamics among advanced, emerging and developing economies.

These two approaches have however been criticized that they fail to address the fact that economic time series usually have a unit root. A major contribution in this analysis comes from Nelson and Plosser (1982) who showed that real GDP usually has a unit root process. Consequently, the alternative to these two preceding detrending approaches is the growth rate method which assumes that the logarithm of variables in question is integrated of order one. That is, natural logarithm of output and its aggregate demand components have unit root at levels but are stationary (no unit root) at first difference. In this case, the stochastic trend is modeled with a presumption of a unit root in the time series. This notwithstanding, Stock and Watson (1999) argue that linear/quadratic time trends or first differentiation to eliminate the unit root do not provide satisfactory results for identifying the cyclical component series of the observed data. On one hand, they asserts that the log-linear/-quadratic approaches to extract time trends result in the generation of false effects of business cycles in de-trending series. On the other hand, they aver that the first differentiation also aggravates the role of short-term noise.

Consequently, numerous alternative approaches have recently been proposed in the business cycles literature to address the separation of the trend from the cyclical components of the time series. One of these approaches is the so-called Hodrick−Prescott (HP) filter, developed by Hodrick and Prescott (1997). The HP filter identifies the transitory and trend components of y_t for $t = 1,2, \dots, T$ by minimizing the quadratic form in a given series:

$$\min_{[\hat{y}_t, \bar{y}_t]_{t=1}^{T}} \left\{ \sum_{t=1}^{T} (\hat{y}_t)^2 + \lambda \sum_{t=2}^{T} [(\bar{y}_{t+1} - \bar{y}_t) - (\bar{y}_t - \bar{y}_{t-1})]^2 \right\} \tag{3.8}$$

subject to equation (3.1). The FOC associated with the preceding minimization problem yield

$$\begin{aligned} y_1 &= \bar{y}_1 + \lambda(\bar{y}_1 - 2\bar{y}_2 + \bar{y}_3) \\ y_2 &= \bar{y}_2 + \lambda(-2\bar{y}_1 + 5\bar{y}_2 - 4\bar{y}_3 + \bar{y}_4) \\ &\dots \\ y_t &= \bar{y}_t + \lambda(\bar{y}_{t-2} - 4\bar{y}_{t-1} + 6\bar{y}_t - 4\bar{y}_{t+1} + \bar{y}_{t+2});\ t = 3, \dots, T-2, \\ y_{T-1} &= \bar{y}_{T-1} + \lambda(\bar{y}_{T-3} - 4\bar{y}_{t-2} + 5\bar{y}_{T-1} + 2\bar{y}_T) \end{aligned}$$

and

$$y_T = \bar{y}_T + \lambda(\bar{y}_{T-2} - 2\bar{y}_{t-1} + \bar{y}_T) \tag{3.9}$$

Let suppose that $y = [y_1, y_2, \dots, y_T]$ and $\bar{y} = [\bar{y}_1, \bar{y}_2, \dots, \bar{y}_T]$, the preceding expression can be written as

$$y = (I + \lambda Q)\bar{y} \tag{3.10}$$

where I is a $T\ x\ T$ identity matrix and Q is $T\ x\ T$ matrix of constants. Solving for $\bar{y}$, we obtain

$$\bar{y} = (I + \lambda Q)^{-1} y \tag{3.11}$$

Similarly, suppose that $\hat{y} = [\hat{y}_1, \hat{y}_2, \dots, \hat{y}_T]$, we have

$$\hat{y} = y - \bar{y} \tag{3.12}$$

It is obvious from equation (3.12) that, the HP trend component depends on a trade-off between keeping the growth rate of the trend constant and minimizing the variance of the transitory component. Large values of λ restrict changes in the growth rate of the trend parameter. For instance, as $\lambda \longrightarrow \infty$, the HP filtered trend component coincides with a linear trend and all variations in the time series are accredited to the transitory component. On the contrary, as $\lambda \longrightarrow 0$, the transitory component is nil and all variations in the time series are ascribed to the trend component. Conventionally, business cycle studies assume $\lambda = 100$ for annual data and $\lambda = 1600$ for quarterly data. Many authors, including Singleton (1988), King and Rebelo (1998, 2000), and Cogley and Nason (1995), have studied the properties of the HP filter. For instance, Cogley and Nason declare that dynamic business cycles obtained using HP detrending methods depend on the characteristics of the studied data. According to them, the HP detrending technique has satisfactory features if the observed data are stationary, while the HP detrending methods generate spurious business cycle fluctuations if the observed data are non-stationary (see, Cogley and Nason, 1995).

Recently, Baxter and King (1999) developed another alternative detrending approach, called Band Pass filter (henceforth, BP), which is based on the spectral analysis of economic time series. Precisely, the BP filters and traces the long-term trend of the high-frequency changes in an observed time series. The BP approach maintains the components that are associated with the periodicity of a classic business cycle. Typically, this periodicity is between six quarters and eight years. The BP filter of Baxter and King (1999) is obtained by applying the jth order moving average of a given time series:

$$\hat{y}_t = \sum_{j=J}^{J} \alpha_j\, y_{t-J} \tag{3.13}$$

where the ratio of the moving average is selected to be symmetrical $\alpha_j = \alpha_{-t}$ for $j = 1, \dots, J$, showing that if the sum of the coefficients of the moving average is zero, $\sum_{j=J}^{J} \alpha_j = 0$, then there is a characteristic of trend elimination. Profoundly, the BP either eradicates deterministic quadratic trends or produces a stationary series that is integrated of order two or less. Another important feature of the BP is that its cyclical components are not contingent on the sample size nor does it change the relationship between time series at any frequency. In essence, the BP was created taking into consideration the low-pass and high-pass filters with the required properties (Skare and Stjepanovic,

2015). Table 3.1 provides the summary of the various methodologies used by researchers in defining business cycles.

Table 3.1: Methods of defining business cycles

Authors	Methods for defining business cycles
Burns and Mitchell (1946)	Business cycles are a type of fluctuation in aggregate economic activity.
Zarnowitz (1992), Mendoza (1991), Uribe and Schmidt-Grohe (2017)	Considers growth cycles where the fall in the series is determined by the deviation from the long-term trend.
King, Plosser and Stock (1991)	Using a model of real business cycle, they implied that growth and business cycles are mutually determined.
Singleton (1988), King and Rebelo (1999), Cogley and Nason (1995), Uribe and Schmidt-Grohe (2017)	An alternative approach for defining business cycles using the Hodrick-Prescott (HP) filter.
Baxter and King (1999)	Another alternative approach for defining business cycles using spectral analysis of time series – Band Pass filter.
NBER (2010)	Business cycles are based on two parts: cyclical peaks and bottoms

Source: Skare and Stjepanovic (2015)

Nevertheless, the literature is inconclusive about the single most outstanding solution for measuring business cycles as each method has its own merits and shortcomings (see, Skare and Stjepanovic, 2015). Consequently, we apply all the existing five detrending methodologies in the literature to determine the business cycle dynamics for Ghana in order to ensure a robust analysis. These include log-linear detrending, log-quadratic detrending, HP filtering, BP filtering and first differencing methods (i.e. growth cycles).

This chapter uses both annual and quarterly dataset covering the period 1975-2018. The first group of dataset used for the business cycle analysis includes real GDP and its aggregate demand components (i.e. public consumption, household consumption, imports, exports and trade balance). In addition, monetary policy is the first line of defense against economic slowdowns. Therefore, we also explore the extent to which monetary policy cycles has influenced the cyclical frequencies in Ghana. As a small-open economy, it is equally critical to understand how exchange rate dynamics contributes to the business cycle frequencies in Ghana. Moreover, the role of fiscal expenditure and its financing implication on domestic interest rate cannot be overlooked. Accordingly, the second group of dataset employed includes the short-term interest rates (such as 91-Day Treasury bill rate and monetary policy rate), exchange rate (both nominal and real) and consumer inflation.

To validate this assumption under growth rate method, we first carry out two unit root tests for the variables in question based on Augmented Dickey-Fuller (ADF) and KPSS tests. The ADF test has a

null of unit root (non-stationary) at levels against an alternative hypothesis of no unit root (stationary). In contrast, the KPSS test has a null of no unit root (stationary) against an alternative hypothesis that the series has unit root (non-stationary) at levels. Table 3.2 presents the result from ADF and KPSS unit root tests which unanimously suggest that all the variables in question are integrated of order one. The unit root results lend support to the application of first differencing method in addition to the log-quadratic detrending and HP filter for the Ghana's business cycle analysis. Nevertheless, the results of ADF and KPSS test are conditional on the assumption that output has a univariate representation. The result is thus interpreted with caution as theoretical models of business cycle do not imply that output has a univariate representation.

Table 3.2: Results of unit root test

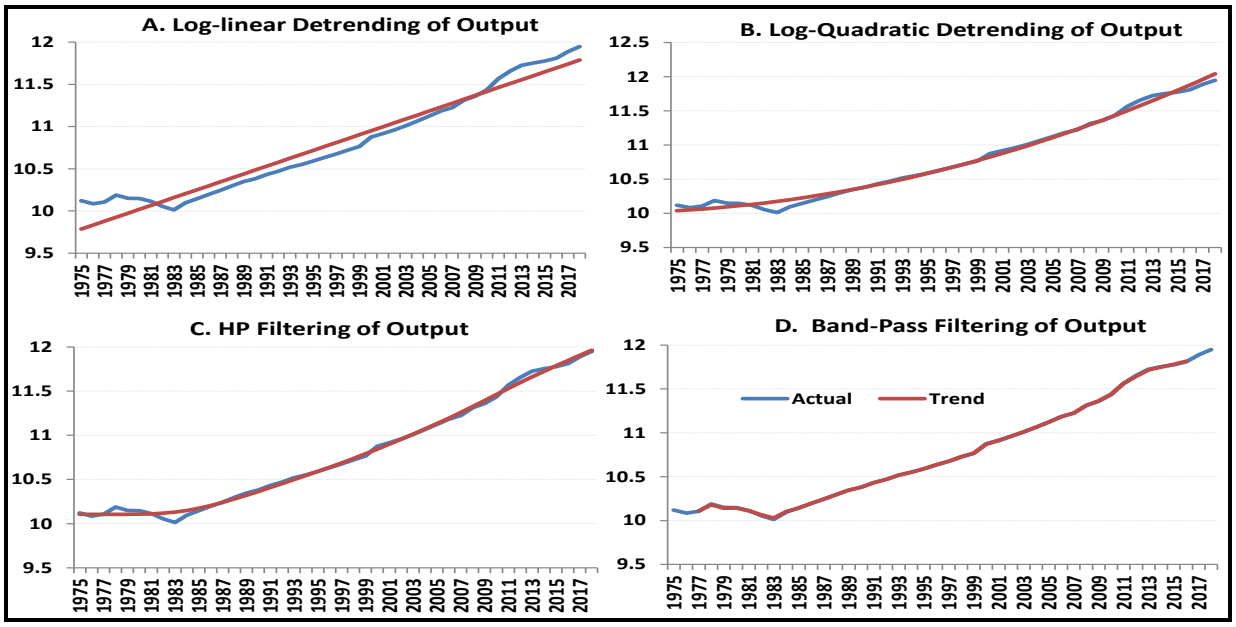
	ADF Test							
Lags	y	c	g	i	X	m	tb	tby
0	0.747	-0.817	-1.585	-0.27	-0.704	-1.602	1.702	1.630
1	0.218	-1.020	-1.584	-0.522	-0.936	-1.728	-0.062	-0.040
2	-0.055	-1.081	-1.544	-0.651	-1.109	-1.810	-0.342	-0.300
3	-0.014	-1.068	-1.448	-0.681	-1.221	-1.837	-0.142	-0.106
4	-0.130	-1.625	-1.237	-0.681	-1.249	-1.729	0.908	0.901
AIC for lag length	-0.055	-1.215	-1.585	-0.522	-0.936	-1.602	0.077	0.089
First Difference	-2.804***	-3.256**	-8.319*	-6.386*	-6.699*	-7.479*	-2.661***	-2.696*
	KPSS Test							
0	7.246*	7.007*	1.279*	6.986*	5.685*	4.352*	4.928*	5.224*
1	3.690*	3.585*	0.683**	3.550*	2.893*	2.232*	2.548*	2.694*
2	2.496*	2.437*	0.481**	2.399*	1.959*	1.521*	1.751*	1.846*
3	1.898*	1.862*	0.380^	1.824*	1.493*	1.166*	1.354*	1.424*
4	1.539*	1.519*	0.321	1.480*	1.215*	0.955*	1.119*	1.173*
AIC for lag length	1.130*	1.126*	0.253	1.088*	0.900*	0.715*	0.853*	0.889*
First Difference	0.142	0.041	0.222	0.076	0.082	0.182	0.345	0.333

Note: *, ** & *** denote 1%, 5% & 10% significant levels respectively; ^ denotes null accepted at 5%.

Figure 3.6 presents the Ghana's actual GDP and its trend implied by the four detrending approaches (log-linear, log-quadratic, HP (with λ=100) filter and band-pass filter) for the period 1976-2018, while Figure 3.7 displays the annual cyclical components of Ghanaian output suggested by the five detrending methods over the same period (log-linear, log-quadratic, HP filter, Band-Pass filter and First Differencing or growth rate methods). In particular, Figure 3.6 unveils monotonically increasing trends implied by the four detrending methodologies. Notably, the Band Pass (BP) filtered trend appears to much closely track the actual GDP, leading to relatively narrower business cycles as exhibited in Figure 3.7. On the contrary, the log-linear detrending method does a poor job as there is considerable gap between the trend and actual GDP. Nevertheless, all the detrending methods attribute the economic contractions (that is, actual GDP growth below its long run trend) particularly in 1981-

1984 and the economic expansion in 2011-2014 (that is, actual GDP growth above its long run trend) to cyclical phenomenon.

Figure 3.6: Trend and Actual Output Dynamics



A close examination of the annual cyclical components (in Figure 3.7) reveals a unilateral detection of economic downturn in 2009 by all the detrending methods, which is intuitively link to the effect of the recent global financial crises. Another important observation is that the log-linear detrending method indicates an economic expansion since 2011. Although the log-quadratic detrending, HP (λ=100) and BP filtering methods reinforce that economic booms between 2011 and 2014, the latter approaches rather point to an economic downturn since 2015. The post-2011 economic upbeat is accredited to the commencement of production and export of oil and gas in Ghana in 2011.

Broadly, similar dynamics in the economic cycles are detected from the quarterly output cycles, as displayed in Figure 3.8. The discussion of quarterly cycles is deemed appropriate as most business cycle analysis for advanced economies are done using quarterly data. On one hand, cyclical components implied by the HP filter (λ=1600) generally indicate economic boom cycles for the periods 2000-2002Q4, 2008, 2011-2014 and 2017 but point to economic downturns for the periods 2007, 2009-2010, 2015-2016 and 2018. On the other hand, the cyclical components implied by the log-linear and log-quadratic detrending methods suggest economic downturn or recession in Ghana over the periods 2002-2010, 2015Q4-2017Q2 and 2018 but reveal economic boom cycles during 2011-2015Q3 and 2017Q3-4. Although the cyclical component implied by the BP filter is broadly akin to the HP filter since 2006, the magnitudes of economic booms or downturns are relative modest in the former filtering method. We however note that the unilateral indication of economic boom in early 2000 and 2017 is

linked to boost in investor confidence following the transfer of political power to new administration. Nevertheless, the conflicting outcomes from the various detrending methods thus warrant cautious economic interpretation of cyclical component implied by each secluded filtering method.

Figure 3.7: Comparative Output Cycles for Ghana

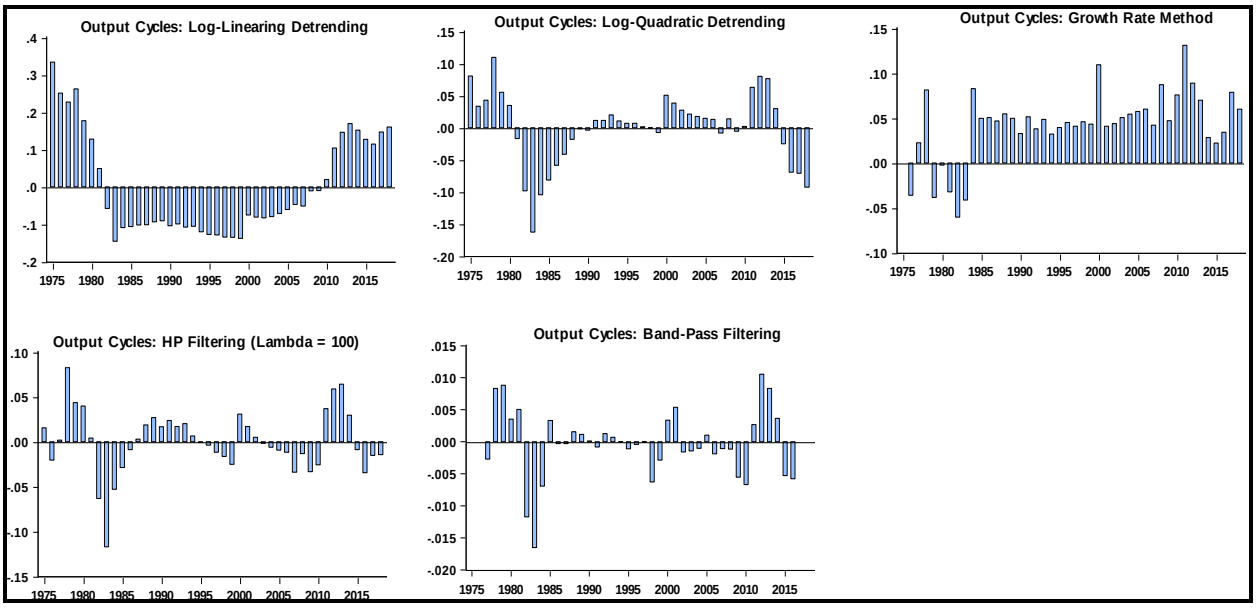
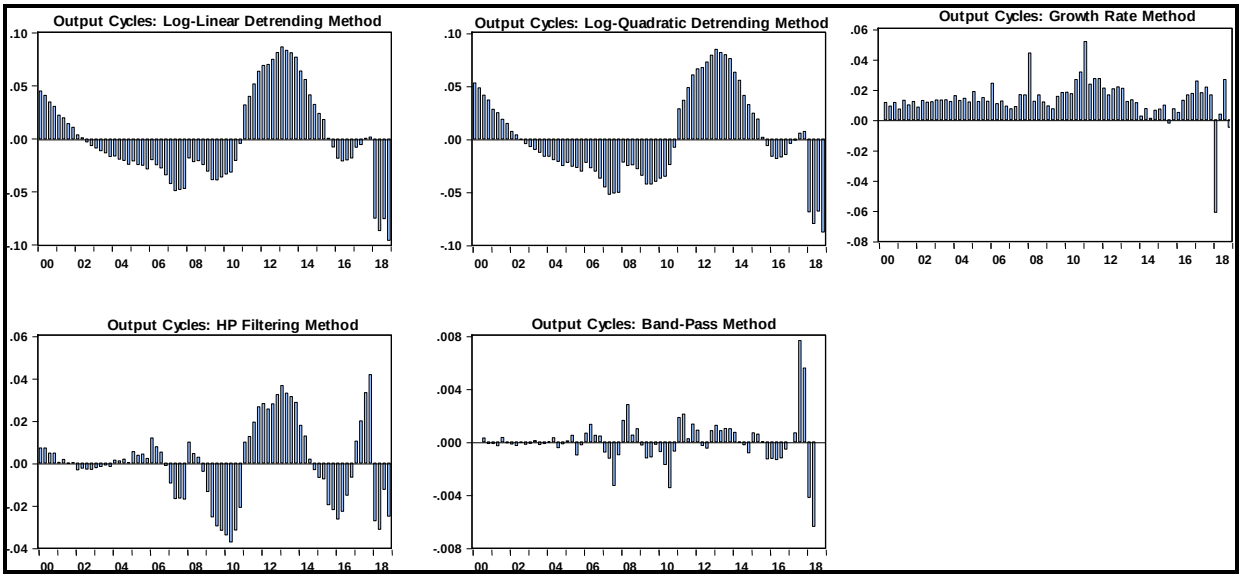


Figure 3.8: Comparative Quarterly Output Cycles for Ghana



3.2.2 **IT Regime and the Cyclical Economic Fluctuations**

Table 3.3 presents the results implied by the five filtering methods. The Panel A of the table reports the relative standard deviations of output and its aggregate demand components (i.e. private aggregate consumption, government consumption spending, investment, exports, imports and trade balance). A key observation from Panel A is that the filters imply quite different amplitudes for the Ghanaian

business cycle. For instance, the standard deviation of the cyclical component of output implied by log-linear detrending is average 1.27% for the annual full sample respectively, but it plummets to a corresponding average of 0.05% with the BP filter. The considerable reduction in the volatility of the cycle implied by BP filter is underpinned by the fact that when the latter approach is applied the trend moves much more closely with the actual data series. Another striking observation from table is that private consumption on average is 5.6% more volatile than output. This empirical observation may attract some attention amid the concept of consumption smoothing which is a mainstay of optimizing models of the business cycle. Nonetheless, this evidence is perhaps conceivable as the measure of private consumption in this chapter also includes durable consumption goods which are very infrequently and hence volatile. It is also apparent from the table that government does not appear to smooth its own consumption of goods and services. On average, the standard deviation of public spending is more than six times as large as that of output over the past four decades. Even the relativity volatility of government spending with respect to output appears to have heightened since the year 2002, with standard deviation of about 13 times as large as that of output (implied the HP filter). In terms of ranking of average standard deviations from top to bottom since 2002, the table unveils trade balance at the pole position and this is followed by government spending, exports, imports, investment, private consumption and output. The subsample analysis reveals that the volatility of output and its components has subsided in the post-2002 era, except for private and government consumption and spending expenditures.

We further explore whether the components of aggregate demand are procyclical or countercyclical. A variable is said to be procyclical (or countercyclical) when the variable in question has a positive (or negative) correlation with output. Panel B presents the correlation coefficients of the aggregate demand components with output. The panel reveals strong evidence of procyclicality for private consumption, investment, exports and imports as their correlations with output are broadly positive in the context of Ghana. This observation is robust irrespective of the data sample and frequency. Import is the most procyclical component of aggregate demand for Ghana, followed sequentially by exports, investments and private consumption. The positive correlation between import and output is conceivably robust as the bulk of domestic economic activities in Ghana depend heavily on the importation of capital and intermediate goods and at the same time a sizeable proportion of consumer price index is imported consumption goods. Strangely, government-spending-to-output appears to be acyclical as the latter is roughly uncorrelated with output for the annual full sample analysis (1976-2018).

However, the post-2002 correlation analysis indicates some evidence of procyclicality for government expenditure as its correlation with output is broadly positive and statistically significant (at least, 3 out of 5 cases). This empirical evidence still runs counter to the conventional Keynesian stabilization policy prescription that the share of government spending in GDP should be increased during recessions and be dwindled during economic booms. Yet, our empirical outcome is very intuitive, at least for Ghana for two main reasons. First, the acyclicality of government spending share in output for the full sample could be linked to the fact that the latter does not include investments which are more procyclical than government consumption spending. Second, it excludes government transfers which are rather more countercyclical than government consumption spending and the former is mostly directed to low-income households with high propensity to consume. The exclusion of government transfers is perhaps mainly due to the fact that such transfers are less evident or even non-existent in developing economies (including Ghana).

We also found contrasting cyclical outcomes for trade balance and trade-balance-to-output ratio for the annual dataset. The log-linear detrending and HP filter implied a procyclicality for trade-balance-to-output ratio while BP filter, log-quadratic detrending and first difference approaches indicate acyclical trade-balance-to-output ratio (statistically insignificant correlation) for the full sample. The full sample estimates point to a procyclical link between trade balance and output by both log-linear and HP detrending methods, while acyclical link between the two variables is rather established by log-quadratic and BP detrending approaches. Although the post-2002 annual data broadly indicates a weak (acyclical) link between trade balance and output, the quarterly analysis points to strong countercyclical linkage between the two variables in the post-2002 era. This means that the Ghana in the post-2002 period tends to import more than it exports during economic expansions (booms) and to export more than it imports during recessions.

Serial correlation (or persistence) means that changes in a variable tend to revert quickly or slowly. Therefore, persistence in fluctuation entails that if stabilization policy successfully reverses downturns, then the social welfare improvements are very large (Delong and Summers, 1986). Besides volatilities and linkages with output, we also ascertain the degree of persistence in output and its components using the standard time series measure of first-order serial correlation. Panel C of Table 3.3 exhibits the serial correlations of the all the variables in question. It is clear from the table that the components of aggregate supply (output and imports) and aggregate demand (private and public consumption, investments and exports) are all positively serially correlated across data sample and frequencies. Particularly, serial correlations implied by the growth rates (FD) method are much lower than their

detrended level counterparts, while the BP method rather shows anti-persistence and moderate persistence for the annual and quarterly respectively. As expected, the serial correlation of the macroeconomic variables is higher in quarterly data than in annual data (see Panel C of Table 3.4). The quarterly average serial correlation for all the macroeconomic variables implied by the remaining five detrending methods is 0.793 per year with a range of 0.758-0.823 in the post-2000, indicating a very persistent cycle fluctuations in Ghana. On a whole, output is the most persistent variable across dataset and frequency, with average serial correlation of 0.891. This is followed sequentially by exports, imports, government consumption, investment, private consumption and trade balance. Above all, we find that the variables are more persistence in the post-2002 era than the preceding period (see Tables 3.3 and 3.4). In line with Delong and Summers (1988), we can conclude that improvement in socio-economic welfare has been larger during the Inflation targeting regime compared to that of the preceding monetary policy regimes in Ghana.

The Panel D of Table 3.3 also displays the relative long run shares of aggregate demand components in output. From the table, the ranking of the relative shares from top to bottom based on the full sample analysis is capital (125%), private consumption (77%), imports (32%), exports (22%), government consumption (17%) and investment (14%). Also, average trade openness ratio, defined as the sum of export and import divided by output, is 54% for the entire period. Although the ranking has not changed, the relative shares of the aggregate demand components in output have increased considerably in the post-2002 era across data frequencies.

Table 3.3: Business-cycle facts for Ghana (annual frequency)

Annual Frequency															
	Period: 1975-2018					**Period: 1975-2001**					**Period: 2002-2018**				
	LL	**LQ**	**HP**	**FD**	**BP**	**LL**	**LQ**	**HP**	**FD**	**BP**	**LL**	**LQ**	**HP**	**FD**	**BP**
Panel A: Standard Deviations															
σ_y	1.27	0.52	0.33	0.36	0.05	1.45	0.58	0.37	0.40	0.06	0.86	0.41	0.26	0.23	0.04
σ_c/σ_y	1.08	1.86	1.86	1.82	1.91	1.08	1.54	1.67	1.54	1.94	0.97	2.54	2.39	3.17	1.75
σ_g/σ_y	1.54	3.77	4.43	4.54	5.26	1.18	2.98	3.57	3.55	3.66	2.64	5.34	6.43	8.53	8.21
σ_i/σ_y	2.99	6.94	7.07	8.19	9.42	3.13	7.10	7.10	8.33	9.77	2.55	6.29	7.00	10.14	8.37
σ_x/σ_y	3.18	6.41	5.30	5.35	5.96	3.33	6.75	4.84	5.27	6.07	2.89	5.24	6.42	7.24	5.60
σ_m/σ_y	3.36	8.09	5.86	5.56	5.64	3.61	8.72	5.84	5.43	5.63	2.52	5.73	5.89	7.58	5.61
$\sigma_{tb/y}$	26.81	716.32	728.65	1187.32	1062.91	25.68	810.31	829.59	1364.18	1235.93	34.56	235.44	94.29	108.84	56.61
Panel B: Correlations with y															
y	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
c	0.873	0.834	0.729	0.559	0.607	0.961	0.861	0.807	0.771	0.705	0.480	0.865	0.630	0.337	0.405
	[11.58]^A	[9.79]^A	[6.90]^A	[4.32]^A	[4.70]^A	[17.42]^A	[8.47]^A	[6.82]^A	[5.93]^A	[4.76]^A	[2.11]^B	[6.68]^A	[3.14]^A	[1.38]	[1.59]
g/y	-0.452	-0.097	0.086	0.170	-0.135	-0.623	-0.002	-0.123	0.061	-0.397	0.207	-0.204	0.454	0.466	0.189
	[-3.28]^A	[-0.63]	[0.55]	[1.10]	[-0.83]	[-3.98]^A	[-0.01]	[-0.61]	[0.30]	[-2.07]^B	[0.81]	[-0.80]	[1.97]^C	[2.03]^B	[0.69]
i	0.472	0.594	0.273	0.338	0.420	0.661	0.716	0.405	0.408	0.407	-0.405	0.271	-0.049	0.180	0.456
	[3.46]^A	[4.78]^A	[1.84]^C	[2.29]^B	[2.85]^A	[4.40]^A	[5.13]^A	[2.21]^B	[2.19]^B	[2.13]^B	[-1.71]	[1.08]	[-0.19]	[0.71]	[1.84]^C
x	0.763	0.753	0.454	0.294	0.110	0.776	0.747	0.341	0.214	-0.094	0.747	0.807	0.667	0.508	0.518
	[7.65]^A	[7.42]^A	[3.29]^A	[1.96]^C	[0.67]	[6.14]^A	[5.61]^A	[1.81]^C	[1.07]	[-0.45]	[4.35]^A	[5.28]^A	[3.47]^A	[2.28]^B	[2.18]^B
m	0.463	0.862	0.688	0.381	0.416	0.600	0.870	0.700	0.454	0.369	-0.119	0.869	0.669	0.466	0.512
	[3.38]^A	[11.04]^A	[6.13]^A	[2.64]^B	[2.81]^A	[3.75]^A	[8.81]^A	[4.89]^A	[2.49]^B	[1.90]^C	[-0.46]	[6.78]^A	[3.48]^A	[2.04]^B	[2.15]^B
tb	0.452	-0.583	-0.373	-0.114	-0.328	0.255	-0.674	-0.493	-0.224	-0.411	0.911	-0.310	0.098	0.017	-0.016
	[3.27]^A	[-4.65]^A	[-2.60]^B	[-0.73]	[-2.13]^B	[1.31]	[-4.56]^A	[-2.83]^A	[-1.12]	[-2.15]^B	[8.56]^A	[-1.26]	[0.38]	[0.06]	[-0.05]
tb/y	0.457	-0.570	-0.377	-0.116	-0.332	0.265	-0.665	-0.496	-0.222	-0.415	0.916	-0.265	0.116	0.028	-0.005
	[3.33]^A	[-4.49]^A	[-2.63]^B	[-0.74]	[-2.16]^B	[1.37]	[-4.45]^A	[-2.85]^A	[-1.11]	[-2.18]^B	[8.84]^A	[-1.06]	[0.45]	[0.11]	[-0.02]
Panel C: Serial Correlations															
y	0.899	0.805	0.665	0.446	0.120	0.845	0.782	0.622	0.349	0.486	0.970	0.952	0.673	0.372	0.526
c	0.816	0.838	0.541	0.142	0.401	0.806	0.729	0.624	0.386	0.493	0.648	1.150	0.384	-0.222	0.090
g	0.654	0.651	0.431	-0.014	0.250	0.656	0.661	0.469	-0.088	0.332	0.619	0.601	0.390	0.039	0.210
i	0.633	0.633	0.285	-0.111	0.160	0.656	0.638	0.328	-0.101	0.214	0.429	0.598	0.161	-0.142	0.018
x	0.795	0.826	0.548	0.241	0.310	0.789	0.819	0.496	0.214	0.392	0.790	0.887	0.607	0.309	0.134
m	0.851	0.873	0.594	0.245	0.273	0.847	0.859	0.659	0.330	0.255	0.948	1.099	0.410	-0.003	0.317

tb	0.717	0.447	0.155	-0.257	0.119	0.487	0.349	0.139	-0.296	0.106	0.852	0.756	0.237	-0.152	0.241
tb/y	0.695	0.413	0.130	-0.264	0.116	0.480	0.329	0.130	-0.299	0.104	0.855	0.741	0.146	-0.144	0.246
Panel D: Great Ratios (Steady State Estimates, %)															
C/Y	77.1					78.1					78.6				
G/Y	17.0					18.3					18.8				
I/Y	14.7					17.4					16.6				
X/Y	22.4					29.9					29.3				
M/Y	31.6					44.1					43.7				
(X-M)/Y	-9.2					-14.1					-14.4				
(X+M)/Y	54.1					74.0					73.1				
K/Y	124.6					308.5					292.0				

Note: LL denotes log-linear detrending method; LQ denotes log-quadratic detrending method; HP is the Hodrick-Prescott Filtering method; and FD is first differencing method; BP is band-pass filtering method; The variable y, c, g, i, x, m and tb represent output, private consumption, government spending, investment, exports, imports and trade balance respectively. The variables y, c, g, i, x and m, are detrended in log and expressed as percentage deviation from trend using the three approaches. The variables g /y and tb/y are respective government spending and trade balance scaled by GDP. The upper case letters denote steady state values. K is steady state capital stock. The superscript A, B & C are 1%, 5% & 10% significant levels respectively. Values in square brackets are t-statistics

Table 3.4: Real Business Cycles at Quarterly Frequency

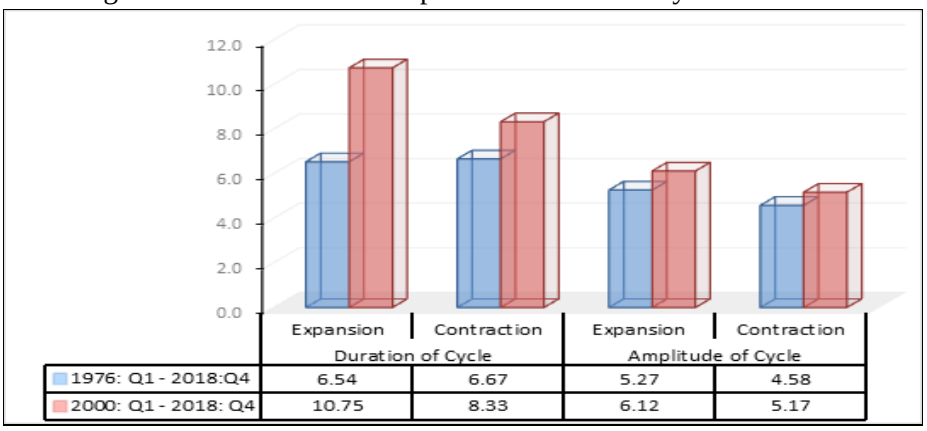
Period: 2002Q1 - 2018Q4					
	LL	**LQ**	**HP**	**FD**	**BP**
Panel A: Standard Deviations					
σ_y	0.37	0.37	0.22	0.08	0.12
σ_c/σ_y	2.14	1.61	1.90	2.88	0.28
σ_g/σ_y	9.17	9.05	9.64	14.38	1.26
σ_i/σ_y	6.23	6.20	8.16	8.05	0.71
σ_x/σ_y	7.31	6.69	7.80	9.26	0.81
σ_m/σ_y	6.68	5.38	7.08	8.64	0.77
$\sigma_{tb/y}$	276.13	71.28	73.16	152.38	13.11
$\sigma_{tb/y}$	254.10	86.69	73.38	152.18	13.11
Panel B: Correlations with y					
y	1	1	1	1	1
c	0.419	0.496	0.291	0.211	0.088
	[3.97]^A	[4.63]^A	[2.47]^B	[1.75]^C	[0.70]
g/y	0.556	0.608	0.003	0.014	-0.004
	[5.76]^A	[6.22]^A	[0.02]	[0.11]	[-0.03]
i	0.110	0.103	0.391	0.272	0.225
	[0.95]	[0.844]	[3.44]^A	[2.29]^B	[1.84]^C
x	0.428	0.371	0.335	0.153	0.061
	[4.06]^A	[3.24]^A	[2.89]^A	[1.26]	[0.48]
m	0.363	0.354	0.348	0.189	0.125
	[3.35]^A	[3.07]^A	[3.01]^A	[1.56]	[1.00]
tb	0.199	0.233	0.036	-0.054	-0.099
	[1.74]^C	[1.94]^C	[0.28]	[-0.44]	[-0.79]
tb/y	0.232	0.260	0.038	-0.046	-0.095
	[2.05]^B	[2.18]^A	[0.31]	[-0.37]	[-0.75]
Panel D: Serial Correlations					
y	0.988	0.981	0.829	0.265	0.505
c	0.983	0.934	0.863	0.512	0.682
g	0.954	0.949	0.932	0.686	0.690
i	0.962	0.960	0.935	0.678	0.654
x	0.966	0.958	0.924	0.625	0.682
m	0.968	0.947	0.915	0.619	0.678
tb	0.909	0.898	0.821	0.441	0.677
tb/y	0.906	0.903	0.823	0.444	0.677
Panel D: Great Ratios (Steady State Estimates, %)					
C/Y	78.65				
G/Y	18.83				
I/Y	16.65				
X/Y	29.38				
M/Y	43.78				
(X-M)/Y	-14.40				
(X+M)/Y	73.16				
K/Y	292.05				

Note: LL denotes log-linear detrending method; LQ denotes log-quadratic detrending method; HP is the Hodrick-Prescott Filtering method; and FD is first differencing method; BP is band-pass filtering method; The variable y, c, g, i, x, m and tb represent output, private consumption, government spending, investment, exports, imports and trade balance respectively. The variables y, c, g, i, x and m, are detrended in log and expressed as percentage deviation from trend using the three approaches. The variables g /y and tb/y are respective government spending and trade balance scaled by GDP. The upper case letters denote steady state values. K is steady state capital stock. The superscript A, B & C are 1%, 5% & 10% significant levels respectively. Values in square brackets are t-statistics

We further explore the duration and amplitude of Ghana's business cycle. Following Calderon and Fuentes (2010) and Uribe and Schmidt-Grobe (2017), we decompose the cycle into contractions and expansions and then estimate the corresponding duration and amplitude. We first identify the peak and trough in the logarithm of real quarterly GDP. In line with the literature, a peak is defined as real quarterly GDP (or output) observation that is higher than the two immediately preceding and succeeding observations. Precisely, a peak takes place when $y > y_{t+q}$ for $q = -2, -1, 1, 2$ and y denotes logarithm of real quarterly GDP. On the other hand, a trough is defined as real quarterly GDP (or output) observation that is lower than the two immediately preceding and succeeding observations: $y < y_{t+q}$ for $q = -2, -1, 1, 2$. Duration of a cycle is a period of time between a peak and the next peak. Specifically, the duration of an expansion is a period of time that it takes to go from a trough to the next peak while the duration of a contraction is the period of time that it takes to move from a peak to the next trough. On the other hand, the amplitude of an expansion is the percentage output gain between a trough and the next peak while the amplitude of a contraction is the percentage output loss between a peak and the next trough.

Figure 3.9 displays comparative empirical estimates for average duration and amplitude of business cycles in Ghana based on log-quadratic detrending approach over the periods 1976Q1-2018Q4 and 2000Q1-2018Q4. The figure reveals that average duration of economic contraction slightly supersedes expansion for longer data span (6.7 vs. 6.5 quarters). The post-2000 estimates rather reveal higher average duration of expansion than that of contraction (10.8 vs. 8.3 quarters). On the other hand, the empirical estimates indicate that the average amplitudes are relatively higher for expansion than that of contraction across sample periods.

Figure 3.9: Duration and Amplitude of Business Cycles in Ghana



	Duration of Cycle		Amplitude of Cycle	
	Expansion	Contraction	Expansion	Contraction
1976: Q1 - 2018:Q4	6.54	6.67	5.27	4.58
2000: Q1 - 2018: Q4	10.75	8.33	6.12	5.17

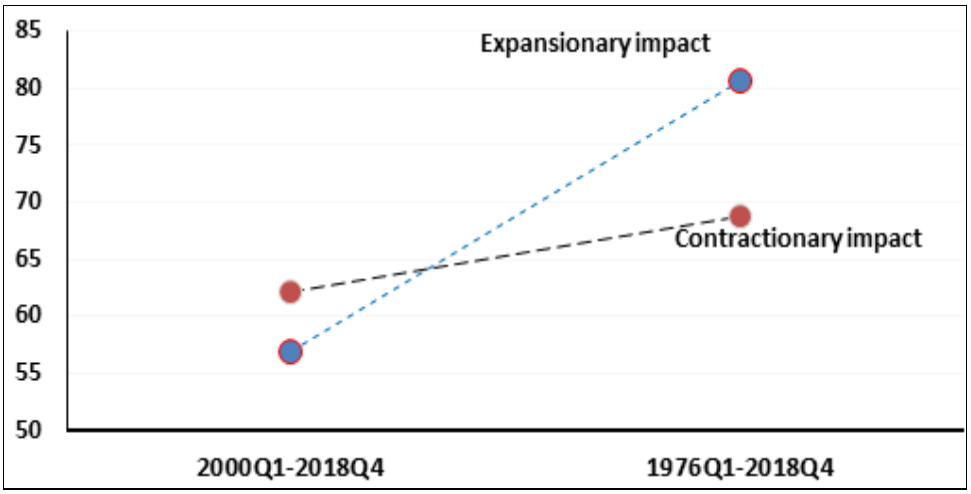
Note: This is derived from log-quadratic detrending

Yet, the divergent durations of contraction and expansion make economic comparison of cyclical amplitudes less persuasive. Consequently, we propose a measure, known as the relative amplitude index (RAI), that proffers fairly precise comparative assessment on cyclical impact on an economy. Our index is formally defined

$$RAI = \frac{average\ amplitude\ of\ a\ cycle_j}{average\ duration\ of\ a\ cycle_j} * 100 \qquad (3.14)$$

where j is either a contraction or an expansion. Based on Figure 3.9 estimates, Figure 3.10 displays the corresponding RAI estimates for the expansionary vs. contractionary cycles in Ghana over the same analytical periods. The RAI estimates in Figure 3.10 clearly unveil that the average expansionary (or boom) cycles have exerted much greater economic impact than that emanating from contractionary cycles for the entire four decades ago. However, the estimates for the post-2000 era reveal much deeper economic impact from contractionary cycles than that originating from expansionary cycles.

Figure 3.10: Estimates of Relative Amplitude Index for Ghana (%)



Economists regard monetary policy as the first line of defense against economic slowdowns. Therefore, to facilitate our understanding of the dynamics of economic cycles observed in the preceding section, we further examine the extent to which monetary policy cycles reflect or explain the detected dynamics of business cycles in Ghana. As a small-open economy, exchange rate plays an important role in Ghanaian macroeconomy. In addition, the role of fiscal expenditure and its financing implication on domestic interest rate cannot be overlooked. As a result, we begin the investigation in this section by comparing the HP filtered cyclical components of output with that of short-term interest rates (including 91-Day Treasury bill rate and monetary policy rate), exchange rate (both nominal and real) and consumer inflation. Figures 3.11 and 3.12 display the graphical results based on annual and quarterly datasets respectively. Particularly, Figure 3.11 demonstrates much higher cyclical volatilities for the pre-2002 era except for the 91-day Treasury bill rate which exhibits relatively greater post-

2002 volatilities. This validates the similar heightened volatilities in government consumption expenditure in the post 2002 era. Another important finding is that relationships between monetary policy and economic cycles are more discernible for the post-2002 quarterly data (in Figure 3.12) than the annual cyclical components (in Figure 3.11).

Consistent with economic theory, Figure 3.12 reveals that the cyclical components of interest rate and output are broadly negative link, indicating a countercyclical policy. Similar inverse relationship is discernible between cyclical components of exchange rate and output in the post-2002 era. As clearly demonstrated in Figure 3.12, economic downturns in 2009-10 (which was largely instigated by the recent global financial crisis), 2015-16 and 2018 are closely linked to above-trend levels of both exchange rate (i.e. depreciation) and interest rate (i.e. policy tightening). Conversely, the economic booms in 2011-14 and 2017 are also linked with below-trend levels of both exchange rate (i.e. appreciation) and interest rate (i.e. policy easing).

Figure 3.11: Annual Monetary and Real Business Cycles using HP Detrending method

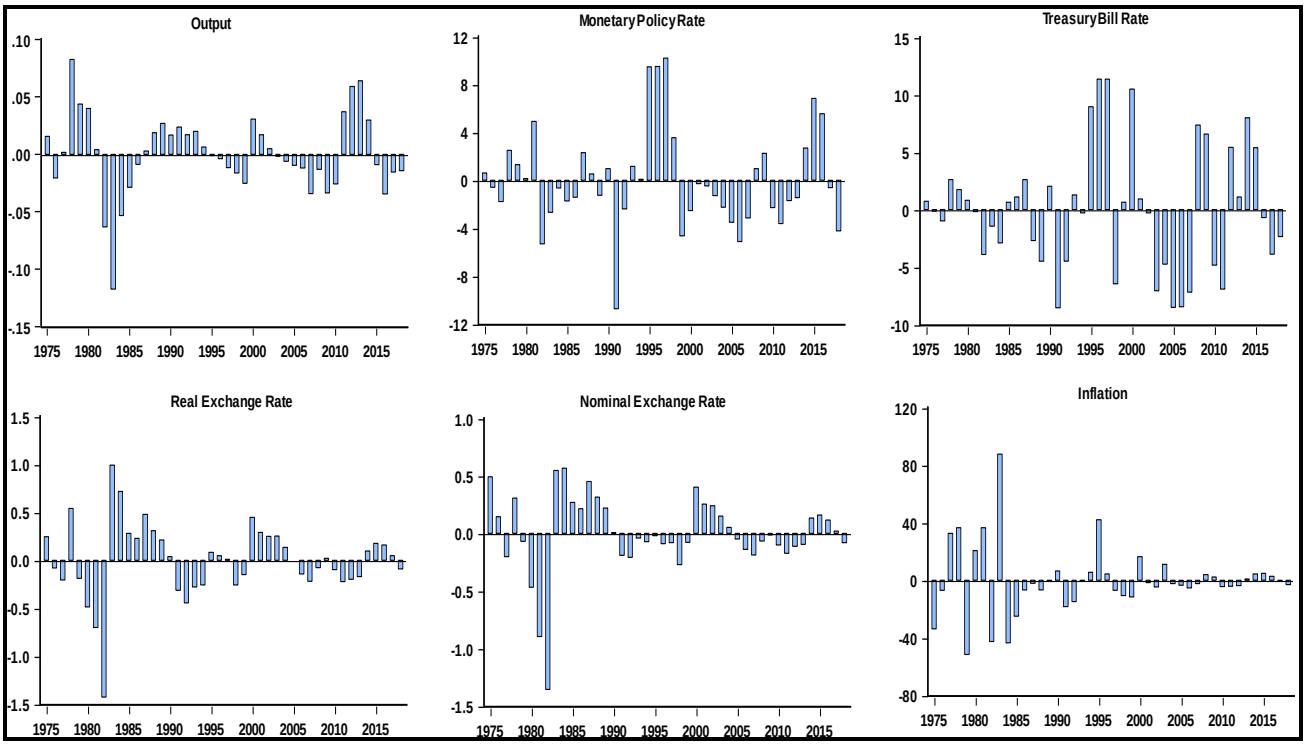
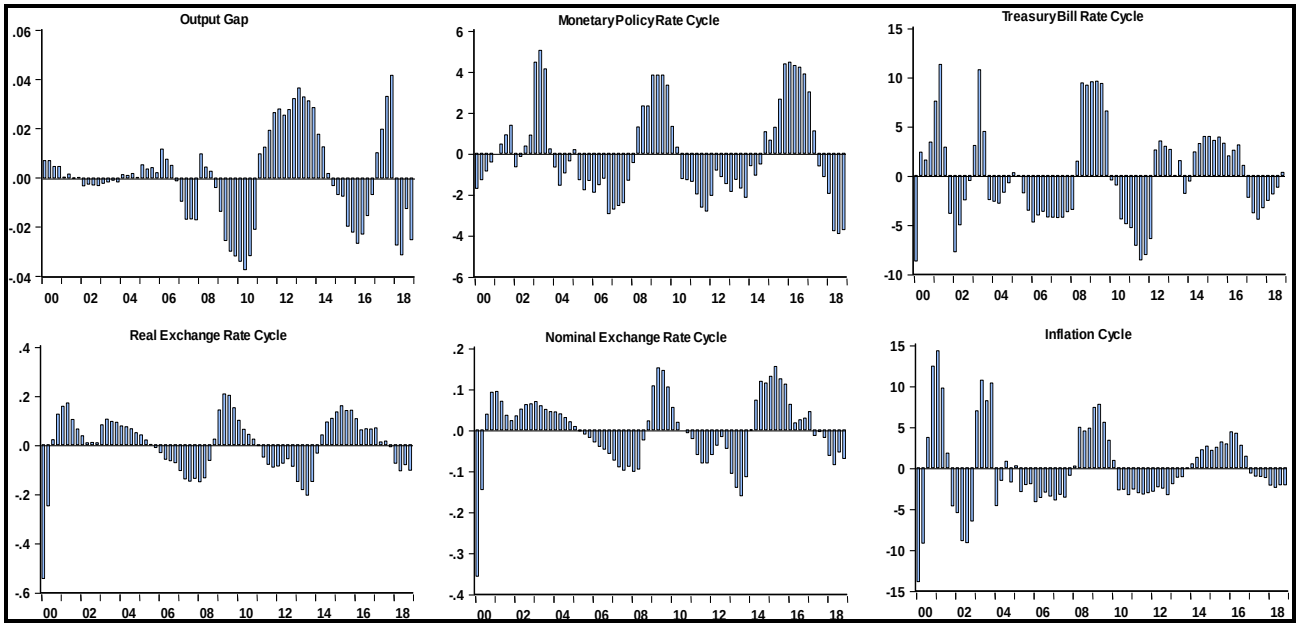


Figure 3.12: Monetary and Real Business Cycles using HP Detrending method



The seeming inverse link between output and exchange rate cycles is instinctively consistent, given the observed procyclical relationship between imports and output in the preceding section. This is because the depreciation (or appreciation) of the domestic currency dampens (or stimulates) import demand which in turn weakens (or boosts) domestic economic activities. In addition, the figure also reveals positive relationships between policy interest rate (MPR) and 91-day treasury bill rate, between MPR and exchange rate, and between MPR and inflation, especially during the IT regime (i.e. post-2002 era).

In addition to the ocular inspection, the extent of macroeconomic interlinkages is precisely quantified and discussed in the ensuing paragraph. Tables 3.5 and 3.6 report monetary and business cycle statistics, implied by the five detrending methods based on annual and quarterly datasets respectively. Panel A of the tables presents the relative standard deviations for the cyclical components of output, 91-day Treasury bill rate, monetary policy rate (MPR), exchange rate (in real and nominal terms) and consumer inflation. Consistently, output is the least volatile variable, while CPI is the most volatile variable based on the annual full sample. Yet, the cyclical volatilities of output, inflation and interest rates have generally moderated since 2002 while that of exchange rate has heightened over the same period. By implication, the post-2002 adoption of inflation targeting regime has yielded relative stability in overall macroeconomy along with greater flexibility in the domestic currency when compared to the previous policy regimes in Ghana. We can therefore conclude that the IT regime has improved macroeconomic outcomes in Ghana compared to the previous monetary policy regimes during pre-2002 era (i.e. direct control and monetary targeting regimes).

Panel B of Table 3.6 displays the correlations of 91-day Treasury bill rate, monetary policy rate (MPR), exchange rate (in real and nominal terms) and consumer inflation with output. First of all, inflation has a countercyclical link with output and this is robust across data frequency and sample size. This is not surprising given the frequent supply-side shocks that hit the Ghanaian economy (including, but not limited to, adjustment in administrative prices of petroleum products and utilities; exchange rate depreciation, energy supply challenges, etc). The panel also shows general weak cyclical linkages of interest rate (both MPR and 91-day Treasury bill rate) and exchange with output for the full sample and pre-2002 era. There is a general countercyclical link between MPR and output which appears to have modestly strengthened during the post-2002, while procyclical output-treasury bill rate link has weakened further in the post-2002 era. The opposite is true for the quarterly dataset for output-MPR linkage and output-treasury bill rate. MPR is countercyclical with output in one out of 5 cases. The result for Treasury bill-output linkage is rather mixed from the quarterly dataset, as we find Treasury bill rate to be procyclical with output in 2 out of 5 cases but is countercyclical with output in 1 out of 5 approaches (HP filter). We therefore conclude of a general weak direct linkage between output and interest rate in Ghana.

Since monetary policy transmission channels are multidimensional, we then explore potential indirect interest rate link with output via exchange rate. In this case, we find a conspicuous countercyclical linkage between exchange rate (in both real and nominal terms) and output in Panel B, especially in the post-2002 era across data frequency. The negative linkage between exchange rate and output is consistent with the earlier reported procyclical link between output and imports (in Table 3.6). This is intuitive as conventional wisdom posits that stronger GDP growth of an economy attracts foreign (direct and/or portfolio inflows) which in turn generates appreciation in the domestic currency. On the other hand, the huge dependence on imported raw material for domestic economic activities makes exchange rate depreciation counterproductive for economic growth as the former inhibits the importation of the requisite raw materials to boost domestic production and hence low output growth. Besides, exchange rate movements have implications of the financial balance sheets of especially individuals and firms with foreign denominated liabilities. Therefore, currency depreciation (appreciation) has adverse (favourable) effect on the financial balance sheets of these individuals and firms which results in reduction (increase) in consumption and investment, hence reducing (raising) output growth.

Table 3.5: Annual Cyclical Dynamics of Monetary Policy Instruments and Output in Ghana

	Annual Frequency														
	Period: 1975-2018					**Period: 1975-2001**					**Period: 2002-2018**				
	LL	**LQ**	**HP**	**FD**	**BP**	**LL**	**LQ**	**HP**	**FD**	**BP**	**LL**	**LQ**	**HP**	**FD**	**BP**
Panel A: Standard Deviations															
σ_y	1.27	0.50	0.34	0.36	0.18	1.45	0.58	0.37	0.40	0.06	0.86	0.41	0.26	0.23	0.04
σ_{cpi}/σ_y	75.90	182.03	131.28	0.42	72.74	85.18	207.54	149.44	0.57	84.12	10.58	4.60	3.07	0.20	3.27
σ_{mpr}/σ_y	40.88	69.69	56.87	99.55	17.66	42.05	43.00	51.30	58.45	51.45	36.15	111.38	70.54	217.49	83.56
σ_{rmpr}/σ_y	153.20	476.76	895.87	1204.70	668.78	86.65	348.91	989.78	1304.87	2641.54	316.58	748.03	473.27	1113.64	767.58
σ_{tbill}/σ_y	45.66	94.51	87.54	388.19	20.57	41.79	49.60	48.41	437.38	74.56	57.76	159.10	149.23	150.35	48.28
σ_{rtbill}/σ_y	170.47	672.54	1220.86	63.30	789.29	87.09	587.84	1318.86	63.03	3081.77	367.31	883.87	767.98	77.62	1328.24
σ_{nxrate}/σ_y	27.36	86.81	139.57	1.12	1032.94	19.73	28.11	42.50	1.20	78.17	28.46	161.78	267.17	0.42	1962.05
σ_{rxrate}/σ_y	177.41	149.52	148.80	1.47	119.68	20.82	32.09	50.03	1.53	132.30	427.33	229.64	292.98	0.52	57.15
Panel B: Correlations with y															
y	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
cpi	-0.959	-0.724	-0.395	-0.443	-0.381	-0.959	-0.726	-0.391	-0.324	-0.363	-0.951	-0.865	-0.656	-0.473	-0.677
	[-22.01]^{A}	[-6.80]^{A}	[-2.78]^{A}	[-3.16]^{A}	[-2.54]^{B}	[-16.92]^{A}	[-5.27]^{A}	[-2.12]^{B}	[-1.67]	[-1.86]^{C}	[-11.8]^{A}	[-6.69]^{A}	[-3.36]^{A}	[-2.08]^{B}	[-3.31]^{A}
mpr	-0.610	-0.080	0.056	-0.025	0.129	-0.681	0.255	0.131	0.102	0.274	0.009	-0.585	-0.155	-0.241	-0.536
	[-4.98]^{A}	[-0.51]	[0.36]	[-0.15]	[0.80]	[-4.64]^{A}	[1.31]	[0.65]	[0.50]	[1.36]	[0.03]	[-2.79]^{B}	[-0.60]	[-0.96]	[-2.28]^{B}
$rmpr$	-0.393	-0.222	-0.106	-0.007	-0.015	-0.456	-0.153	-0.139	0.014	-0.018	0.315	-0.448	0.044	-0.130	-0.065
	[-2.76]^{A}	[-1.47]	[-0.69]	[-0.04]	[-0.09]	[-2.55]^{B}	[-0.77]	[-0.70]	[0.06]	[-0.08]	[1.28]	[-1.94]^{C}	[0.16]	[-0.51]	[-0.23]
$tbill$	-0.559	0.125	0.180	0.069	0.141	-0.629	0.399	0.146	0.112	0.027	0.019	-0.243	0.242	0.187	0.506
	[-4.37]^{A}	[0.81]	[1.18]	[0.44]	[0.87]	[-4.04]^{A}	[2.17]^{B}	[0.74]	[0.55]	[0.12]	[0.07]	[-0.97]	[0.96]	[0.73]	[2.11]^{C}
$rtbill$	-0.381	-0.001	0.033	0.009	0.141	-0.485	-0.040	-0.124	-0.024	0.027	0.222	0.133	0.448	0.168	0.506
	[-2.66]^{B}	[-0.01]	[0.21]	[0.05]	[0.87]	[-2.77]^{B}	[-0.20]	[-0.62]	[-0.12]	[0.12]	[0.88]	[0.51]	[1.94]^{C}	[0.66]	[2.11]^{C}
$nxrate$	-0.822	-0.059	0.016	-0.102	-0.032	-0.778	0.111	0.035	0.030	0.026	-0.919	-0.614	-0.108	-0.235	-0.554
	[-9.35]^{A}	[-0.38]	[0.10]	[-0.65]	[-0.19]	[-6.19]^{A}	[0.55]	[0.17]	[0.14]	[0.12]	[-9.02]^{A}	[-3.01]^{A}	[-0.42]	[-0.93]	[-2.39]^{C}
$rxrate$	-0.909	-0.340	-0.103	-0.227	-0.129	-0.891	-0.204	-0.079	-0.074	-0.065	-0.941	-0.699	-0.286	-0.419	-0.654
	[-14.10]^{A}	[-2.34]^{B}	[-0.67]	[-1.49]	[-0.80]	[-9.81]^{A}	[-1.04]	[-0.39]	[-0.36]	[-0.31]	[-10.7]^{A}	[-3.78]^{A}	[-1.15]	[-1.79]^{C}	[-3.12]^{B}
Panel C: Correlations with mpr															
cpi	0.613	0.039	0.243	0.384	0.288	0.712	-0.189	0.276	0.398	0.265	-0.067	0.779	0.143	0.150	0.559
	[5.03]^{A}	[0.24]	[1.62]	[2.65]^{B}	[1.85]^{C}	[5.07]^{A}	[-0.96]	[1.43]	[2.12]^{B}	[1.31]	[-0.26]	[4.80]^{A}	[0.55]	[0.58]	[2.43]^{B}
$tbill$	0.907	0.840	0.671	0.580	-0.094	0.929	0.812	0.681	0.578	-0.130	0.576	0.831	0.680	0.619	0.003
	[13.95]^{A}	[10.03]^{A}	[5.87]^{A}	[4.55]^{A}	[-0.58]	[12.58]^{A}	[6.96]^{A}	[4.64]^{A}	[3.47]^{A}	[-0.62]	[2.73]^{B}	[5.78]^{A}	[3.59]^{A}	[3.04]^{A}	[0.01]
$nxrate$	0.685	0.328	0.097	0.326	0.165	0.744	0.113	0.025	0.274	0.097	0.159	0.834	0.639	0.822	0.883

	[6.08]^{A}	[2.25]^{B}	[0.63]	[2.20]^{B}	[1.03]	[5.57]^{A}	[0.57]	[0.12]	[1.39]	[0.46]	[0.62]	[5.85]^{A}	[3.22]^{A}	[5.58]^{A}	[6.79]^{A}
$rxrate$	0.683	0.311	0.173	0.392	0.223	0.775	0.030	0.121	0.358	0.154	0.075	0.817	0.564	0.752	0.832
	[6.06]^{A}	[2.12]^{B}	[1.14]	[2.72]^{A}	[1.41]	[6.12]^{A}	[0.14]	[0.60]	[1.88]^{C}	[0.74]	[0.29]	[5.49]^{A}	[2.64]^{A}	[4.42]^{A}	[5.40]^{A}
Panel D: Serial Correlations															
y	0.899	0.805	0.665	0.446	0.120	0.845	0.782	0.622	0.349	0.486	0.970	0.952	0.673	0.372	0.526
cpi	0.887	0.701	0.360	0.289	0.346	0.807	0.670	0.349	0.076	0.335	0.636*	0.899^	0.629	0.397	0.440
mpr	0.874	0.818	0.470	0.012	0.867	0.845	0.697	0.412	-0.124	0.388	0.674	0.942	0.619	0.499	0.602
$rmpr$	0.276	0.183	0.032	-0.343	0.451	0.235	0.085	0.031	-0.349	0.223	0.137	0.634	0.012	-0.278	0.042
$tbill$	0.813	0.685	0.345	-0.099	0.808	0.830	0.632	0.275	-0.269	0.289	0.363	0.675	0.380	-0.005	-0.203
$rtbill$	0.312	0.168	0.037	-0.424	0.490	0.315	0.094	0.047	-0.387	0.289	0.062	0.243	-0.017	-0.527	-0.203
$nxrate$	0.928	0.595	0.421	0.056	0.293	0.885	0.529	0.402	-0.050	0.290	0.954	0.920	0.696	0.370	0.368
$rxrate$	0.928	0.526	0.289	-0.007	0.272	0.870	0.397	0.255	-0.202	0.264	0.986	0.969	0.703	0.420	0.396

Note: LL denotes log-linear detrending method; LQ denotes log-quadratic detrending method; HP is the Hodrick-Prescott Filtering method; and FD is first differencing method; BP is band-pass filtering method; the superscript A, B & C are 1%, 5% & 10% significant levels respectively. Values in square brackets are t-statistics; cpi denotes log of consumer price index; mpr and $rmpr$ represent nominal and real monetary policy rate respectively; $tbill$ and $rtbill$ denote nominal and real interest rate on 91-day Treasury bill respectively; $nxrate$ and $rxrate$ represent nominal and real bilateral exchange rate respectively (where $+ = depreciation$ and $- = appreciation$). The real interest rate is computed as $rz = \frac{1+z}{1+inf} - 1$ where $z \in (mpr, tbill)$; inf is consumer inflation rate; $rxrate = \frac{nxrate * GHCPI}{USCPI}$; GHCPI and USCPI denote Ghana and United States' consumer price indices respectively. The superscripts * and ^ denote that the persistent parameters are computed using ARMA (2, 1) and ARMA (1, 1) respectively.

Table 3.6: Quarterly cyclical dynamics of monetary policy instruments and output in Ghana

	Period: 2002Q1 - 2018Q4				
	LL	**LQ**	**HP**	**FD**	**BP**
Upper Panel: Standard Deviations					
σ_y	0.42	0.41	0.19	0.13	0.02
σ_{cpi}/σ_y	3.62	3.06	3.73	3.78	3.76
σ_{mpr}/σ_y	63.17	42.35	67.38	49.98	50.03
σ_{rmpr}/σ_y	1198.76	856.10	1864.58	1841.15	1342.91
σ_{tbill}/σ_y	124.92	104.95	149.11	128.79	148.34
σ_{rtbill}/σ_y	665.58	657.55	678.40	1186.30	1331.74
σ_{nxrate}/σ_y	1903.61	1032.31	1527.12	2264.36	1567.47
σ_{rxrate}/σ_y	75.38	67.56	158.56	248.47	131.47
Panel B: Correlations with y					
y	1	1	1	1	1
cpi	-0.461	-0.693	-0.282	-0.087	0.049
	[-4.47]^A	[-8.26]^A	[-2.52]^B	[-0.74]	[0.41]
mpr	-0.073	0.169	-0.333	-0.035	0.007
	[-0.59]	[1.39]	[-2.87]^A	[-0.28]	[0.05]
$rmpr$	0.045	0.146	0.162	-0.042	-0.139
	[0.36]	[1.19]	[1.32]	[-0.34]	[-1.12]
$tbill$	0.291	0.449	-0.234	-0.053	-0.101
	[2.46]^B	[4.07]^A	[-1.95]^C	[-0.43]	[-0.80]
$rtbill$	0.595	0.615	0.093	-0.057	-0.203
	[6.02]^A	[6.33]^A	[0.76]	[-0.46]	[-1.65]
$nxrate$	-0.178	0.004	-0.423	-0.031	-0.003
	[-1.47]	[0.03]	[-3.79]^A	[-0.24]	[-0.02]
$rxrate$	-0.367	-0.306	-0.463	-0.023	0.004
	[-3.20]^A	[-2.60]^B	[-4.24]^A	[-0.18]	[0.03]
Panel C: Correlations with mpr					
cpi	-0.449	0.112	0.462	0.244	0.476
	[-4.32]^A	[0.96]	[4.47]^A	[2.14]^B	[4.53]^A
$tbill$	0.725	0.709	0.687	0.619	0.696
	[8.56]^A	[8.15]^A	[7.68]^A	[6.41]^A	[7.75]^A
$nxrate$	0.889	0.747	0.678	0.209	0.211
	[15.79]^A	[9.12]^A	[7.49]^A	[1.74]^C	[1.72]^C
$rxrate$	0.800	0.623	0.711	0.121	0.381
	[10.84]^A	[6.47]^A	[8.21]^A	[0.99]	[3.29]^A
Panel D: Serial Correlations					
y	0.988	0.981	0.829	0.265	0.505
cpi	0.979	0.964	0.870	0.691	0.598
mpr	0.951	0.969	0.903	0.436	0.508
$rmpr$	0.749	0.713	0.669	-0.142	0.377
$tbill$	0.915	0.921	0.818	0.339	0.496
$rtbill$	0.800	0.806	0.612	-0.059	0.384
$nxrate$	0.970	0.959	0.912	0.086	0.633
$rxrate$	0.963	0.957	0.927	-0.092	0.654

Note: LL denotes log-linear detrending method; LQ denotes log-quadratic detrending method; HP is the Hodrick-Prescott Filtering method; and FD is first differencing method; BP is band-pass filtering method; the superscript A, B & C are 1%, 5% & 10% significant levels respectively. Values in square brackets are t-statistics; cpi denotes log of consumer price index; mpr and $rmpr$ represent nominal and real monetary policy rate respectively; $tbill$ and $rtbill$ denote nominal and real interest rate on 91-day Treasury bill respectively; $nxrate$ and $rxrate$ represent nominal and real bilateral exchange rate respectively (where $+ = depreciation$ and $- = appreciation$). The

real interest rate is computed as $rz = \frac{1+z}{1+inf} - 1$ where $z \in (mpr, tbill)$; inf is consumer inflation rate; $rxrate = \frac{nxrate * GHCPI}{USCPI}$; GHCPI and USCPI denote Ghana and United States' consumer price indices respectively.

Panel C of Table 3.6 reports the correlations of exchange rate (in real and nominal terms), 91-day Treasury bill rate and consumer inflation with MPR for sample periods. Over the entire samples, there is general procyclical links for exchange rate, Treasury bill rate and consumer inflation with MPR. In terms of magnitudes, exchange rate and Treasury bill rate links with MPR are much stronger especially in the post-2002 era. The collective results of Panels B and C of Table 3.6 clearly demonstrate that macroeconomic interactions have strengthened during the inflation targeting regime compared to the previous monetary policy regimes in Ghana. Another striking feature from the table is a strong indirect cyclical link between policy interest rate and output and this is via the exchange rate channel. In addition, the procyclical link of inflation with policy interest rate is very intuitive as monetary authority raises interest rate in response to positive inflationary shock.

Panel D of Table 3.6 also reports the respective serial correlations (i.e. persistence) of exchange rate (real and nominal), 91-day Treasury bill rate (real and nominal), consumer price index (CPI) and MPR (real and nominal). Here, the serial correlation analysis focuses on three detrending methods (including log-linear, log-quadratic and HP filter) because the remaining two approaches (namely, growth rates and BP filter) broadly generate much lower and even negative values. For both full sample and pre-2002 era, the average estimates from the three methods (i.e. log-linear, log-quadratic and HP filter) reveal output as the most persistent variable, followed sequentially by MPR, CPI, nominal exchange rate, treasury bill rate and exchange rate. The ranking varies however for the post-2002 era with real exchange rate emerging as the most persistent variable, followed serially by output, nominal exchange rate, MPR, CPI and Treasury bill rate. A crucial observation from Panel D is a greater persistence of these variables in the post-2002 era. In the case of the quarterly data in Table 3.7, MPR emerges as the third most persistent variable, on average, after nominal and real exchange rates.

In synthesis, we find that monetary policy actions have strongly contributed to and are influenced by the business cycle dynamics in Ghana. It is however important to emphasize that there is a generally limited direct effect of monetary policy action (using interest rate) on output dynamics. On the contrary, we find much stronger indirect effect of monetary policy action (using interest rate) on output via exchange rate especially during the inflation targeting regime.

There is also a strong link between inflation and output and robust direct link between MPR and inflation, implying that authority is more mindful of inflation dynamics than output developments. There is a robust evidence of greater persistence along with decreased macroeconomic volatilities during the post-2002 era compared to pre-2002 periods, a proof that stabilization policy has been successful during the IT regime than the previous regimes in Ghana. Above all, the high degree of persistence in MPR is a substantiation of strong policy inertia in Ghana.

3.3 **Quantitative Economic Impact of IT Regime in Ghana**

3.3.1 Estimation Methods

The conflicting outcomes from the various detrending methods thus warrant cautious economic interpretation of estimated summary statistics for the cyclical components implied by each secluded filtering method. Consequently, this section precisely gauges the macroeconomic impact of IT regime in Ghana, since the latter regime officially commenced in May 2007. For this purpose, we employ more standard econometric estimation techniques while accounting for endogeneity problem, macroeconomic shocks and other key events (such as drought in 1982/3; election cycles, global financial crisis, commodity price shocks, etc.). However, the subsequent analysis focuses solely on implication of the IT strategy on inflation and output dynamics in Ghana.

In this case, we first estimate the mean macroeconomic impact of inflation targeting regime in Ghana based on the following

$$\begin{cases} z_t = \beta_0 + \psi ITD + \gamma_\alpha z_{t-1} + v_t \\ with\ ITD = \begin{cases} 1 & for\ IT\ regime^{31} \\ 0 & otherwise \end{cases} \end{cases} \tag{3.15}$$

where z_t denotes log of selected macro-variables such as CPI, real GDP, nominal exchange rate level and interest rates;γ_α is the autoregressive, AR(1), coefficient. To account for the potential effects of other influencing variables as well as macroeconomic events, we then estimate a multivariate regression based on the following vector error correction model (VECM):

[31] Based on Bawumia et al. (2003), we allow the IT regime to include the preparatory stage.

$$\Delta z_t = \beta_0 + \sum_{i=1}^{p-1} \varphi_i \Delta z_{t-i} + \psi z_{t-1} + \gamma_\omega MP_{reg,j} + \gamma \Lambda_\alpha + v_t, \quad (3.16)$$

Where Δ represent the first difference operator, ψz_{t-1} is the error correction term (i.e. speed of adjustment); while β_0, φ_i, γ and ψ are parameters to be estimated; v_t is a random disturbance; MP_{reg} is a vector of exogenous dummy variables. Specifically, the $MP_{reg,j}$ captures the (i) stage of monetary targeting regime ($MP_{reg,MT}$), (ii) the preparatory stage of the IT regime ($MP_{reg,ITL}$) and (iii) the full adoption of inflation targeting ($MP_{reg,IFT}$) regime in Ghana, variously defined as follows:

$$MP_{reg,MT} = \begin{cases} 1 \; for \; for \; the \; period \; 1992 - 2002Q3 \\ 0 \qquad\qquad\qquad\qquad otherwise \end{cases} \quad (3.17)$$

$$MP_{reg,ITL} = \begin{cases} 1 \; for \; for \; the \; period \; 2002Q4 - 2007Q1 \\ 0 \qquad\qquad\qquad\qquad otherwise \end{cases} \quad (3.18)$$

$$MP_{reg,IFT} = \begin{cases} 1 \; for \; for \; the \; period \; 2007Q2 \; onwards \\ 0 \qquad\qquad\qquad\qquad otherwise \end{cases} \quad (3.19)$$

The term Λ_α is also a vector of other exogenous dummy variables that captures (ii) key natural disasters or events in Ghana such as the drought (famine) in 1982/3 and (iii) other domestic and external shocks or events including the global financial crisis of 2008/9 alongside rising international commodity prices; declining international commodity price of 2014-16; and domestic election cycles effects. The justification for including additional variables in this paper is to precisely decipher the true impact of monetary policy regime (particularly IFT regime) on the z variables in Ghana. Particularly, for a long run cointegrating relationship to exist among the selected macro-variables, the adjustment coefficient, ψ, must be negative, significant and less than one ($i.e. -1 < \psi < 0$).

The impact of IT regime on inflation and output volatilities is also investigated using Generalized Autoregressive Conditional Heteroskedasticity (GARCH) model developed by Bollerslev (1986). This is because most financial and economic time series exhibit periods of unusually high volatility followed by more tranquil periods of low volatilities. In such case, the more preferable approach is to examine the conditional variance which allows the variance to depend upon its history. The choice of GARCH model was mainly due to the fact that it overcomes the need for long lag to improve the goodness of fit when the autoregressive conditional heteroskedasticity (ARCH) model is adopted. The GARCH model considers conditional variance to be a linear combination past values of shocks captured by the lagged

squared residual term and lagged values of conditional variance. By the parsimony principle, the chapter employed the GARCH (1,1) which is summarized as follow:

$$y_t = \alpha + \beta' X_t + \mu_t, \tag{3.20}$$

$$\mu_t|\Omega_t \sim iid\ N(0, \varphi_t^2)$$

$$\varphi_t^2 = \vartheta + \gamma\mu_{t-1}^2 + \rho\varphi_{t-1}^2, \tag{3.21}$$

where equation (3.20) is GARCH (1,1). In equation (3.21), φ_t^2 is conditional variance of μ_t and $\vartheta > 0$, $\gamma > 0$, $\rho > 0$. In addition, equation (3.21) is stationary if the sum of the ARCH coefficient, γ, and the GARCH coefficient, ρ, is less that 1 and if it comes much closer to 1, volatility shock will be much more stationary. The paper further applies an Exponential GARCH (EGARCH) model espoused by Nelson (1991). The EGARCH model is able to make the conditional variance non-negative regardless of the plus or minus sign of parameter in the model by applying logarithm to φ_t^2 in the conditional variance equation. Contrary to the GARCH models, EGARCH model does not have to restrict the parameters to obtain stationary estimation. Like the TARCH model, the conditional variance in the EGARCH model is dependent on the sign and magnitude of the parameters. The specification of the conditional variance in the EGARCH (1,1) model is given by:

$$log(\varphi_t^2) = \vartheta + \gamma \left| \frac{\mu_{t-1}}{\sqrt{\varphi_{t-1}^2}} \right| + \lambda \frac{\mu_{t-1}}{\sqrt{\varphi_{t-1}^2}} + \rho log(\varphi_{t-1}^2), \tag{3.22}$$

The application of logarithm is distinctive as it makes the leverage effect to be exponential instead of quadratic which guarantees the estimates of the conditional variance to be non-negative. In equation (3.22), if $|\gamma| < 1$, the model is stationary. Also, ρ measures the persistence in conditional volatility irrespective of anything happening in the market. When ρ is relatively large, then volatility takes a long time to die out following a crisis in the market (see, Alexander, 2009). To test for asymmetry and whether it is existent or not, the parameter of importance is λ. If the testing null hypothesis, H_0: $\lambda = 0$ is rejected in favour of the alternative hypothesis, H_1: $\lambda \neq 0$, then model presume the existence of asymmetry. In particular, when $\lambda < 0$, then the leverage effect is considered to be existent such that positive shocks (good news) generate less volatility than negative shocks (bad news) of the same magnitude. However, if $\lambda > 0$, then positive shocks (good news) generate more destabilizing effects on inflation/output than negative shocks (bad news) of the same magnitude.

We first examine the behaviour of inflation in the various monetary policy regimes, focusing on actual inflation rate, inflation persistence, the pace of disinflation, inflation persistence and variability during the IT regime. After that, we quantitatively assess the implications of the IT strategy on output dynamics in Ghana.

3.3.2 **Empirical Analysis**

We first examine how IT strategy in Ghana has impacted average and expected inflation as well as inflation variability. Afterwards, the estimated impact on average growth rate and its volatility is investigated.

3.3.2.1 **IT Impact on Inflation Dynamics**

3.3.2.1.1 **Average Inflation**

Table 3.7 presents estimates based on OLS and VECM using both annual and quarterly dataset spanning the period 1975-2018. The estimates indicate that the IT dummy (see either *ITD or IT_2007* variables in Table 3.7) has negative and significant effect on CPI inflation across models and datasets. Although the coefficient for monetary targeting regime dummy is also negative but it is generally insignificant. Consistent with summary statistic in Table A1 of Appendix A, this finding is suggestive that the IT strategy has been quite successful in reducing the levels of CPI inflation in Ghana compared to the previous policy regimes. This corroborates the findings of Wu (2004), Batini and Laxton (2007), Goncalves and Salles (2008) that the IT strategy has significantly reduced the average inflation rate in OECD countries.

Table 3.7: Average CPI Inflation and IT Strategy

	Annual Frequency				**Quarterly Frequency**				
	OLS		**VECM**						
			Panel A: Long run Equation						
	π_t		$LCPI_t$						
	I	II	I	II	I	II	III	IV	V
$LogY_{t-1}$			2.859	-1.218	5.984	0.351	5.533	7.926	-19.049
			[5.05]*	[-2.72]*	[13.35]*	[0.46]	[15.12]*	[8.55]*	[-3.18]*
$logCPI_{t-1}$			1	1	1	1	1	1	1
$logXrate_{t-1}$			-0.296	-0.693	0.109	0.019	-0.011	0.703	3.636
			[-3.03]*	[-4.79]*	[1.70]	[0.64]	[-1.64]	[4.44]*	[3.60]*
$logMPR_{t-1}$			0.103	0.210	-0.244	-0.991	0.017	-0.405	-3.517
			[0.44]	[0.46]	[-1.50]	[-5.36]*	[0.26]	[-1.14]	[-1.09]
t	0.28	0.012	-0.285	-	-0.133		-0.123	-0.201	
	[9.60]*	[1.71]***	[-6.83]*		[-16.31]*		[-17.49]*	[-10.32]*	
C	-3.34	0.214	-28.158	7.858	-45.842	-9.155	-43.286	-55.783	197.040
	[-5.75]*	[2.56]**							
π_{t-1}		0.919							
		[33.10]*							
			Panel B: Short run Equation						
-	-	-	**Dependent Variable: D(LCPI)**						

ECM_{t-1}			-0.311	-0.142	-0.099	-0.004	-0.117	-0.021	-0.003
			[-2.80]**	[-2.46]**	[-3.21]*	[-0.36]	[-3.34]*	[-1.41]	[-2.15]**
C					0.063	0.097	0.076	0.098	0.079
					[4.20]*	[5.53]*	[4.26]*	[5.70]*	[4.93]*
ITD	-1.37	-0.045	-0.131	-0.148	-0.025	-0.039	-0.041		
	[-2.11]***	[-0.98]	[-2.44]**	[-2.45]**	[-1.92]***	[-2.26]**	[-2.49]**		
ITD_2007								-0.063	-0.049
								[-2.46]**	[-2.39]**
ITD_LITE								-0.049	-0.024
								[-2.20]**	[-0.94]
MTD						-0.020	-0.026	-0.021	-0.007
						[-1.35]	[-1.78]***	[-1.44]	[-0.41]
$D1$				0.015					0.016
				[0.14]					[0.62]
$D2$				0.144					0.036
				[1.29]					[1.25]
$Election$									0.004
									[0.23]
$Drought$									-0.004
									[-0.15]
Adj. R2	*0.956*	*0.998*	*0.607*	*0.574*	0.389	0.309	0.357	0.356	0.343
F-stat.	*484.17*	*5840.91*	*7.327*	*5.596*	6.01	4.37	5.17	4.98	4.79

Note: D1 denotes dummy for falling commodity price shock in 2014-2016; D2 denotes dummy for the global financial crisis along with the rising commodity prices of 2008-2009. ITD is inflation targeting regime from the preparatory stage to the official adoption (i.e. from 2002 to date).

3.3.2.1.2 Inflation Persistence, Disinflation and Expectation

Kuttner and Posen (1999) show that temporary price shocks should have less persistent effects on inflation if the formulation of monetary policy changes after the adoption of inflation targeting in such a way that the emphasis on fighting inflation increases. Reduced inflation persistence would also indicate that the monetary policy credibility has increased and that inflation expectations are more forward looking after the introduction of inflation targeting.

We then proceed by discussing persistence estimates for the actual consumer inflation in Ghana and Panel A of Table 3.8 presents the empirical result based on first-order autoregressive process, following much of the empirical literature. Panel A of Table 3.8 demonstrates high degree of persistence of the consumer inflation Ghana with a significant coefficient of 0.89 since 1975. Comparatively, however, the persistence has rather increased during the inflation targeting (i.e. IFT) regime with the coefficient close to unity (0.944). As robustness check, we also consider an alternative measure of persistence by utilizing the equation (3.23)

$$\pi_t = \alpha + \sum_{j=1}^{K} \beta_j \, \pi_{t-j} + \varepsilon_t \qquad (3.23)$$

where $\sum_{j=1}^{K} \beta_j$ is the sum of the autoregressive coefficients (see Levine et al. 2004). To estimate the equation, an autoregressive lag order K must be chosen for each segment of inflation series. For this reason, we utilize the Akaike information criterion (AIC), proposed by Akaike (1973), with a maximum lag order of K=4 considered in line with Levine et al. (2004). Panel B of

Table 3.8 reports the sum of autoregressive coefficient for consumer inflation in Ghana while the optimal lag order chosen for each segment is reported in Panel C. Consistently, the estimates in Panel B also reinforce the findings in Panel A that inflation persistence has rather elevated during the IT regime in Ghana. In congruence, the ADF test (with constant and/or trend) for the inflation series could not reject the null of unit root at 5% alpha level (see Panel D).

Table 3.8: Persistence Estimates for Inflation in Ghana

	Full Sample	Pre-IFT	ITL & IFT	ITL	IFT
	1975-2018Q4	1975-2007Q1	2002-2018Q4	2002-2007Q1	2007Q2-2018Q4
Panel A: First order Autoregressive Coefficient					
	0.894	0.875	0.885	0.836	0.944
Half-life	6.213	5.209	5.696	3.860	11.938
Panel B: Sum of Autoregressive Coefficients					
	0.846	0.813	0.855	0.770	0.894
Half-life	4.131	3.342	4.437	2.647	6.163
Panel C: AIC Lag Selection					
K = 1	-1.932	-1.615	-4.929	-3.888	-6.037
K = 2	-2.095	-1.804	**-5.065**	**-3.979**	**-6.533**
K = 3	**-2.113**	**-1.815**	-5.037	-3.889	-6.514
K = 4	-2.097	-1.794	-5.046	-3.847	-6.505
Panel D: ADF Test for the Realized inflation Series					
P-Value	{0.097}***	{0.000}*	{0.095}***	{0.058}***	{0.321}

Note: the estimates in Panel A of table 5 are computed using this equation: $\pi_t = \alpha + \beta\pi_{t-1} + \varepsilon_t$; and β is the inflation persistence parameter; the estimates in Panel B are computed using this equation: $\pi_t = \alpha + \sum_{j=1}^{K} \beta_j \pi_{t-j} + \varepsilon_t$; and $\gamma = \sum_{j=1}^{K} \beta_j$ is the sum of autoregressive coefficients. The half-life is computed as: $\log(0.5)/\log(\alpha)$, where α denotes the estimated AR(p) Coefficient.

We then modified univariate AR(p) model in equation (3.23) to include dummy variables for the various monetary policy regimes to further assess the exact impact of IT regime on inflation persistence

$$\pi_t = \alpha + \varpi t + \sum_{j=1}^{K} \gamma_j \pi_{t-j} + \eta ITD_{2007,t} + \zeta ITD_{Lite,t} + \theta mtd_t + \varepsilon_t; \qquad j = 1, \dots, K;\ t = 1, \dots T \quad (3.24)$$

We also include a trend polynomial, ϖt, to capture the effects of gradually declining average inflation (i.e. disinflation). In equation (3.24), the memory of the inflation process after inflation targeting is given by $\gamma_j + \eta$, during the monetary targeting regime is given by $\gamma_j + \theta$ and during inflation targeting lite is given by $\gamma_j + \zeta$. Particularly, a negative and significant η would then suggest that inflation persistence had declined so that the strength of the effects of temporary shock on inflation had dwindled. The estimation of γ_j, η, ζ and θ is reported in Table 3.9. The estimated sum of the autoregressive coefficients, γ_j, reinforces that inflation persistence has increased since 2000. Particularly, the estimated coefficients for the various

monetary policy regimes are all statistically insignificant, although the estimated η and ζ coefficients are negative in the post-1990 era.

Table 3.9: Estimation of the effect of IT on Inflation persistence

Panel A: Estimated IT impacts on Inflation Persistence					
		Periods			
		1975-2018	**1990-2018**	**2000-2018**	**2007-2018**
Estimates	γ_j	0.759	0.718	0.765	0.899
	ϖ	-0.0014	-0.0002	-0.0002	-0.0001
		[-2.97]*	[-1.09]	[-0.98]	[-0.72]
	η	0.080	-0.010	-0.014	
		[1.55]	[-0.90]	[-1.10]	
	ζ	0.048	-0.003	-0.010	
		[1.16]	[-0.30]	[-1.17]	
	θ	0.027	0.007		
		[1.00]	[0.69]		
Panel B: Speed of convergence toward medium-term inflation target					
Short run	κ			**0.133**	**0.328**
				[1.61]	[6.91]*
Long Run	κ/ς			**0.449**	**0.943**

Note: the estimates in Panel B is based on the equation: $\Delta i_t = \alpha + \varsigma \Delta i_{t-1} + \kappa \Delta(\pi_t - \bar{\pi}) + \psi \Delta \tilde{y} + \varepsilon_t$; where i_t is policy interest rate; π_t is current inflation; $\bar{\pi}$ is the medium-term inflation target; $\tilde{y}$ is output gap; ε_t is the error term. This is explored further in Chapter 5.

This result is a demonstration that the IT regime has indeed not reduced inflation persistence in Ghana. The latter evidence further suggests that inflation is still not well anchored in the IT regime in the context of Ghana. Our results contradict the findings in Siklos (1999), Bernanke et al (1999a), Corbo et al. (2001), Levin et al. (2004) and Petursson (2005). In addition, the full sample estimates (i.e. 1975-2018) in Table 3.8 also show significant trend decline in inflation (i.e. disinflation), in line with the long run estimates in Table 3.9. Yet, the coefficient for the disinflation trend, ϖ, is negative but statistically insignificant in the post-1990 era. This empirical finding is robust when the disinflation trend is approximated with a second-order polynomial, $\varpi t, = \varpi_1 t + \varpi_2 t^2$. The result thus suggests that although IT regime has moderated average inflation, the extent of disinflation due to targeting has been marginal while inflation persistence has been elevated in the IT regime in Ghana.

One possible explanation for the elevated level of inflation persistence in the IT regime could be that the Bank of Ghana has not pursued an active/aggressive monetary policy to quickly stamp out deviation of inflation from target level in the face of several challenges including, but not limited to, frequent supply-side shocks, fiscal weaknesses. In particular, Cukierman et al., (1992) associated the high and embedded inflation inertia in Ghana to lack of legal independent of the central bank to keep the fiscal authority in check (i.e. weak institutions). Undeniably, the Bank of Ghana (BOG) is still compelled by law to finance the fiscal deficit up

to 5% of the previous year's fiscal revenue, a clear symptom of fiscal dominance (see, Akpan et al., 2014; Bleaney et al. 2020). The relegation of monetary policy to fiscal necessities encourages private economic agents to consider that the Bank's promise to control inflation is incredible. For that reason, the inflationary pressures of a fiscal origin may set off formal and informal indexation mechanisms in the private sector, and thus, complicating the tasks of the central bank (Bleaney et al., 2020). Therefore, some studies (e.g. Kovanen 2011; Kwakye, 2010) ascribe the poor performance of BOG in controlling inflation to inefficient interest rate transmission mechanism owing to underdeveloped banking/financial system as a contributing factor to the imbedded inflation inertia in Ghana. These assertions may underscore the fact that actual inflation has repeatedly exceeded the medium-term target.

The literature however posits that disinflation too fast might generate short-term losses in output and jobs which could impair the support for the disinflation program and the central bank independence (see, Petursson, 2005). That is, tightening too much risks loss of public supports for the IT regime on one hand. On the other hand, much slower speed of convergence towards price stability is risky, especially when initial credibility of the regime is low. In the latter case, as inflation expectations might get stuck at higher level of inflation which would make further disinflation very challenging. For this reason, we estimate a standard linear Taylor rule with interest rate inertia and Panel B of Table 3.9 reports the both the short-run (i.e. instant reaction) and long run (i.e. cumulative reaction) estimated speed of convergence (i.e. disinflation) in the case of Ghana. The estimates show positive and significant coefficient for the short-run policy response to inflation deviation from target. The magnitude of instant speed of disinflation is 0.328, yielding a cumulative speed of convergence of 0.943 in the long-run. The estimated speed of convergence (disinflation) is below unity even in the long run, a clear violation of the Taylor principles (this is explored comprehensively in Chapter 5). Nonetheless, the estimated speed of disinflation presages that the monetary authority practices flexible rather that strict IT strategy in Ghana, consistent with the observed high level of inflation persistence and the marginal trend decline in inflation for the post-2007 era (as reported in Table 3.8 and Panel A of Table 3.9).

The slower speed of convergence is however not surprising as it could be linked to weak policy passthrough due to protracted policy transmission lags (see Kovanen, 2011; Fukac and Baltini, 2014), unremitting high levels of government debt and unfavourable growth of traditional export market which create new sources of political pressures that the central bank finds it

difficult to ignore. If these assertions are true, one would expect this to hamper the central bank's ability to delink inflation expectation from the actual inflation. To investigate this potential explanation, we assess the sensitivity of inflation expectation to actual inflation since the implementation of IT strategy in May 2007 based on the following:

$$\pi_{i,t}^{e} = \alpha + \beta_i \pi_{i,t-1}^{e} + \chi \pi_{t+p}^{j} + \varepsilon_t \quad (3.25)$$

In equation (3.25), the left hand side variable ($\pi_{i,t}^{e}$) is change in the aggregated inflation expectation data from the financial and business surveys conducted by Bank of Ghana before each round of monetary policy committee (MPC) meetings. Since the inflation expectations are derived from the question "*What is your expectation about the rate of inflation by the end of the current year?"* (See, Bleaney et al. 2020), we use both inflation expectation for the current period (π_t^e) and a 1-year-ahead inflation expectation (π_t^{e12}) for robustness check. The right hand side variable is change in realized inflation. Beside the current realized inflation (π_{t-1}), we also utilize a 3-month (π_t^{3MA}), 6-month (π_t^{6MA}), 12-month (π_t^{12MA}), 24-month (π_t^{24MA}) and 36-month ((π_t^{36MA}) moving average of realized inflation. The use of longer actual and expected inflation horizons is to help ascertain the ability of the central bank to delink expectation from actual inflation especially in the medium-to-long term as central bank has a medium term inflation target. The β_i coefficient in equation (3.25) determines whether agents' formation of inflation expectation is backward or forward-looking in Ghana. Table 3.10 reports the estimated response of change in inflation expectations to change in actual inflation in the IT regime.

Table 3.10: Estimated Response of Change in Inflation Expectations to Change in Actual Inflation in the IT Regime

Response Var.:	π_t^e						π_t^{e12}	
	I	II	III	IV	V	VI	VII	VIII
C	-0.006	-0.004	-0.005	-0.002	0.013	0.017	-0.005	0.006
	[-0.18]	[-0.13]	[-0.14]	[-0.04]	[0.35]	[0.41]	[-0.12]	[0.14]
β^e	0.640	0.588	0.626	0.654	0.700	0.705		
	[11.56]*	[11.61]*	[11.63]*	[10.71]*	[11.15]*	[10.39]*		
β^{e12}							0.633	0.678
							[10.14]*	[10.11]*
π_t	0.156							
	[2.42]**							
π_t^{3MA}		0.345						
		[5.66]*						
π_t^{6MA}			0.314					
			[4.45]*					
π_t^{12MA}				0.289				
				[2.63]*				
π_t^{24MA}					0.220		0.374	
					[1.42]		[2.37]**	
π_t^{36MA}						0.204		0.340

						[0.94]		[1.46]
R2	0.535	0.570	0.544	0.529	0.516	0.496	0.541	0.540
Adj. R2	0.528	0.564	0.538	0.522	0.509	0.487	0.534	0.532
SSR	21.04	19.43	20.61	21.29	20.53	19.34	19.58	18.49
LL	-65.98	-60.40	-64.52	-66.82	-64.51	-60.70	-61.47	-58.09
DW	1.863	1.822	1.834	1.832	1.842	1.839	1.792	1.841
HT	0.516	0.287	0.175	0.296	0.504	0.465	0.088	0.053
SC	0.335	0.275	0.374	0.368	0.427	0.419	0.129	0.420
RRT	0.669	0.926	0.951	0.921	0.698	0.808	0.820	0.912

Note: The estimates in the table are computed using dataset from 2007Q2 to 2018Q4; LL is log-likelihood; SSR is sum of squared residuals; AIC is Akaike information criterion; SBC is Schwarz information criterion; DW denotes Durbin Watson statistic; HT is Breusch-Pagan-Godfrey heteroskedasticity test; SC is Breusch-Godfrey serial correlation LM test; RRT is Ramsey RESET test for stability; The values in the squared brackets are t-statistics; the superscript *,** & *** denote 1%, 5% & 10% alpha levels respectively.

From the table, the estimated β coefficients are positive and statistically significant across all models, indicating that the economic agents' formation of inflation expectation is more backward-looking in Ghana. Consistent with preceding persistence outcome, the estimates clearly demonstrate a positive and significant coefficient for realized current or moving average inflation up to 12-month policy horizon. It indicates that inflation inertia is considerably ingrained in the private agents' formation of inflation expectation in Ghana even in the IT regime. This is also in line with findings of Kovanen (2011) that expectations were backward-looking and not well-anchored in Ghana. This is further suggestive that the central bank has so far been unsuccessful in delinking inflation expectation from the actual inflation in the short run. However, the estimated coefficients for actual inflation at the 3-year horizon are positive but statistically insignificant. This is an indication that the central bank has a greater prospect to delink expectation from actual inflation in the medium-to-long run in Ghana but not in the short run.

3.3.2.1.3 Inflation Volatility

Another essential issue is whether inflation targeting contributes to reducing inflation volatility. Therefore, we ascertain the impact of the IT regime on inflation variability utilizing both GARCH (1, 1) and EGARCH (1, 1) models, specified in equations (3.19)-(3.21). Table 3.11 reports the results of the variance equation for inflation based on both GARCH family models.

Table 3.11: IT Effects on Inflation Volatility in Ghana (Quarterly dataset)

	Response Variable: Inflation volatility			
	I	II	III	IV
C	0.0009	0.002	-0.260	-5.078
	[27.96]*	[1.67]***	[-0.52]	[-3.61]*
γ	0.0173	0.018	-0.204	0.209
	[0.48]	[0.53]	[-0.74]	[1.38]
λ			0.216	-0.028

			[1.79]***	[-0.30]
p	0.8705	0.795	0.917	-0.115
	[19.62]*	[8.31]*	[18.12]*	[-0.37]
ITD_2007	-0.0008	-0.002	-0.090	-3.173
	[-11.77]*	[-1.61]	[-0.94]	[-3.52]*
ITD_LITE	-0.0009	-0.002	-0.393	-2.719
	[-19.31]*	[-1.70]***	[-2.84]*	[-2.72]*
MTD	-0.0007	-0.001	-0.127	-2.524
	[-9.85]*	[-1.56]	[-1.95]***	[-3.43]*
$Drought$		0.003		0.662
		[0.88]		[1.06]
$D1$		0.000		0.297
		[0.52]		[0.89]
$D2$		0.000		0.416
		[0.87]		[1.67]***
R^2	0.190	0.170	0.168	0.171
Adj. R^2	0.167	0.151	0.133	0.152
SSR	0.965	0.989	0.992	0.989
LL	275.98	272.54	285.91	270.42
DW	1.98	1.91	1.81	1.92
AIC	-3.00	-2.94	-3.08	-2.90
SBC	-2.78	-2.69	-2.81	-2.63

Note: ITD_2007 represents official inflation targeting regime since May 2007; ITD_LITE represents dummy for the preparatory stage of the IT regime in Ghana covering 20002 to April 2007; MTD is monetary targeting regime between 1992-2002Q3; D1 denotes dummy for falling commodity price shock in 2014-2016; D2 denotes dummy for global financial crisis along with the rising commodity prices of 2008-2009; Drought is a dummy for the drought in 1982-1983; Values in the squared bracket are t-statistics; LL is log-likelihood; SSR is sum of squared residuals; AIC is Akaike information criterion; SBC is Schwarz information criterion; The values in the squared brackets are t-statistics; the superscript *,** & *** denote 1%, 5% & 10% alpha levels respectively.

The estimates in Table 3.11 clearly satisfy the non-negativity constraints of GARCH (1, 1) model while the EGARCH estimates seem to suggest a weak asymmetric inflation volatility response to negative and positive shocks in Ghana. The estimated variance coefficient for the inflation targeting dummy variable (i.e. ITD_2007) is negative across the GARCH models. The coefficient is statistically significant in the simple GARCH (1, 1) model I but insignificant in the simple EGARCH (1, 1) model III. The level of statistical significance for the coefficient also differs after controlling for other macroeconomic events in both models. In this case, the coefficient for the IT dummy variable is insignificant and significant in the GARCH model II and EGARCH model IV respectively. Since the simple GARCH (1, 1) model I relatively optimizes the objective function (in terms of lowest SSR and information loss), it can be concluded that IT regime has considerably dampened inflation volatility in Ghana. This is in line with the findings in Corbo et al. (2001), Neumann and von Hagen, (2002) and Petursson (2005). Similarly, both the monetary targeting regime and the IT preparatory stage (i.e. IT_Lite) seem to have notably dampened inflation volatility in Ghana as the estimated

coefficients for both regimes are negative and broadly significant. Yet the magnitude of impact during the IT is slightly largely than that of the preceding regimes.

3.3.2.2 IT Impact on Output Dynamics

3.3.2.2.1 Average Output Growth

The theoretical literature provides no palpable justification that inflation targeting impact average output growth. But, Mishkin (1999) suggests "A conservative conclusion is that, once low inflation is achieved, inflation targeting is not harmful to the real economy. Given the strong economic growth after disinflation was achieved in many countries that adopted inflation targets, New Zealand being one outstanding example, a case can be made that inflation targeting promotes real economic growth in addition to controlling inflation." (p. 597). Based on this assertion, other empirical evidences (such as Ball and Sheridan, 2003; Corbo et al. 2001; Levine et al. 2004; Petursson, 2005; among others) as well as the fact that actual inflation has frequently exceeded the medium-term target in Ghana, we further ascertain whether inflation targeting has had any significant impact on output behaviour in Ghana.

Table 3.12 reports the estimated impact of IT on average economic growth based on OLS and VECM with dummy variables that capture the IT regime in Ghana. In all cases, the coefficient of the IT dummy is positive and statistically significant even when we control for other key domestic and external macroeconomic events. This is an indication that the IT strategy has increased the pace of average economic (output) growth in Ghana. Yet, the magnitude of impact on average output growth is marginal in the short run, ranging from 0.01 to 3.4 percentage points depending of the specification. This observed marginal positive impact of IT on average output growth in this paper however contradicts the findings of Goncalves and Carvalho (2009) that the OECD countries with IT regime suffer much higher output loss than their non-IT counterparts.

Table 3.12: Output Growth and IT Regime (1975-2018)

Annual Frequency			Quarterly Frequency				
OLS	VECM						
	Panel A: Long run Equation						
$\Delta logY_t$	$logY_t$						
$LogY_{t-1}$	1	1	1	1	1	1	1
$logCPI_{t-1}$	0.296	-0.821	8.855	0.167	0.168	0.545	-0.052
	[11.85]*	[-6.66]*	[3.90]*	[11.44]*	[11.40]*	[4.47]*	[-0.45]
$logXrate_{t-1}$	-0.040	0.568	-8.834	0.018	-0.040	-0.588	-0.191
	[-1.55]	[4.48]*	[-4.42]*	[1.70]	[-1.40]	[-5.76]*	[-1.96]***
$logMPR_{t-1}$	-0.004	-0.172	6.355	-0.041	0.015	0.098	0.185

			[-1.50]	[-0.60]	[1.30]	[-1.42]	[1.27]	[0.35]	[1.02]
$Trend$	0.002	0.001	-0.099			-0.022	-0.022	-12.807	
	[2.66]*	[1.14]	[-21.63]*			[-29.87]*	[-29.69]*		
C	-0.010	0.008	-9.343	-6.45	-76.583	-7.661	-7.680		-10.344
	[-0.65]	[0.50]							
			Panel B: Short run Equation						
-	-	-	$\boldsymbol{\Delta logY_t}$						
ECM_{t-1}			-0.254	0.022	0.000	-0.036	-0.041	-0.006	-0.013
			[-2.51]**	[1.53]	[-2.03]**	[-2.18]**	[-2.45]**	[-3.55]*	[-4.88]*
C					0.000	0.000	-0.001	-0.003	0.004
					[0.28]	[-0.11]	[-0.43]	[-1.58]	[2.40]**
ITD	**-0.0200**	**0.0001**	**0.037**	**0.023**	**0.002**	**0.002**	**0.003**		
	[-1.19]	[0.01]	**[2.55]****	**[1.82]*****	**[1.95]*****	**[1.95]*****	**[1.73]**		
ITD_2007								0.010	0.004
								[4.12]*	[2.15]**
ITD_LITE								0.004	-0.004
								[1.84]***	[-1.60]***
MTD							0.001	0.001	-0.003
							[0.53]	[0.72]	[-1.85]***
$D1$				-0.040					-0.003
				[-1.86]***					[-1.11]
$D2$				0.009					-0.003
				[0.37]					[-1.00]
$Election$									0.0003
									[0.19]
$Drought$									-0.006
									[-2.41]**
$\boldsymbol{\Delta logY_{t-1}}$		0.311							
		[2.51]**							
Adj. R2	*0.288*	*0.305*	*0.408*	*0.404*	0.730	0.731	0.732	0.742	0.717
F-stat.	*9.69*	*7.14*	*3.826*	*3.318*	22.21	22.33	21.51	21.75	19.37

Note: ITD is inflation targeting regime from the early preparatory stage to the official adoption (i.e. from 2002 to date). ITD_2007 represents official inflation targeting regime since May 2007; ITD_LITE represents dummy for the preparatory stage of the IT regime in Ghana covering 20002 to April 2007; MTD is monetary targeting regime between 1992-2002Q3; D1 denotes dummy for falling commodity price shock in 2014-2016; D2 denotes dummy for global financial crisis along with the rising commodity prices of 2008-2009; Drought is a dummy for the drought in 1982-1983; Election is a dummy for the democratic election periods since 1992 constitution in Ghana; Values in the squared bracket are p-values; LL is log-likelihood; SSR is sum of squared residuals; AIC is Akaike information criterion; SBC is Schwarz information criterion; The values in the squared brackets are t-statistics; the superscript *,** & *** denote 1%, 5% & 10% alpha levels respectively.

3.3.2.2.2 Output variability

Some economists argue that flexible inflation targeting alleviates output and inflation volatilities. Others such as Cecchetti and Ehrmann (2002) rather argued that inflation targeting makes output more volatile as monetary authority manipulate output gap in order to reverse shocks to inflation. However, since preceding analysis shows high levels of inflation persistence along with slower pace of disinflation process, we would expect to see decreased levels of output variability during the IT regime in Ghana (see, Levin et al 2004). While this conjecture seems to be broadly supported by the preliminary business cycles analysis, we further ascertain the specific impact of IT strategy on output volatility using GARCH family

models. Table 3.13 report the variance estimates implied by GARCH (1, 1) and EGARCH (1, 1) for output growth as well as the least square estimates for output gap using dummy variable to capture policy regime effects while controlling for other additional key macroeconomic events.

Table 3.13: IT Effect on Output Volatilities

	GARCH (1,1)		EGARCH (1,1)		Ordinary Least Squares		
	Output					Output gap	
	III	IV	III	IV	I	II	III
C	0.00005	0.00007	-10.232	-9.966	-0.005	-0.003	-0.003
	[1.76]***	[1.80]***	[-6.30]*	[-6.84]*	[-2.51]**	[-1.63]	[-1.85]***
γ	0.187	0.091	1.210	1.298			
	[2.10]**	[1.39]	[8.18]*	[7.58]*			
λ			0.259	0.145			
			[1.39]	[0.71]			
p	0.497	0.530	0.009	0.044			
	[2.34]**	[2.65]*	[0.05]	[0.32]			
$Trend$					0.0001	0.0001	0.0001
					[2.18]**	[2.34]**	[2.63]*
ITD_2007	-0.00003	-0.00005	-0.888	-1.343	-0.010	-0.012	-0.010
	[-1.54]	[-1.52]	[-1.85]***	[-2.63]*	[-1.81]***	[-2.31]**	[-1.94]***
ITD_LITE	-0.00005	-0.00007	-3.967	-3.562	-0.006	-0.008	-0.010
	[-1.75]***	[-1.80]***	[-4.12]*	[-5.21]*	[-1.38]	[-1.89]***	[-2.30]**
MTD	-0.00005	-0.00007	-2.853	-2.766	-0.004	-0.006	-0.007
	[-1.76]***	[-1.80]***	[-3.54]*	[-3.84]*	[-1.36]	[-2.09]**	[-2.52]**
$Drought$		0.00003		0.294		-0.016	-0.017
		[0.42]		[0.23]		[-4.64]*	[-4.99]*
$D1$		0.00001		1.547			-0.006
		[0.41]		[2.53]**			[-1.76]***
$D2$		-2E-05		-0.317			-0.011
		[-1.37]		[-0.41]			[-3.77]*
$Election$							0.002
							[1.13]
$Y_{gap,t-1}$					0.885	0.838	0.824
					[33.30]*	[30.90]*	[31.13]*
R^2	0.587	0.591	0.584	0.577	0.866	0.881	0.891
Adj. R^2	0.577	0.582	0.581	0.567	0.863	0.877	0.885
SSR	0.010	0.010	0.010	0.010	0.014	0.013	0.012
LL	697.64	697.05	706.38	711.88	590.49	601.05	608.77
DW	2.31	2.29	2.47	2.48	0.70	0.68	0.75
AIC	-7.80	-7.76	-7.92	-7.92	-6.53	-6.64	-6.69
SBC	-7.60	-7.51	-7.76	-7.65	-6.42	-6.51	-6.51

Note: ITD_2007 represents official inflation targeting regime since May 2007; ITD_LITE represents dummy for the preparatory stage of the IT regime in Ghana covering 20002 to April 2007; MTD is monetary targeting regime between 1992-2002Q3; D1 denotes dummy for falling commodity price shock in 2014-2016; D2 denotes dummy for global financial crisis along with the rising commodity prices of 2008-2009; Drought is a dummy for the drought in 1982-1983; Election is a dummy for the democratic election periods since 1992 constitution in Ghana; Values in the squared bracket are p-values; LL is log-likelihood; SSR is sum of squared residuals; AIC is Akaike information criterion; SBC is Schwarz information criterion; The values in the squared brackets are t-statistics; the superscript *,** & *** denote 1%, 5% & 10% alpha levels respectively.

In line with preceding estimates of high levels of inflation persistence, the estimated coefficient for IT dummy is negative and significant the EGARCH (1, 1) and the OLS models. While the corresponding estimate implied by the GARCH (1, 1) model is negative but insignificant, the

EGARCH (1, 1) model appears to provide better fit for the output model between to two GARCH-family models. We can therefore conclude that the IT strategy has reduced both the economic growth volatility (i.e. business cycles fluctuations) in Ghana. Similarly conclusion can be drawn for both IT-lite and monetary targeting as the estimated coefficients for their respective dummies are negative and statistically different from zero across model specifications.

3.4 Conclusion

This chapter investigates whether the IT regime has been beneficial for Ghana compared to the previous monetary policy frameworks. Secondly, we analyse the monetary and business cycle dynamics in Ghana to address the following policy questions: Are the components of aggregate demand (including consumption, investment, government spending, and net exports) move pro or countercyclical? How persistent is the movement in aggregate activity? Are economic expansions and contractions associated with deficits or surpluses in the trade balance? Is aggregate consumption less or more volatile than output? How do monetary policy cycles explain the business cycle dynamics in Ghana? The answers to these questions form a basic set of empirical/stylized-facts about business cycles that are used to validate our open economy DSGE model. Besides, the great ratios based on the national income accounting are used as prior information in the calibration of our Bayesian DSGE model. Lastly, we quantitatively determine, in terms of both signs and magnitudes, the precise macroeconomic impact of IT strategy in Ghana using more standard econometric estimation methods.

The general observation from the real business cycle analysis is that the Ghanaian macroeconomy is more cyclical and has experienced much deeper contraction in recent years. There is also strong evidence that all the components of aggregate demand are more volatile than output. In addition, components such as private consumption, investment, exports and import are found to be procyclical as their correlations with output are broadly positive. The post-2002 quarterly analysis points to procyclicality for government spending, although the full sample exhibits acyclicality (insignificant coefficient). Similarly, the quarterly analysis suggests that trade balance is countercyclical for the post-2002 era. This means that Ghana tends to import more than it exports during economic expansions (booms) but exports more than it imports during recessions over the post-2002 period. On a whole, output is the most

persistent variable across filters in the post-2002 period, followed sequentially by exports, imports, government consumption, investment and private consumption.

In addition, the collective results from the monetary policy cycles strongly suggest that monetary policy actions have greatly propelled and been guided by real business cycle dynamics in Ghana. A striking observation is that monetary policy action (using interest rate) has stronger indirect countercyclical effect on output dynamics via exchange rate and this is much greater during the inflation targeting regime. The estimates further demonstrate a strong direct link between MPR and inflation and between inflation and output. This, together with a general weak direct countercyclical link between MPR and output, suggests that monetary authority is more heedful to inflation stabilization than output stabilization. There is also an overwhelming evidence of greater persistence alongside reduced macroeconomic volatilities during the post-2002 era compared to pre-2002 periods. This evidence is an attestation that monetary policy stabilization has been successful during the IT regime than the previous monetary policy regimes in Ghana. The estimates further point to substantial policy inertia especially during the inflation targeting regime in Ghana.

The result suggests that the inflation targeting strategy has been beneficial for Ghana. Strikingly, the IT strategy has not only increased the pace of average economic (output) growth and reduced average inflation rate but also dampened the volatilities in both inflation and output in Ghana. This surmises that the IT strategy has effectively enhanced macroeconomic management in Ghana. Despite improving the macroeconomic management in general, the empirical estimates show that a highly persistent inflation along with much slower disinflation process while economic agents' formation of inflation expectation remains backward-looking despite decade of practicing IT regime in Ghana. The latter empirical findings can be attributed to weak monetary policy passthrough to the real economy due to protracted policy transmission lags, unremitting high levels of government debt frequent supply-side shocks (e.g. exchange rate depreciation at the back of unfavourable growth of traditional export market) which create new sources of economic pressures that the central bank finds it difficult to ignore. Another possible explanation for the high inflation persistent is the effect of weak economic and social institutions in Ghana which adversely affect central bank credibility.

From the preceding empirical findings, apposite monetary and fiscal policy measures that inure exchange rate stability are indispensable to achieving the price stability objective while promoting a sustained economic growth in Ghana. In addition, proactive policies and reforms aim at strengthening the domestic financial sector is warranted in order to hasten financial and real sector responses to policy action and hence, shorten the policy transmission lags. Furthermore, strengthening the policy transparency and communication by Bank of Ghana is pivotal to deal with supply-side shocks and hence to achieve low and more stable inflation.

CHAPTER FOUR

Time-Frequency Analysis of Monetary Policy Transmission and Effectiveness:

The Interest Rate and Real Sector Nexus in Ghana

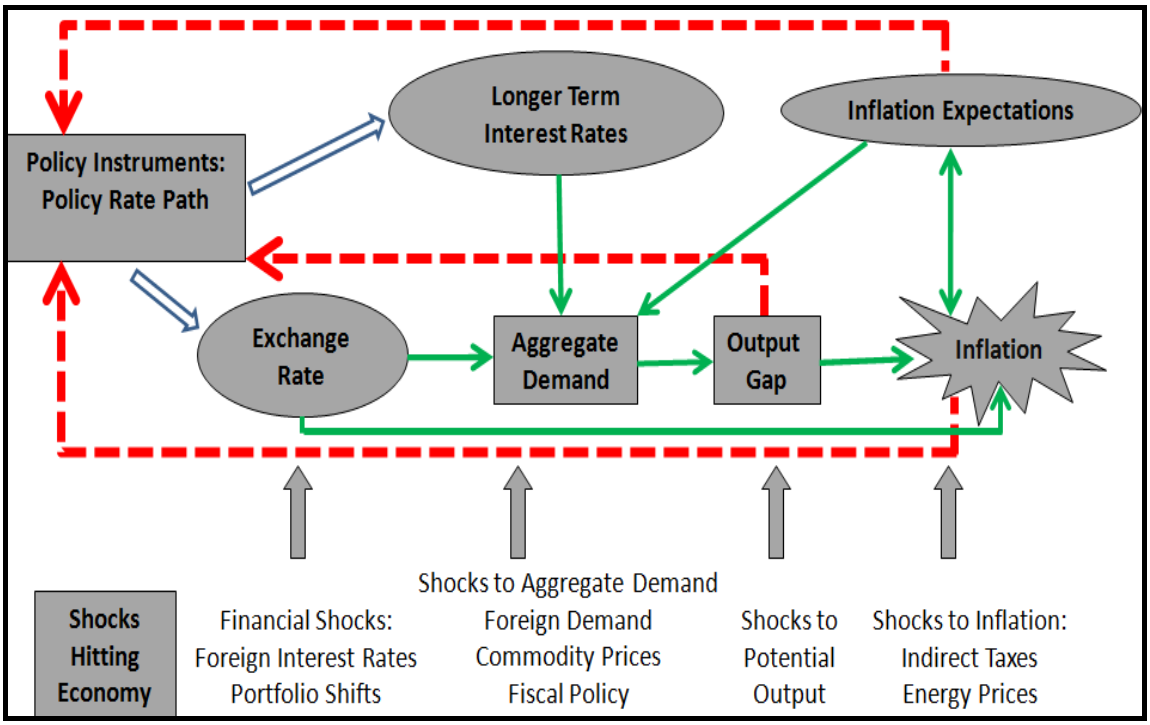
4.0 Introduction

Although not a new phenomenon, the monetary policy transmission mechanism (MPTM) has remained topical in the extant literature on the contemporary monetary policy regime. The MPTM describes how changes in the policy instruments (either nominal money stock or the short-term nominal interest rate) impact on the real variables such as aggregate demand (output) and inflation (see Ireland, 2005). Consequently, the volume of literature on the MPTM devoted to the search for appropriate channel is enormous and contemporary amid considerable developments in both the financial system and monetary policy implementation. Indeed, the operation of the financial market has changed significantly especially following the Great Recession. Likewise, the conduct of monetary policy has shifted dramatically over the past three decades towards inflation targeting with increasing focus on price stability. Despite increasing role of inflation expectations, the macroeconomic models usually underscore two main conduits of monetary policy transmission to the real economy. These are: (1) the domestic channel, via the short-term market interest rate; and (2) the external channel, through the exchange rate (see Figure 4.1). While the former medium is controlled fairly closely by the central banks, the latter channel is not within their grips.

Studies (including Bryant et al., 1993; Smets 1995; etc) found the effects of the exchange rate channel to be larger for smaller but more open economies. Consequently, one major concern for economic policy makers, especially in emerging and developing (EDE) inflation targeting (IT) economies, has been the movement of exchange rate and its role in IT regime for EDEs. The conundrum of whether exchange rate should be allowed to independently/freely float in such IT economies largely hinges on the relatively higher pass-through from the latter to prices as well as large proportion of foreign currency denominated liabilities (both private and public) in these economies. For instance, Hausmann et al., (1999, 2001) show that the EDEs with a *de-jure* floating exchange rate behave differently from their developed counterparts. They argue that the EDEs show greater inclination to interfere in the foreign exchange market to influence

the value and volatility of their currencies either using reserves or interest rate policy. Consequently, the EDEs do not permit the same degree of flexibility for exchange rate to adjust to shocks due to its dire economic ramifications for these economies.

Figure 4.1: Monetary Policy Transmission Mechanism



Source: Al-Mashat et al., (2018); Clinton et al., (2015)

Besides, the extant literature remains open-ended on whether or not it is prudent for EDEs to permit full exchange rate flexibility alongside an IT framework. A strand of the literature emphasizes a flexible market-determined exchange rate as a precondition for successful adoption of IT (see, Mishkin and Schmidt-Hebbel, 2002; and McCallum, 2007). Another realm of the literature (see, Airaudo et al., 2016) however accentuates a tight management of exchange rate (via direct official sterilized purchases/sales of foreign exchange) as a pivot for successful IT implementation and outcomes in EDEs with sufficiently high degree of substitutability between domestic and foreign currencies. This policy dilemma largely reflects the formidable role the exchange rate plays in macroeconomic dynamics in small-open EDEs.

With Ghana as the second longest practicing IT economy in Africa (after South Africa)[32] and the exchange rate system is best classified as a managed rather than independently float[33] (see IMF, 2016), it is of interest to consider how the exchange rate influences interest rate setting and the overall monetary transmission mechanism in Ghana. Without doubt, the exchange rate has remained highly volatile over the years alongside persistent and high inflation, placing Ghana among the sub-Saharan African economies with highest consumer inflation (see Akosah and Dasah, 2015). The major culprit for the acute inflationary pressures in Ghana has often been ascribed to incessant exchange rate vulnerability, instigated primarily by inherent domestic structural weaknesses such as overdependence of foreign inputs for domestic economic activities, the perennial fiscal excesses (especially during election cycles) accompanied by monetary accommodation, and large external imbalances (see, the figures at Appendix 1Aii-1Aiii).

Against this background, this chapter seeks to address the following fundamental policy questions: (1) what is the degree of interlinkages/spillovers among money market interest rates? Do such inter-linkages vary with time intervals and investment scales? (2) What is (are) the most dominant money market interest rate(s)? (3) What is the degree of pass-through of policy interest rate to the real sector? Is relevant is exchange rate in the interest rate setting and the entire macrostructure in Ghana? The focus of this chapter is motivated by the voluminous literature devoted to the search for appropriate channel amid considerable developments in both the financial system and monetary policy implementation. Another drive is the significant change in the operation of the financial market especially following the Great recession. Yet, the dramatic shift in the conduct of monetary policy over the past three decades towards inflation targeting with increasing focus on price stability also spurs the focus of this chapter.

We tackle the questions in this chapter in two folds. First, it examines the inter-linkages or spillovers among money market interest rate in Ghana. Due to the typical small-open economic dynamics of the Ghanaian economy, our second objective is to determine the extent of exchange rate relevance in Ghana's macrostructure. We tackle this quest in this chapter by

[32] Ghana started IT framework in November 2002, although the official announcement for the adoption was in May 2007 (see, Bawumia, 2010).
[33] The central bank, however, maintained a presence in the market to provide foreign exchange to meet part of the demand. The Bank is obliged to do this because a sizable portion of the proceeds from traditional exports was surrendered to it.

exploring the interconnectedness among the policy rate, the exchange rate and other key policy targeted macro-variables (inflation and output gap) utilizing both in-sample and out-sample techniques for volatility spillovers. This is broadly motivated by the widespread application of a policy rule for EDEs (including Ghana) that minimizes a quadratic or linex loss function excluding exchange rate volatility term despite perceived importance of the latter in overall macro-dynamics of small-open EDEs. Besides, it is also observed that the inclusion of exchange rate in the policy reaction function in some empirical studies (including Takáts, 2012; etc) is purely subjective as it is not backed by empirical underpinnings. In addition, the empirical literature is virtually unfilled with multiple scale analysis of exchange rate spillovers to policy interest rate, inflation and output gap. This is despite the fact that innovations to economic activity usually affect variables at various frequencies with different strengths (Barunik and Krehlik, 2015, 2016).

Although the focus of this chapter is not new in the Ghanaian literature, prominent studies (including, Akosah, 2015; Akosah and Dasah, 2015; Kovanen, 2011; Amidu, 2006; Acheampong, 2005; Quartey, 2005; Abradu-Otoo et al, 2003; etc) focused predominantly on two policy horizons (i.e. short and long-run periods). Not only may such analysis offer limited strategies for policymakers but they mostly provide time-domain analysis and hence, offer virtually no information about the frequency dimension of macroeconomic interactions. However, the policy relevance of frequency domain analysis is well acknowledged in the extant literature because macroeconomic data are time-varying and subject to structural changes. Moreover, the monetary authority may simultaneously operate at more than two time-scales (Aguiar-Conraria, et al., 2008, 2012), while economic and financial processes can be the results of decisions of heterogeneous agents with different time horizons (see, Gallegati, et al, 2011; Lynch and Zumbach, 2003). As a consequence, an approach that captures dynamic linkages across several policy horizons could be more informative for policymakers. The chapter overcomes such knowledge gap by examining inter-linkages among money market rates in a multiscale framework, thereby providing wide-ranging policy options for policymakers. Thus, our exploration of monetary policy effectiveness at both time- and multi-scale (frequency) domains offers all-encompassing analysis than the existing literature on monetary policy transmission.

The chapter also complements the growing literature on connectedness and volatility spillovers among key macroeconomic policy variables, especially for the small-open frontier and developing economies, by offering two unique contributions. First, the use of a more novel technique like Maximal Overlap Discrete Wavelet Transform (MODWT)[34] with Debauches least asymmetric filter of length (LA8) to obtain wavelet time-scale coefficients for the analysis of macro interdependence at multiple time-scales is a methodological contribution worth mentioning. Second, the parallel application of linear and nonlinear Granger non-causality tests as well as the generalized forecast error variance decomposition (GFEVD) methodology to evaluate the dynamic linkages between monetary policy instruments and the targeted macro-variables at multiscale domain is equally a notable empirical and methodological contribution. The rareness of this study hinges on the fact that empirical studies have widely employed either linear or nonlinear Granger non-causality test (e.g. Diks and Panchenko [DP], 2006 approach) or GFEVD methodologies but not both approaches in a single study. More so, these approaches have been predominantly focused on connectedness between financial markets (including Cryptocurrencies) or commodity markets (i.e. Karanaso et al., 2018; Corbet et al., 2018; Das et al., 2018; Yarovaya et al., 2016; Diebold and Yilmaz, 2015; Balli et al., 2015; Lucey et al., 2014; Chau and Deesomsak, 2014; Antonakakis and Vergos, 2013; etc). So far, few number of papers have analyzed directional and intensity of spillovers across macroeconomic variables, although the focus is quite different from this chapter. For instance, Barunik et al (2017) and Greenwood-Nimmo et al (2016) examined volatility spillovers between the forex market and the federal funds rate, while Curcuru et al (2018) explored monetary policy spillover between US and German bond yields. To the best of our knowledge, no study has explored spillovers dynamics among money market rates on one hand and among the key macroeconomic variables such as policy interest rate, inflation gap, output gap and exchange rate at frequency domain on the other hand. In addition, such empirical perspective coupled with a complementary application of DP2006 and GFEVD techniques at multiscale domain remains non-existent in the extant literature for frontier economies. Indeed, adequate knowledge of such connectedness and transmission is crucial not only for the effectiveness of policy instrument(s) but also for the understanding of the MPT mechanism and entire macrostructure of Ghana. The paucity of such studies on developing and frontier economies justifies the novel contribution of this chapter to empirical literature.

[34] See Section 3.4 for the overriding advantages of MODWT over DWT.

4.1 Related Empirical Literature on Monetary Policy Transmission

Most researches on MPT mechanism researches have focused on the advanced economies of North America and Europe. Kuttner and Mosser (2002) argued that the four main conduits of monetary policy transmission (including the interest rate channel, the asset channel, the exchange rate channel and the credit channel) are not mutually exclusive as the overall economic response to monetary policy will incorporate the impact of several channels. However, the dominant channel(s) of monetary policy transmission in a specific economy is (are) contingent on the restrictions (presence or absence of barrier) to international capital movements, its exchange rate regime and financial structure (influenced by its legal and institutional environments). Consequently, the differences in country characteristics matter for monetary policy transmission (Mishra and Montiel, 2012)[35].

It is argued that these channels are however more prevalent in advanced economies than developing and emerging economies. In spite of the level of development, the practical knowledge of the transmission mechanism remains imperfect due to difficulties in estimating the transmission mechanism (Mahadeva and Sinclair, 2001). This is attributed to a number of factors such as lack of reliable data, unforeseeable changes in the structure of the economy, difficulty in separating cause from effect in the data as well as lags with which monetary policy acts are long and variable. But the situation is more acute in the less developed countries (LDC), especially the SSA economies excluding South Africa, as they are considerably less integrated with the international financial markets and more inclined to intervene in the foreign exchange market. This feature however tends to weaken the exchange rate channel. In addition, the underdeveloped domestic stock and bond markets, particularly in the LDC, also restrained the asset price channels and the conventional interest rate channel respectively. Unlike the advanced economies, the LDCs generally have larger informal sectors, alongside less competitive banking systems and unfavourable institutional environments, questioning the strength and reliability of the credit (lending) channel in LDCs. Indeed, several authors (including Sacerdoti, 2005) have posited that the relevance of the bank lending channel is limited by the size of and imperfections in the financial sector in many SSA countries.

[35] See Mishra et al (2012) for a more exhaustive discussion on the empirical evidence of monetary policy transmission in low income countries prior to 2013.

Notable studies on MPT mechanism in SSA (excluding Ghana) since 2012 are Simpasa *et al.*, (2014) for Zambia; Opolot and Nampewo (2014) for Uganda using disaggregated bank-level data, Ishioro (2013) for Nigeria; Walker (2012) for countries in East African Countries using disaggregated bank-level data. With the exception of Opolot and Nampewo (2014) and Walker (2012) who used GMM methods to examine the bank lending channel, all the other researches for developing African economies have applied either VAR or SVAR. A fewer number of studies have also explored the effectiveness of monetary policy in Ghana via the interest rate transmission channel. For instance, Acheampong (2005) examined the bank interest rate channel of monetary policy transmission in Ghana for the period September 1994-February 2014. He concluded that policy shift has some impact on lending rate decisions of the banks but no significant effect on the borrowing rate. Ghartey (2005) also examined the impact of monetary policy on the term structure of interest rate in Ghana during 1994-2004 and reported a significant effect of monetary policy rate on Treasury bill interest rate.

Similarly, Kovaren (2011) appraised interest rate pass through of monetary policy in Ghana with dataset spanning the period 2005-2010 using Vector Autoregressive (VAR) framework and simulation techniques. He found a relatively strong short-term response of wholesale market interest rate (interbank and treasury bills) to changes in monetary policy rate, but a delayed long term response of the former (interbank rate) to changes in the latter. CEPA (2012) also assessed the relevance of monetary policy rate in the transmission mechanism between November 2009 and May 2012. The study finds changes in MPR to strongly impact on both the interbank and 91-day Treasury bill interest rate. In addition, Fukac and Baldini (2014) explored inflation and monetary policy transmission in Ghana during 2007-2012 and found reduced-form evidences that the interest rate transmission mechanism is now central to keeping inflation in check. They however found a limited signaling ability of monetary policy rate to other money market rates in 12-ordered Vector Auto-Regression (VAR) model.

Employing a battery of statistical and econometric techniques, Akosah (2015) also examined the effectiveness of monetary policy transmission mechanism in Ghana over the period 2002M1 – 2014M12. The study finds monetary policy rate (MPR) to be fairly effective in signaling the money market interest rates in both the short run and long run, but the effect remains incomplete (that is, not one-to-one) even in the long run. In addition, the study identifies a hierarchy of short-term money market rates in Ghana is identified as follows:

Monetary Policy Rate, Treasury bill rate, Interbank rate and retail rates (preferably, lending rate), which emphasized the predominant role of Treasury bill interest rate in the interest rate transmission channel in Ghana. The study further unveils that monetary authority responds positively and contemporaneously to output and inflationary pressures. He finds inflation to be driven mostly by interest rate shock over the medium to long term, while exchange rate shock exerts relatively larger influence on inflation in the short term. In contrast, output was observed to be driven largely by credit and assets prices shocks.

In a slightly different focus, Akosah and Dasah (2015) explored the effectiveness of monetary policy in dampening exchange market pressure induced by fiscal excesses in Ghana over the period 2000Q1-2014Q1. Based on structural VAR framework, they found sterilization interventions to be more effective than interest rate as a monetary policy tool in moderating tensions in foreign exchange market. Also utilizing a recursive VAR framework, Loloh (2014) investigated exchange rate pass-through to domestic prices for the period January 1994 to December 2012. The study generally unveils that exchange rate pass-through is positively correlated with the level of inflation. Nonetheless, the exchange rate pass through is incomplete and more benign to overall CPI inflation than for non-food inflation. The study also found pass through to inflation to be mostly felt within 12 months but decays within 18-24 months.

Notwithstanding, the empirical findings of these researches including those documented by Mishra and Montiel (2012) particularly for countries in the SSA region, are generally mixed. Besides, these studies predominantly present linear and semi-parametric analysis at time-domain and hence overlook possible nonlinear dynamics as well as offer virtually no information about the frequency at which policy interaction takes place. Therefore, recent empirical work has applied copula functions to explore nonlinear dependence and interrelationship between macroeconomic variables (see Paton, 2006 and 2012; Nguyen and Bhatti, 2012; Hammoudeh et al., 2014; Mensah and Alagidede, 2017; Mensah and Premaratne, 2017; etc). Nevertheless, these studies have largely focused on stock market dependence and spillovers. Key exceptional study however is by Bouezmarni et al., (2009) who examine the nonlinear interdependence among money growth, income and prices in USA and find significant evidence of nonlinear relationship from money growth to inflation and real disposal personal income but no significant linear effect from money growth to inflation.

Another realm of empirical studies (including Jena et al., 2018; Karanaso et al., 2018; Das et al., 2018; Polanco-Martinez et al., 2018; Barunik and Krehlik, 2015; Barunik et al., 2017; Liow and Zhou, 2016; Diebold and Yilmaz, 2012 & 2014; Fernando-Macho, 2012; Galagedera and Kitamura, 2012; among other) examine macroeconomic spillovers employing various time- and frequency domain methodologies such as bivariate wavelet coherency, multivariate wavelet (cross) correlation, wavelet-scaled linear/nonlinear Granger non-causality tests and frequency-domain generalised forecast error variance decomposition (GFEVD) techniques. Nonetheless, these empirical studies have principally hovered around connectedness within and between different financial markets (assets, commodities, and/or currencies including cryptocurrencies) of the advanced economies in Europe, Asia and North America.

To the best of our knowledge, the extant literature offers no empirical evidence on the co-movements and (non)linear spillovers among key monetary policy instruments and targeted macro-variable in a multi-scale domain. This is where we seek to fill the knowledge gap. Besides, our study offers complementary approaches, and hence, offers more comprehensive analysis of connectedness and shock transmission.

4.2 Estimation Methodology and Data

In this segment, highlights on key methodologies used to explore the dynamic co-movements and spillovers of the selected macro-variables are presented. We briefly explain the wavelet-based correlation framework for exploring dynamic pairwise and multiple co-movements and patterns of macro-variables in Section 4.2.1. In addition, we highlight in Section 4.2.2 the methodologies to determine macro-volatility spillovers based on linear and nonlinear causality methods as well as the generalised forecast error variance decomposition approaches of Diebold-Yilmaz (2012) and Barunik-Krehlik (2015) for the respective time- and frequency domain.

4.2.1 Wavelet Pairwise and Multiple Correlation Method

Since the time-domain analysis overlooks salient frequency at which macro-interaction takes place, we resort to present more encompassing and robust macro-interdependence. As a result, we employ wavelet analysis which is one of the most preferred forms of wavelet-based analysis for measuring co-movements in two different macro-data in a time-frequency domain (see Das et al, 2018; Boako and Alagidede, 2017, etc.). A wavelet is simply a small wave, which can be

stretched over time to obtain frequency constituents from complex signals. The wavelet function, i.e. the mother wavelet, can be expressed mathematically as

$$\beth_{\varsigma_p,\Phi_s}(t) = \frac{1}{\sqrt{\Phi_s}}\beth\left(\frac{t-\varsigma_p}{\Phi_s}\right) \tag{4.1}$$

Where $\frac{1}{\sqrt{\Phi_s}}$ connotes the normalization factor which ensure that wavelets are compatible across scales and time series; Φ_s is the dilation (scale) factor that controls the width of the wavelet. On one hand, it stretches the macro-data into a long wavelet function to measure the low frequency movements (long-run cycles). On the other hand, it compresses the data series into a short wavelet function to measure the high frequency movements. ς_p is the translation factor that determines the time location of the wavelet.

We first explore wavelet coherence analysis (WCA) which is one of the most preferred forms of wavelet-based analysis for measuring co-movements in two different macro-data in a time-frequency domain (see Das et al, 2018; Boako and Alagidede, 2017, etc.). We measure the correlation of a pair of our macro-data in time-frequency domain using the wavelet squared coherence (WSC) with continuous transforms $W_n^x(\varsigma_p, \Phi_s)$ and $W_n^{\mathrm{y}}(\varsigma_p, \Phi_s)$. The WSC may be defined as[36]

$$R_t^2(\varsigma_p, \Phi_s) = \frac{\left|\vartheta\left(\vartheta^{-1}W_n^{xy}(\varsigma_p, \Phi_s)\right)\right|^2}{\vartheta\left(\vartheta^{-1}\left|W_n^x(\varsigma_p, \Phi_s)\right|^2\right).\vartheta\left(\vartheta^{-1}\left|W_n^{\mathrm{y}}(\varsigma_p, \Phi_s)\right|^2\right)}; \quad R_t^2(.) \in [0,1] \tag{4.2}$$

where $\vartheta(.)$ represents a smoothing parameter; and $R_t^2(\varsigma_p, \Phi_s)$ denotes the localized coherency coefficient over time-frequency domain. The coefficient of WSC ranges from 0 to 1, which denotes weaker to higher co-movements. The mapping of wavelet coherence contours, which signifies statistical significant region, offers deeper insights regarding co-movements of the macro-pairs.

A wavelet coherence phase angel is applied to determine lead/lag linkages between two macro-datasets. In the graphical plot, the phase vectors are shown by arrows. For instance, the left-tailed (→)/right-tailed (←) arrows show the two macro series under consideration are in-phase/anti-phase respectively. The in-phase and anti-phase phenomenon depicts positive and negative co-movement respectively. The upward (↑), right-upward (↗) and left-downward (↙)

[36] For instance refer to Das et al., (2018); Boako and Alagidede (2017).

arrows show that the first macro series leads the second one. Likewise, the downward (↓), left upward (↖) and right-downward (↘) arrows represent that the second macro series leads the first one (see, Das et al., 2018). A cone of influence for the wavelet coherence is constructed which indicates where edge effects occur in the coherence data. Due to the edge effects, less credence is given to areas of apparent high coherence that are outside or overlap the cone of influence.

In order to overcome the limitations associated with the use of pairwise wavelet correlation analysis within a multivariate set of economic variables (Fernández-Macho, 2012[37]), we further explore wavelet multiple correlation (WMC) method. Suppose that $Y = (Y_1, Y_2, \dots, Y_q)$ are the realization of multivariate stochastic process Y_t where $t = 1, 2, \dots, Q$. We then compute wavelet multiple correlation (WMC) as:

$$\tilde{\Upsilon}_y(\psi_j) = \sqrt{1 - \frac{1}{\max\ diag\ Q_j^{-1}}} \tag{4.3}$$

Here, the correlation matrix of $\tilde{Z}_{ij}$ is given by Q_j. Alternatively, WMC could be expressed as:

$$\tilde{\Upsilon}_y(\psi_j) = \frac{Cov\left(\tilde{\zeta}_{ijt}, \hat{\tilde{\zeta}}_{ijt}\right)}{\sqrt{Var(\tilde{\zeta}_{ijt}) Var(\hat{\tilde{\zeta}}_{ijt})}} \tag{4.4}$$

Where ζ_{ij} is chosen in order to maximize $\tilde{\Upsilon}_y(\psi_j)$, and $\hat{\tilde{\zeta}}_{ij}$ are the fitted values in the regression of $\tilde{\zeta}_{ij}$ on the rest of wavelet coefficients at scale ψ_j. The scale j for each of the univariate time series $(y_{i1}, y_{i2}, \dots, y_{iq})$, for $i = 1, 2, \dots, q$ are determine using wavelet transforms (which is explained in section 2.3).

4.2.2 Measuring Macroeconomic Spillovers

Besides the wavelet analysis, we thoroughly assess the extent of macro interdependence or spillovers by further exploring other robust in-sample and out-of-sample frameworks. For the in-sample analysis, we specifically utilized the conventional parametric (or linear) Granger non-causality tests alongside the Diks and Panchenko (hereafter DP) nonparametric Granger non-causality test to uncover nonlinear transmission among the macro-variables. For the latter method, we stick to the specified conventions and bandwidth of Diks and Panchenko (2006),

[37] The WMC measures the overall statistical relationships that may occur among a set of observations at different time-scales. It offers protection against the standard type 1 error (see, Cohen et al., 2003) that may prevail in carrying out all possible pairwise comparisons in a multi-scale context.

henceforth DP2006. For robustness, the macro-spillovers are further examined using out-of-sample techniques such as the GFEVD approaches by Diebold-Yilmaz (2012) and Barunik and Krehlik (2015). The application of both techniques in this chapter is principally to resolve the potential deficiencies associated with each approach so as to ensure robust estimates.

4.2.2.1 Linear and nonlinear causality framework

We utilize the classical Granger causality technique (Granger, 1969) in a VAR framework to discover interdependence between macro-pairs. Given any two stationary data pair, say Z_t and W_t, variable Z_t linearly Granger-causes W_t provided that lags of Z_t offer useful information for explaining current values of W_t, and vice versa. The bivariate Granger causality is specified in a VAR system as follows:

$$Z_t = \beta_1 + \sum_{s=1}^{m} \alpha_{1s} Z_{t-s} + \sum_{v=1}^{m} \sigma_{1v} W_{t-v} + \varepsilon_{1t} \tag{4.5}$$

$$W_t = \beta_2 + \sum_{s=1}^{m} \alpha_{2s} Z_{t-s} + \sum_{v=1}^{m} \sigma_{2v} W_{t-v} + \varepsilon_{2t} \tag{4.6}$$

where, β_1 and β_2 are the constant terms of the system of equation; α and σ denote estimated coefficients; m is the optimal lag length based on the Schwarz Information Criterion (BIC)[38]; and ε_{1t} and ε_{2t} represent errors terms from the VAR model.

Owing to the low power limitation that characterises most linear models when detecting nonlinear causal linkages between variables, models which show higher nonlinear predictive power are often proposed. We however employ the nonparametric approach of DP (2005, 2006) to investigate possible nonlinear linkages among the macro-data due to its relative flexibility and robustness over other nonlinear methods proposed in the extant literature[39]. We specify the processes of the bivariate DP test as follows. Assuming any two pair of stationary and dependent variables, say Z_t and W_t, we denote the information sets of lags for Z_t and W_t

[38] In determining the optimal lag length, we set the lag number to 20.

[39] The DP test is a modified version of the widely used HJ test of Hiemstra and Jones (1994), while the latter is also an improved version of the maiden nonparametric test by Baek and Brock (1992). Essentially, the DP approach alleviates the severe over-rejection rates that epitomise the HJ test under the null hypothesis of Granger non-causality between variables. Furthermore, Diks and Wolski (2016) extend the bivariate DP test to a multivariate case, and endorsed that the DP approach of detecting Granger non-causality is much consistent and robust against several range of alternatives. Consequently, its adoption in this chapter is duly justified.

respectively as $G_{Z,t}$ and $G_{W,t}$, before time $t-1$; and let '~' symbolizes the equivalent distribution. In this case, variable Z_t is upheld to Granger-cause W_t provided that,

$$\left(W_{t+1},...,W_{t+m}\right)\left|\left(G_{Z,t},G_{W,t}\right)\sim\left(W_{t+1},...,W_{t+m}\right)\right|G_{Z,t} \tag{4.7}$$

where, *m* is an integer $(m\geq 1)$ which represents the forecasting horizon. For the lag vectors $Z_t^{l_z}=\left(Z_{t-l_z+1},...,Z_t\right)$ and $W_t^{l_w}=\left(W_{t-l_w+1},...,W_t\right)$, given $\left(l_z,l_w\geq 1\right)$, we test for conditional independence using determinate number of lags, l_z and l_w based on a null hypothesis of:

$$H_0: W_{t+1}\left|\left(Z_t^{l_z};W_t^{l_w}\right)\sim W_{t+1}\right|W_t^{l_w} \tag{4.8}$$

Considering that the null hypothesis of Granger non-causality is a claim about the invariant distribution of $\left(l_z+l_w+1\right)$-dimensional vector $\Psi_t=\left(Z_t^{l_z},W_t^{l_w},X_t\right)$, where for the lead vector $X_t=W_{t+1}$, the time index is dropped and simply written as $\Psi=\left(Z,W,X\right)$. For notational flexibility, we set $l_z+l_w=1$, and $m=1$, and assume that Ψ vector follows a continuous random variable. The null hypothesis of non-causality in (4.8) may be expressed in a joint probability density function $g_{Z,W,X}(z,w,x)$ with its marginal satisfying the condition:

$$\frac{g_{Z,W,X}(z,w,x)}{g_W(w)}=\frac{g_{Z,W}(z,w)}{g_W(w)}*\frac{g_{W,X}(w,x)}{f_W(w)} \tag{4.9}$$

where, for every determinate value of *w*, the continuous random variables *Z* and *X* are conditionally independent on $W=w$. Therefore, under the revised null hypothesis H_0, DP (2006) espoused that:

$$\psi\equiv E\left[g_{Z,W,X}(Z,W,X)g_W(W)-g_{Z,W}(Z,W)g_{W,X}(W,X)\right]=0 \tag{4.10}$$

using a chosen weight function given as $\Omega(z,w,x)=g_W^2(w)$. DP deduced an estimator of ψ in an expression given by:

$$T_p(\xi_p)=\frac{(2\xi_p)^{-\Gamma_Z-2\Gamma_W-\Gamma_X}}{p(p-1)(p-2)}*\sum_i\left[\sum_{m,m\neq s}\sum_{v,v\neq s}(I_{sm}^{ZWX}I_{sv}^{W}-I_{sm}^{ZW}I_{sv}^{WX})\right] \tag{4.11}$$

Here, $I_{sv}^{\Psi}=I\left(\left\|\Psi_s-\Psi_v\right\|<\xi_p\right)$; and ξ_p denote the bandwidth parameter. By representing the local density estimators of a Γ_Ψ-variate random vector Ψ and Ψ_s as:

$$\hat{g}_\Psi(\Psi_i)=\frac{(2\xi_p)^{-\Gamma_\Psi}}{p-1}*\sum_{v,v\neq s}I_{sv}^{\Psi} \tag{4.12}$$

the $T_p(\xi_p)$ statistic of the DP test reduces to:

$$T_p(\xi_p) = \frac{(p-1)}{p(p-2)} * \sum_i \left(\hat{g}_{Z,W,X}(Z_s, W_s, X_s)\hat{g}_W(W_s) - \hat{g}_{Z,W}(Z_s, W_s)\hat{g}_{W,X}(W_s, X_s) \right) \quad (4.13)$$

Given that $\Gamma_Z = \Gamma_W = \Gamma_X = 1$, when $\xi_p = Bp^{-\varpi}$, for $(B > 0, \varpi \in (0.25, 0.67))$, $T_p(\xi_p)$ converges in distribution to the standard normal:

$$\sqrt{p} * \frac{\left(T_p(\varepsilon_p) - \psi\right)}{\Phi_p} \xrightarrow{d} N(0,1) \quad (4.14)$$

where the asymptotic variance of $T_p(\bullet)$ is given by Φ_p.

4.2.2.2 Generalized forecast error variance decomposition (GFEVD) Method

To complement the causality analysis, we also employ the GFEVD methodology of Diebold and Yilmaz (2012), henceforth DY2012, to measure macroeconomic spillovers. In line with DY2012, Koop, Pesaran and Potter (1996), and Pesaran and Shin (1998), we estimate a covariant stationary N-variable VAR(p) model which takes a general form

$$Z_t = \sum_{i=1}^{p} \alpha_i Z_{t-i} + v_t, \quad (4.15)$$

where Z_t is $N\ x\ 1$ vector of endogenous variables, α_i are $N\ x\ N$ autoregressive coefficients matrices and v_t are the vector of error terms assumed to be independently and identically distributed (serially uncorrelated). In this chapter, the VAR contains 4 variables (N = 4), namely real policy interest rate, inflation, output gap (i.e. real GDP deviation from its trend) and exchange rate. The moving average representation of equation (4.15) is $Z_t = \sum_{i=1}^{\infty} A_i v_{t-i}$, where A_i is a $N\ x\ N$ coefficient matrices that obey the recursion $A_i = \omega_1 A_{i-1} + \omega_2 A_{i-2} + \ldots + \omega_p A_{i-p}$ with A_0 being a $N\ x\ N$ identity matrix and $A_0 = 0$ for $j < 0$.

The total, directional and net volatility spillovers are produced using GFEVD of the moving average representation of the VAR model in equation (4.15). The merit of GFEVD is that it jettisons the dependence on the ordering of the variables in the VAR. The variance decomposition permits us to separate the forecast variance of each variable into (i) own shock (own variance share) as the fraction of H-step error variance in forecasting Z_i that is due to shock to Z_i and (ii) cross variance share or spillovers as the fraction of H-step error variance in

forecasting Z_i that is due to shock to Z_j for $j = 1,2,3,4$. According to Pesaran and Shin (1998), the H-step-ahead GFEVD is defined as

$$\psi_{ij}(H) = \frac{\sigma_{jj}^{-1}\sum_{h=0}^{H-1}\left(e_i' A_h \sum e_j\right)^2}{\sum_{h=0}^{H-1}(e_i' A_h \sum A_h' e_i)}, \tag{4.16}$$

Where $\sum$ denotes a variance matric of error vector v_t, σ_{jj} is the standard deviation of the error term for the jth equation and e_i is a selection vector with one as the ith element and zeros otherwise. This results in an $N\ x\ N$ matrix $\psi(H) = \left[\psi_{ij}(H)\right]_{i,j=1,2}$, where each entry provides the contribution of variables j to the forecast error variance of variable i. However, since the own and cross variance shares do not sum up to unity under the GFEVD, we normalised each entry of the GFEVD matrix by row sum as

$$\widetilde{\psi}_{ij}(H) = \frac{\psi_{ij}(H)}{\sum_{j=1}^{N}\psi_{ij}(H)}, \tag{4.17}$$

where $\sum_{j=1}^{N}\widetilde{\psi}_{ij}(H) = 1$ and $\sum_{i,j=1}^{N}\widetilde{\psi}_{ij}(H) = N$ by construction. Using the normalized volatility contribution from GFEVD, we compute total volatility spillover index, $T^s(H)$, as

$$T^s(H) = 100 * \frac{\sum_{i,j=1,i\neq j}^{N}\widetilde{\psi}_{ij}(H)}{\sum_{i,j=1}^{N}\widetilde{\psi}_{ij}(H)} = 100 * \frac{\sum_{i,j=1,i\neq j}^{N}\widetilde{\psi}_{ij}(H)}{N}, \tag{4.18}$$

Equation (4.18) gives the average contribution of spillovers from shock to all (other) variables to the total forecast error variance. We then measure the directional spillovers received by variable i from all other variables j as:

$$D_{i\leftarrow j}^{s}(H) = 100 * \frac{\sum_{j=1,i\neq j}^{N}\widetilde{\psi}_{ij}(H)}{\sum_{i,j=1}^{N}\widetilde{\psi}_{ij}(H)} = 100 * \frac{\sum_{j=1,i\neq j}^{N}\widetilde{\psi}_{ij}(H)}{N}, \tag{4.19}$$

On the other hand, the directional spillovers from variable i to all other variables j are also computed as:

$$D_{i\rightarrow j}^{s}(H) = 100 * \frac{\sum_{j=1,i\neq j}^{N}\widetilde{\psi}_{ji}(H)}{\sum_{i,j=1}^{N}\widetilde{\psi}_{ji}(H)} = 100 * \frac{\sum_{j=1,i\neq j}^{N}\widetilde{\psi}_{ji}(H)}{N}, \tag{4.20}$$

In order to identify which of the variables in the system is a transmitter or receiver of spillovers in the net terms, we compute a net spillover, N_i^s (H), for variable i by subtracting equation (4.20) from (4.19) as follows:

$$N_i^s(H) = D_{i\rightarrow j}^{s}(H) - D_{i\leftarrow j}^{s}(H), \tag{4.21}$$

While the DY2012 methodology presents useful analysis on average connectedness at time domain, the recent extant literature has however articulated frequency domain interconnectedness of financial and macroeconomic variables (see, Barunik and Krehlik, 2015,

2017; Barunik et al., 2018; Corbet et al., 2018; Das et al., 2018; etc). This is motivated by the fact that innovations to economic activity usually affect variables at various frequencies with different strengths (see, Barunik and Krehlik, 2015).

Consequently, we further explore the frequency dynamics of interconnectedness among key monetary instrument and targeted macro-variables. A normal approach to illustrate the frequency-dependent connectedness is to utilize spectral representation of variance decompositions through frequency responses to shocks instead of impulse responses from shocks. Although in a restrictive setting, Stiassny (1996) introduced a first notion of spectral representation for variance decompositions. Subsequently, Barunik and Krehlik (2015), henceforth BK2015, provided a more general spectral representation of variance decompositions, and use it to define and quantify frequency-dependent interconnectedness measures. They essentially utilized the DY2012 methodology as a building block for the frequency connectedness.

Considering an MA(∞) filtered series, the spectral density of ω_t at frequency η can be defined as

$$S_\omega(\eta) = \sum_{h=-\infty}^{\infty} E\,(\omega_t \omega'_{t-h}) e^{-i\eta h} = \Phi\left(e^{-i\eta}\right)\Sigma\Phi' e^{+i\eta}, \tag{4.22}$$

where $S_\omega(\eta)$ represents a power spectrum, and illustrates how the variance of the ω_t is distributed over the frequency component η. With $E(\omega_t \omega'_{t-h}) = \int_{-\pi}^{\pi} S_\omega(\eta) d\eta$, the spectral representation of covariance logically provides the variance decomposition at frequency-domain. We note however that the computation of these theoretical quantities is contingent on an infinite process. For the purpose of practicality, we assume a finite MA(H) approximation with the notion that if the system is stable, there must exist H, such that

$$MSE\left(y_{k,H}\right) - MSE\left(y_{k,H+1}\right) < e, \tag{4.23}$$

Equation (4.23) connotes that the error-form approximation disappears as H grows (see Lukepohl, 2007). The $\widehat{\Phi}_h$ coefficients are then computed through standard recursive scheme $\widehat{\Phi}_0 = I$, $\widehat{\Phi}_h = \sum_{j=1}^{\max\{h,p\}} \Phi(j)\widehat{\Phi}_{h-1}$, where p is the order of VAR and $h \in \{1, \dots, H\}$.[40] Based

[40] Barunik and Krehlik (2016) admonish a setting of higher H in order to obtain better approximation of the quantities at the frequencies especially when small frequency bands are of interest.

on standard discrete Fourier transforms, the cross-spectral density on the interval $\odot \in (n, m)$: $n, m \in (-\pi, \pi), n < m$, can be estimated as follows

$$\int_{\odot} \Phi\left(exp^{-i\eta}\right) \Sigma \Phi'\left(exp^{+i\eta}\right) d\eta = \sum_{\eta} \widehat{\Phi}(\eta) \widehat{\sum} \widehat{\Phi}'(\eta), \tag{4.24}$$

for $\eta \in \left\{\left\lfloor \frac{nH}{2\pi} \right\rfloor, \ldots, \left\lfloor \frac{mH}{2\pi} \right\rfloor\right\}$ where

$$\widehat{\Phi}(\eta) = \sum_{h=0}^{H-1} \widehat{\Phi}_h exp^{-2i\pi\eta/H}, \tag{4.25}$$

and $\widehat{\sum} = \hat{e}'\hat{e}/T$.

The decomposition of the impulse response function at the given frequency band is then computed as

$$\widehat{\Phi}(\odot) = \sum_{\eta} \widehat{\Phi}(\eta), \ \ for \ \eta \in \left\{\left\lfloor \frac{nH}{2\pi} \right\rfloor, \ldots, \left\lfloor \frac{mH}{2\pi} \right\rfloor\right\}, \tag{4.26}$$

Based on equation (4.26), we can define the estimate of the generalized causation spectrum over the interval $\odot \in \{n, m\}$ as follows:

$$\left(\hat{\Gamma}(\odot)\right)_{j,k} \equiv \frac{\hat{\sigma}_{kk}^{-1} \left(\left(\widehat{\Phi}(\eta)\hat{\Sigma}\right)_{j,k}\right)^2}{\left(\Sigma_{\eta} \widehat{\Phi}(\eta)\hat{\Sigma}\widehat{\Phi}'(\eta)\right)_{j,j}}, \tag{4.27}$$

By utilizing the weighting function

$$\hat{\Gamma}_j(\odot) \equiv \frac{\left(\Sigma_{\eta} \widehat{\Phi}(\eta)\hat{\Sigma}\widehat{\Phi}'(\eta)\right)_{j,j}}{\left(\Sigma_{\odot}\Sigma_{\eta} \widehat{\Phi}(\eta)\hat{\Sigma}\widehat{\Phi}'(\eta)\right)_{j,j}}, \tag{4.28}$$

the decomposed GFEVD of a frequency band is estimated as

$$\hat{\psi}_{j,k}(\odot) = \hat{\Gamma}_j(\odot) \left(\hat{\Gamma}(\odot)\right)_{j,k}, \tag{4.29}$$

Equation (4.29) works with two notions, namely frequency and within connectedness. The frequency connectedness on the frequency band $\odot$, defined as

$$\Upsilon_{\odot}^{F} = 100 * \left(\frac{\hat{\Gamma}_j(\odot) \left(\hat{\Gamma}(\odot)\right)_{j,k}}{\sum_k \hat{\Gamma}_j(\odot) \left(\hat{\Gamma}(\odot)\right)_{j,k}} - \frac{Tr\{\hat{\psi}(\odot)\}}{\Sigma \left(\hat{\psi}(\odot)\right)_{j,k}} \right), \tag{4.30}$$

decomposes the original connectedness into distinct parts that sum up to yield the original connectedness measure Υ_{∞}. In contrast, within connectedness on the frequency band $\odot$ can also be defined as

$$\Upsilon_{\odot}^{W} = 100 * \left(1 - \frac{Tr\{\hat{\psi}(\odot)\}}{\Sigma\left(\hat{\psi}(\odot)\right)_{j,k}} \right), \tag{4.31}$$

From (3.31), $\Upsilon_{\odot}^{W}$ gives the connectedness effect that happens within the frequency band and is weighted by the power of the series on the given frequency band exclusively.

4.2.3 Dataset and Wavelet Transformed Coefficients

We apply two main datasets. The first dataset comprises of monthly times series from January 2001 to December 2017 for the analysis of the signaling ability of policy interest rate to other money market interest rates. These comprise monetary policy interest rate (MPR), overnight interbank interest rate, 91-day Treasury bill rate, average lending rate and savings deposits rate. The second is quarterly dataset spanning the period 2001Q1-2017Q4 for the analysis of macro-interdependence and spillovers for monetary-and-real economic series in Ghana. These include nominal (real) Consumer Price Index (CPI), real GDP or output, nominal and real bilateral exchange rate. The choice of the variables is purely based on the literature on MPRF.

The real MPR is computed as $RMPR = \left(\frac{1+MPR}{1+\pi_{t+1}}\right) - 1$. With the exception of the interest rate, all the remaining variables are in logarithmic terms. We compute annual CPI inflation, nominal and real bilateral exchange rate depreciation (or appreciation) as $r_{i,t} = 100 * In(X_{i,t} / X_{i,t-4})$, for $i = 1,2,3;\ t = 1,...,68$; where $X_{i,t}$ and $X_{i,t-4}$ denote the value of ith macro-data (CPI inflation, nominal and real bilateral exchange rate) at the current quarter (*t)* and a year ago (*t*-4) respectively. As prerequisite in this chapter, we further compute gaps as deviations from the interested variables (mainly CPI inflation, exchange rate and output) from a certain policy desired level of following the literature. Notably, inflation gap is defined as a deviation of CPI inflation from official inflation target of 8%. However, for the period where the target was not explicit (especially for the 2001-2007), the target was computed as a linear trend of the actual CPI inflation using the Hodrick-Prescott (HP) filter[41]. Output gap is computed as the difference between the actual real GDP and its trend (or potential) level, with the latter generated using

[41] However, single digit inflation has been a long standing monetary policy target since the inception of the inflation targeting framework in Ghana. For robustness, therefore, we validate our empirical results using inflation target of 10% across the data span. The use of the upper limit of medium-term inflation target is also broadly motivated by the fact that Ghana's headline inflation has consistently exceeded the medium-term target midpoint of 8%.

band pass (BP) filter based on fixed length (Baxter-King) symmetric filter with low and upper durations of 6 and 32 quarters respectively.

Table 4.1 presents the results for unit root tests based on the ADF, PP and KPSS tests. Both the ADF and PP test clearly show that all the monthly and quarterly datasets, except nominal MPR, generally exhibited stationary properties at levels with constant or trend or neither constant and trend, indicating an I(0) processes. In contrast, nominal MPR rather becomes stationary after first differencing, showing an I(1) process. However, the KPSS results are generally mixed.

Table 4.1: Unit root tests of money market rate and key macro-variables

	Augmented Dickey-Fuller (ADF) Test				**Philips-Perron (PP) Test**				**Kwiatkowski-Philips-Schmidt-Shin (KPSS) Test**		
	Ho: Series is non-stationary				***Ho: Series is non-stationary***				***Ho: Series is stationary***		
	None	**Constant**	**Constant & Trend**	**First Difference**	**None**	**Constant**	**Constant & Trend**	**First Difference**	**Constant**	**Constant & Trend**	**First Difference**
					Monthly						
MPR_t	[0.42]	[0.44]	[0.73]	[0.00] ^{A}	[0.27]	[0.28]	[0.57]	[0.00] ^{A}	{0.32}	{0.32} ^{A}	{0.31}
$INTB_t$	[0.09] ^{C}	[0.09] ^{C}	[0.36]	[0.00] ^{A}	[0.11]	[0.08] ^{C}	[0.31]	[0.00] ^{A}	{0.31}	{0.31} ^{A}	{0.22}
$TBILL_t$	[0.06] ^{C}	[0.06] ^{C}	[0.25]	[0.00] ^{A}	[0.06] ^{C}	[0.07] ^{C}	[0.27]	[0.00] ^{A}	{0.31}	{0.24} ^{A}	{0.14}
$LENDR_t$	[0.06] ^{C}	[0.02] ^{B}	[0.37]	[0.00] ^{A}	[0.08] ^{C}	[0.03] ^{B}	[0.35]	[0.00] ^{A}	{0.65} ^{B}	{0.29} ^{A}	{0.39}
SDR_t	[0.10]	[0.05] ^{C}	[0.36]	[0.00] ^{A}	[0.09] ^{C}	[0.05] ^{C}	[0.38]	[0.00] ^{A}	{0.86} ^{A}	{0.12} ^{B}	{0.27}
					Quarterly						
MPR_t	[0.30]	[0.24]	[0.58]	[0.00] ^{A}	[0.30]	[0.33]	[0.73]	[0.00] ^{A}	{0.23}	{0.22} ^{A}	{0.24}
$RMPR_t$	[0.04] ^{B}	[0.01] ^{B}	[0.03] ^{B}	[0.00] ^{A}	[0.01] ^{B}	[0.00] ^{A}	[0.00] ^{A}	[0.00] ^{A}	{0.67} ^{B}	{0.09}	{0.07}
$INF_{gap,t}$	[0.00] ^{A}	[0.01] ^{B}	[0.00] ^{A}	[0.00] ^{A}	[0.00] ^{A}	[0.00] ^{A}	[0.00] ^{A}	[0.00] ^{A}	{0.45}	{0.06}	{0.02}
$Y_{gap,t}$	[0.00]*	[0.02]**	[0.09]	[0.00]*	[0.00] ^{A}	[0.00] ^{A}	[0.00] ^{A}	[0.00] ^{A}	{0.08}	{0.06}	{0.64} ^{B}
$Xdep_t$	[0.06] ^{C}	[0.09] ^{C}	[0.14]	[0.00] ^{A}	[0.00] ^{A}	[0.00] ^{A}	[0.00] ^{A}	[0.00] ^{A}	{0.21}	{0.08}	{0.13}
$CRER_t$	[0.02] ^{B}	[0.20]	[0.16]	[0.00] ^{A}	[0.01] ^{B}	[0.11]	[0.15]	[0.00] ^{A}	{0.49} ^{B}	{0.08}	{0.03}

where

MPR_t	*is the official monetary policy rate (nominal)*
$RMPR_t$	*is the real monetary policy rate)*
$INTB_t$	*is the overnight average interbank rate (nominal)*
$TBILL_t$	*is the 91-Day Treasury bill rate (nominal)*
$LENDR_t$	*is the average lending rate (nominal)*
SDR_t	*is the savings rate (nominal)*
$INF_{gap,t}$	*is the deviation of inflation from the target*
$Y_{gap,t}$	*is the deviation of output from the potential level*
$Xdep_t$	*is the nominal bilateral exchange rate depreciation (GHS per USD)*
$CRER_t$	*is the real bilateral exchange rate (GHS per USD)*

Note: {} and [] denote test statistics and p-values respectively; Superscript A, B & C denote 1%, 5% & 10% significant levels respectively.

For time-frequency analysis, we decompose the raw time series into time-scales coefficients using wavelet transform methodology. There are two ways of decomposing time series using wavelet methods. These are continuous wavelet transforms (CWT) and discreet wavelet transforms (DWT). While CWT deals with times series over the entire axis, the DWT deals with time series at finite range. Thus, DWT can be roughly described as a subsample of CWT at 'dyadic' scales. Since the time series can be perfectly recovered by either wavelet decomposition (CWT or DWT), wavelet methods are satisfactorily a conventional way to deal with time series that have scale characteristics (see, Liow and Zhou, 2016). Particularly, DWT can handle non-stationary data by working in the combined time-and-scale-domain (see, Percival and Walden, 2006; Gencay et al., 2002). We applied the modified version of DWT called the Maximal Overlap Discrete Wavelet Transforms (MODWT) for our data decomposition. Our preference for MODWT is based on the fact that it can handle any sample size T and its variance estimator is asymptotically more efficient than the classical DWT and hence more suitable when calculating wavelet correlations[42]. Besides, the MODWT is not affected by the arrival of new information. Furthermore, the MODWT is invariant to circularly shifting time series and has the multi-resolution detail and smooth coefficients that are linked with zero phase filter, two properties that are not hold for DWT (see, Dar et al., 2014).

We thus decompose each macro-data into wavelet coefficients at different time scales utilizing the MODWT with Daubechies least asymmetric (LA) wavelet filter of length L= 8 (commonly denoted as LA8). The j length-Q vectors of MODWT coefficients for each of the univariate time series $(y_{i1}, y_{i2}, \dots, y_{iq})$, for $i = 1, 2, \dots, q$ are attained as:

$$\tilde{\mathrm{Z}}_j = \left\{\left(\tilde{\zeta}_{1j0}, \dots, \tilde{\zeta}_{qj0}\right), \dots, \left(\tilde{\zeta}_{1j,Q/2^j-1}, \dots, \tilde{\zeta}_{qj,Q/2^j-1}\right)\right\}, \quad for\ j = 1, 2, \dots, J \quad (4.32)$$

The highest decomposition level, j, for the monthly dataset is given by $j = \log_2(n) = J$, where n is the total number of observation. Since $n = 204$ for the monthly datasets, the obtain seven (i.e. $j = \log_2(204) = 7$) maximum number of scales. Knowing the ideal band-pass filters' nature of MODWT, with band-pass from the periodicity interval $[2^{-(j+1)}, 2^{-j})$ for $j = 1, \dots, J$, and through inverting the periodicity range, it is deduced that the associated time periods should be taken as $(2^j, 2^{j+1}]$ time units (Whitcher *et al*. 2000). Therefore, the following respective periods are deemed to be associated with the desired wavelet coefficients of scale $\psi_j = 1, \dots, 7$:

[42]See Percival and Walden (2006) and Daubechies (1992) for detailed readings on MODWT and its competitive advantages over the conventional DWT as well as wavelet filters.

2~4 months (D1: scale 1), 4~8 months (D2: scale 2), 8~16 months (D3: scale 3), 16~32 months (D4: scale 4), 32~64 months (D5: scale 5), 64~128 months (D6: scale 6), 128~256 months (D7: scale 7), etc. It is however proposed that the number of feasible coefficients depends on the highest decomposition levels (j) and the sample size. In this thesis, the relatively smaller sample size of the monthly datasets only necessitates the choice of the first four time-scales (i.e. D1, D2, D3 & D4) to proxy for very short-, short-, medium-, and long run interaction of money market rates.

In the case of the quarterly datasets, the highest decomposition level, j is given by $j = \log_2(68) = 6$, thus 6 maximum levels and 68 is the total number of observations. Therefore, the respective periods are deemed to be associated with the desired wavelet coefficients of scale $\psi_j = 1, \ldots, 6$: are 2~4 quarters (D1: 6months – 1year), 4~8 quarters (D2: 1-2year), 8~16 quarters (D3: 2-4year), 16~32 quarters (D4: 4-8 year), 32~64 quarters (D5: 8-16year), 64~128 quarters (D6: 16-32 year). Accordingly, we prefer to examine MPRF at the first three time-scales (i.e. D1, D2 & D3) to proxy for short-, medium-, and long run interaction of policy rate and macroeconomic shocks due to the small sample size.

4.3 Analysis of Empirical Results

4.3.1 The Signalling Ability of Monetary Policy Rate

Here, we empirically analyze volatility spillovers among money market rates (henceforth MMRs) at time–spectrum and multiscale domain. Specifically, we appraise the signalling[43] ability of policy interest rate in the money market by exploring both linear/nonlinear causal linkages and spillovers/connectedness across time-spectrum and multiscale domain. Unlike the previous studies that predominant hovered around the classical time domain analysis, we rather examine how the other wholesale and retail money market interest rates reacts to changes in MPR at both time- and multi-scale domain.

4.3.1.1 In-Sample Correlations of Money Market Rates at Time-Domain

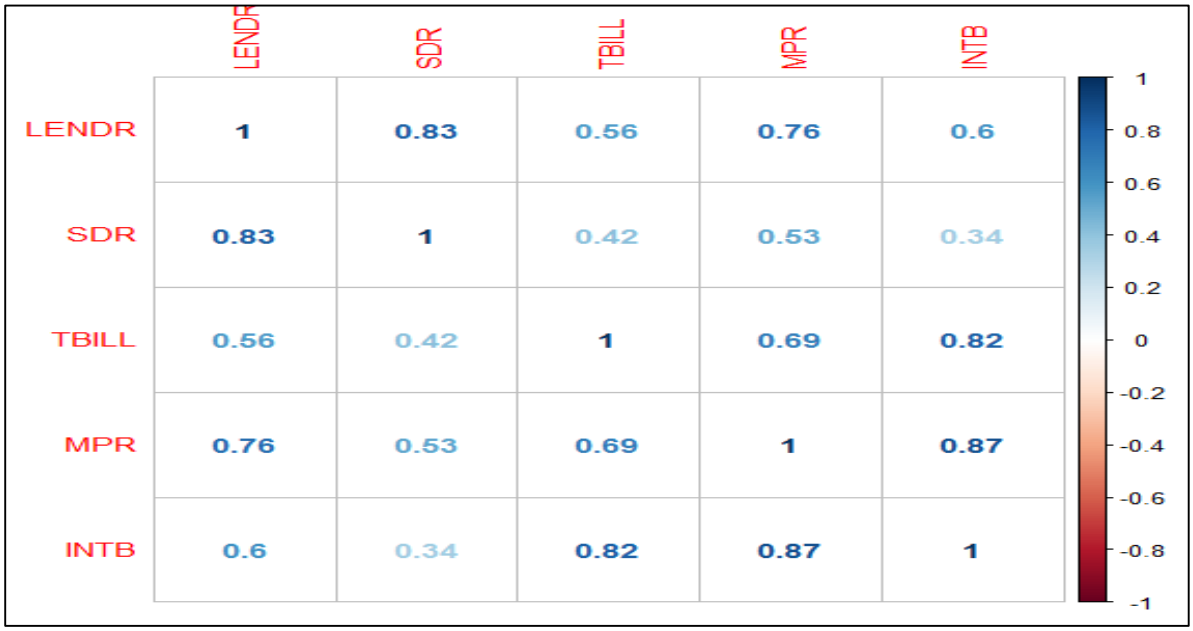
Figure 4.2 presents the correlogram for static time-domain correlation of money market interest rates in Ghana. The figure shows a moderate to high levels of correlations among the money

[43] Signalling ability in this chapter implies a capacity as a leading variable or having strong influence on other variable(s).

market rates in Ghana, with MPR-Interbank pair having the strongest static interaction (0.87), followed sequentially by lending-savings pair (0.83) and Interbank-Tbill pair (0.82). The highest static correlation for MPR-Interbank pair is unsurprising as overnight interbank market interest rate is the target policy interest rate for Ghana which is expected fall within a policy interest rate corridor of MPR±2%. In contrast, the static interaction for the MPR-Tbill pair appears to be moderate over the sample period. In addition, the correlogram also unveils a general moderate static correlations between the wholesale rates (MPR, interbank and Tbill rates) and the retail rates (i.e. lending and savings rates), signifying a moderate interest pass-through from the former to the latter financial market.

In addition to the static (linear) correlations, we also provide the pair-wise analysis of 10-month rolling correlation among the concerned markets sets in Figure 4.3. As it can be observed that the correlations are time-varying and fluctuate across historical time intervals. They are clearly discernible periods of high and low positive and negative interconnectedness among the wholesale and retail market interest rates at time domain.

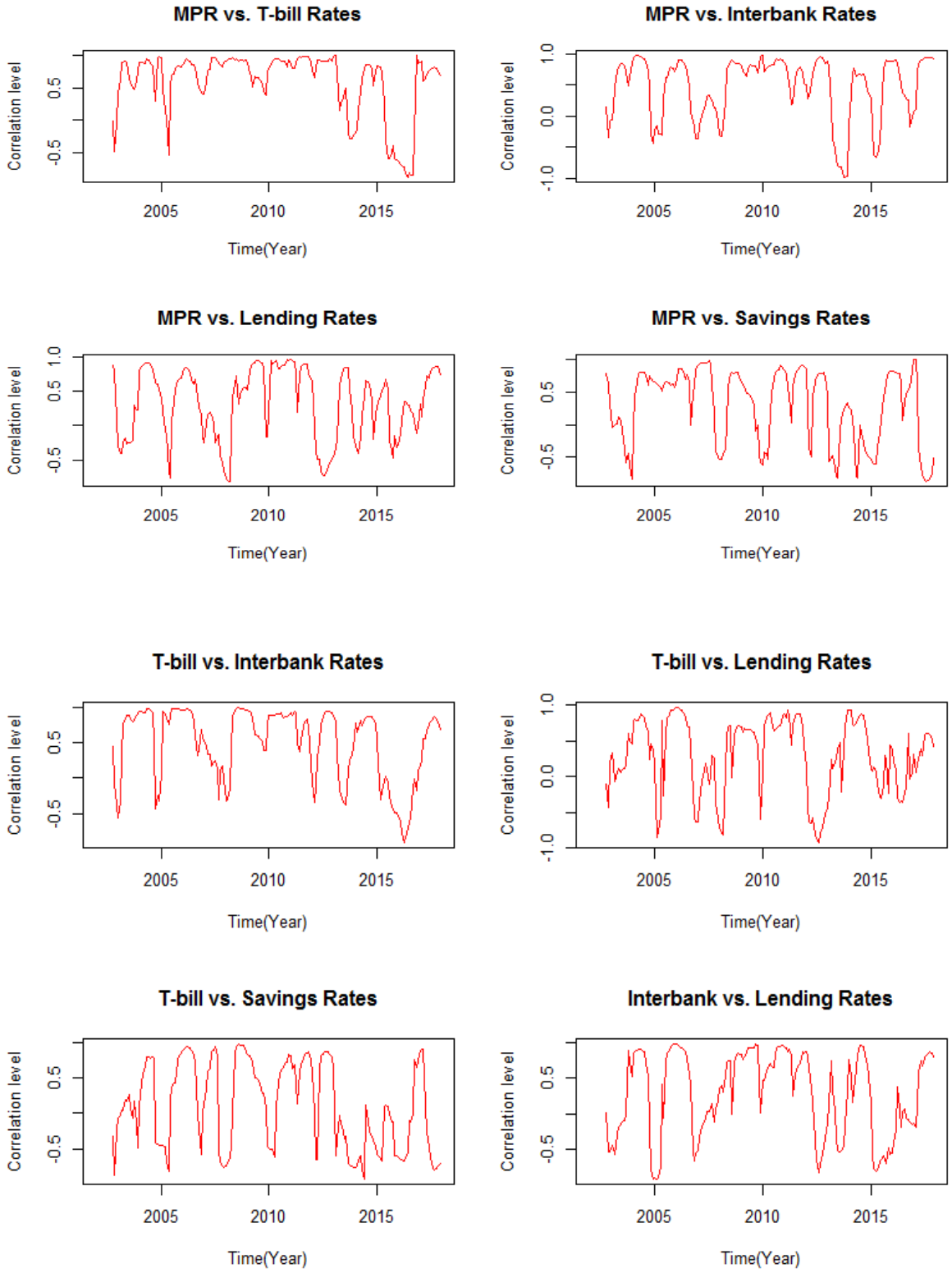
Figure 4.2: Correlogram for static time-domain correlations of money market interest rate

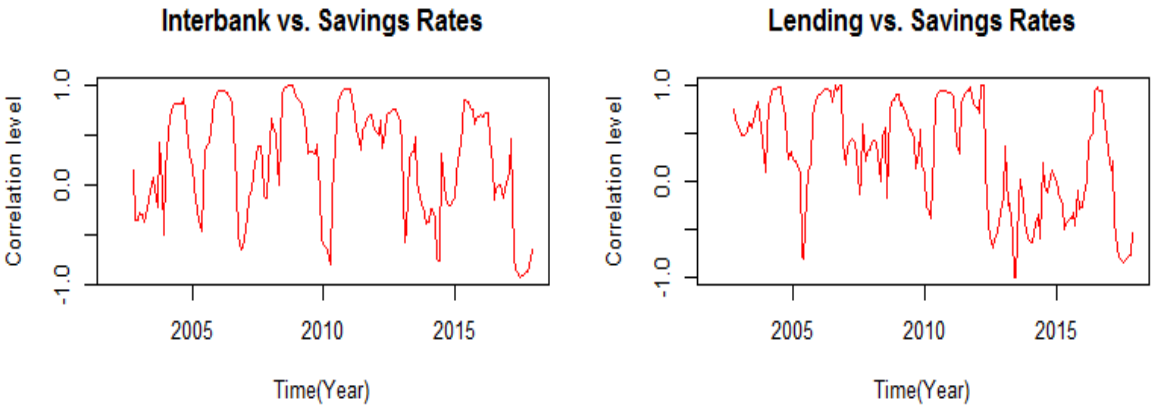


Note: The heat-map gives the static correlation levels over the aggregate time period which get stronger (or shows exact positive or inverse correlation) as the colour becomes warmer. A blank spot (or portion) with no digits denote insignificant correlation, while coloured digits shows statistical significant at 5%. MPR is

monetary policy rate; TBILL is 91-Day Treasury bill rate; INTB is overnight interbank rate; SDR is saving deposit rates & LENDR is average lending rate.

Figure 4.3: Time-varying correlation for money market interest rates at time-domain





Note: The time-varying correlation is based on a 10-month rolling correlation

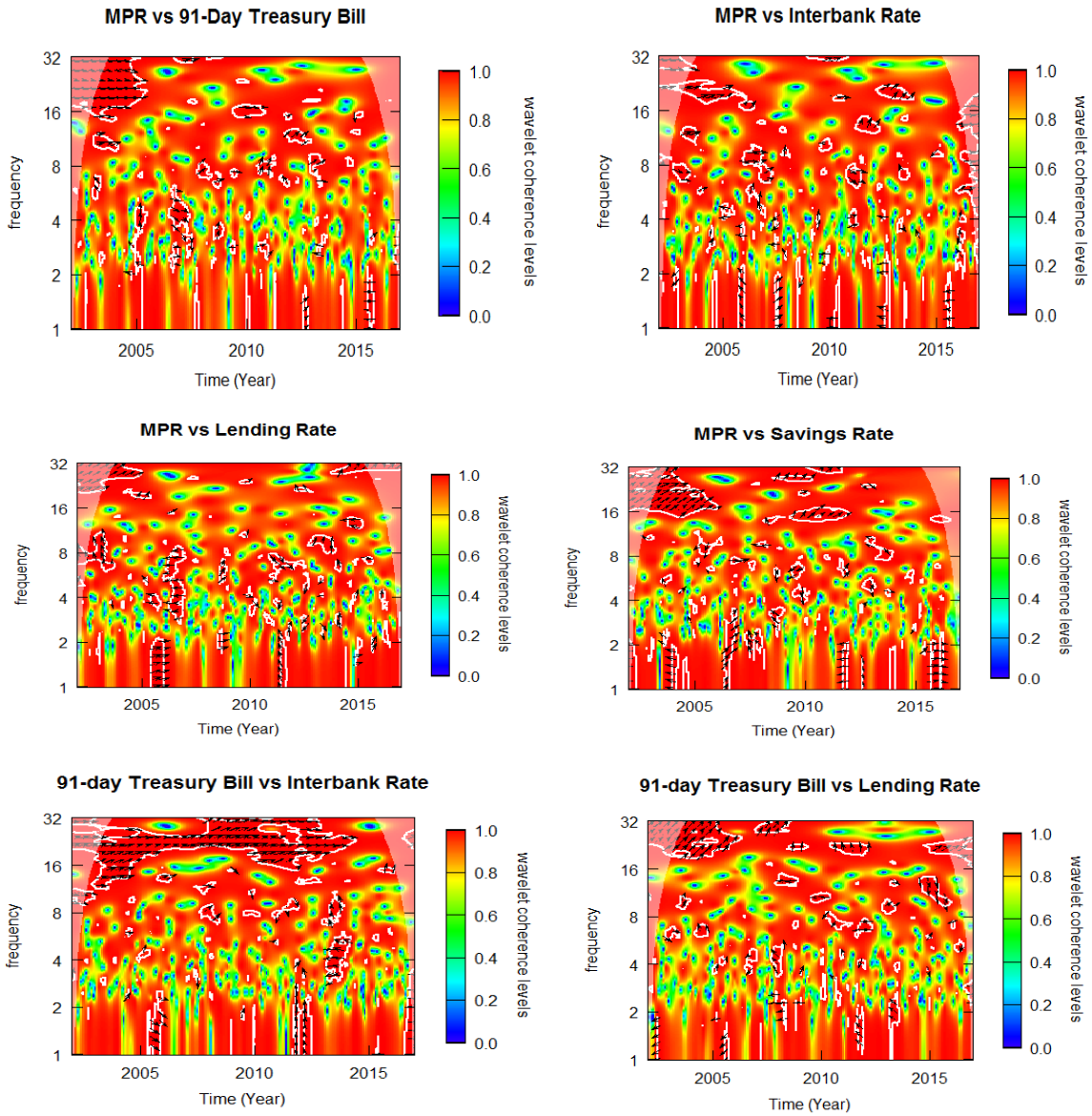
4.3.1.2 In-Sample Dynamics of MMRs at Time-Frequency Domain

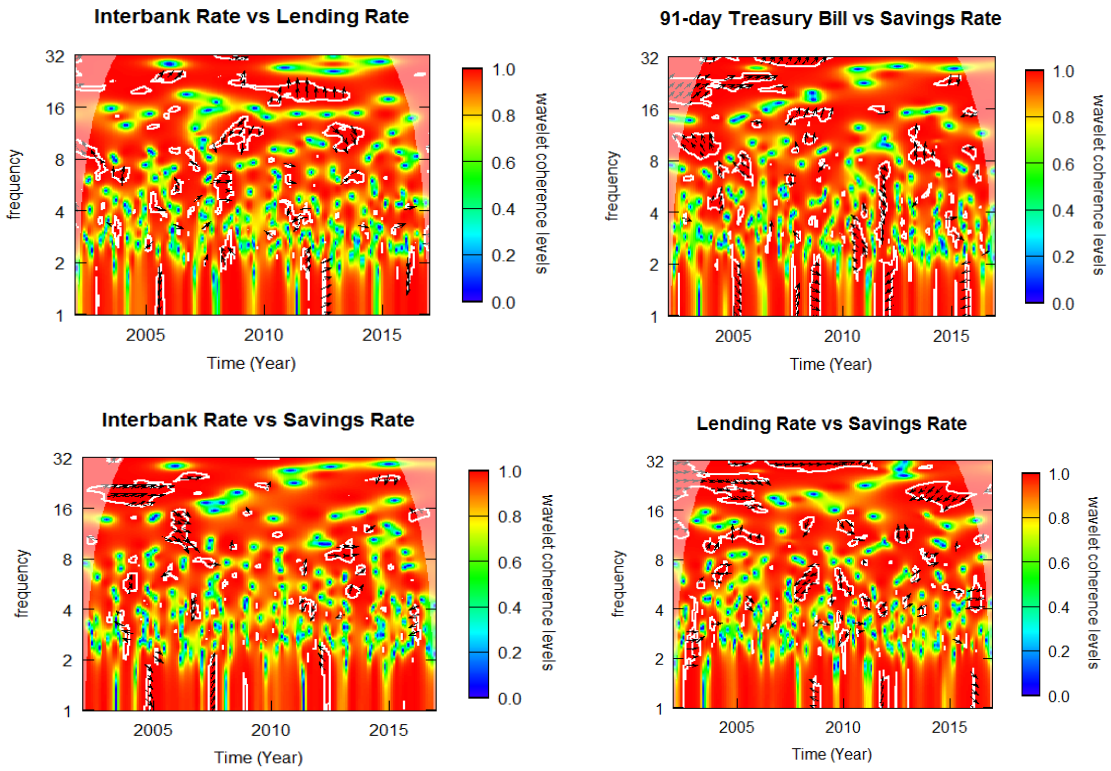
The wavelet coherence plots in Figure 4.4 display bivariate interest rate correlations at wavelet time scales for the period January 2002 to June 2018. The coherency plots reveals a generally low to moderate interaction among the money market interest rates (including MPR, Tbill and Interbank rates), as the mass of the significant white contours increases along time scales, especially from the intra-month to longer- scale horizons. For instance, the mass of the significant white contours are larger for MPR-Tbill pair than that of MPR-Interbank pair particularly at the longer time scale for the pre-2005 era. However, post-2005 period uncovers much greater interaction between MPR-Interbank pair than that of MPR-Tbill pair, as several discernible significant white contours are apparent in the former than the latter pair at the short- to longer time scale. We find somewhat strong correlation between MPR-Interbank pair at the early part of intra-month scale than that of MPR-Tbill pair. This implies somewhat greater correlation between MPR and interbank rate than that of MPR and 91-Day Treasury bill rate since 2005 across short- to longer-time horizon. This is intuitively plausible as the interbank rate, which is the target interest rate, is expected to hover around the official policy rate (MPR) within an interest rate corridor (a MPR± at least 1%). However, a stronger correlation between Tbill and Interbank pair is unveiled by the coherency plots as the significant white contours are much larger at the medium- to longer time scale and also stretched across the historical time interval. Besides, larger patches of significant white contours are also visible at the short-to-medium scale around the year 2013 for the Tbill-Interbank pair.

Regarding the wholesale-retail interest rates dynamics, the coherency plots demonstrate much denser isolated patches of significant white contours for the MPR-lending rate pair at the

shorter scale. In contrast, islands are rather relatively larger for the MPR-Saving rate pair at the medium to longer time scale. This indicates a greater short and medium-to-long time scale correlations for MPR-lending pair and MPR-Saving rate pair respectively in Ghana. On the other hand, the correlation between Tbill-Lending rate pair is much stronger at the longer time scale and this is apparent across historical time interval. However, the link for interbank-lending rate pair appears to be stronger at the medium-to-longer scales for the historical time interval 2008-2014.

Figure 4.4: Bivariate Interest Rate Correlation at multiscale





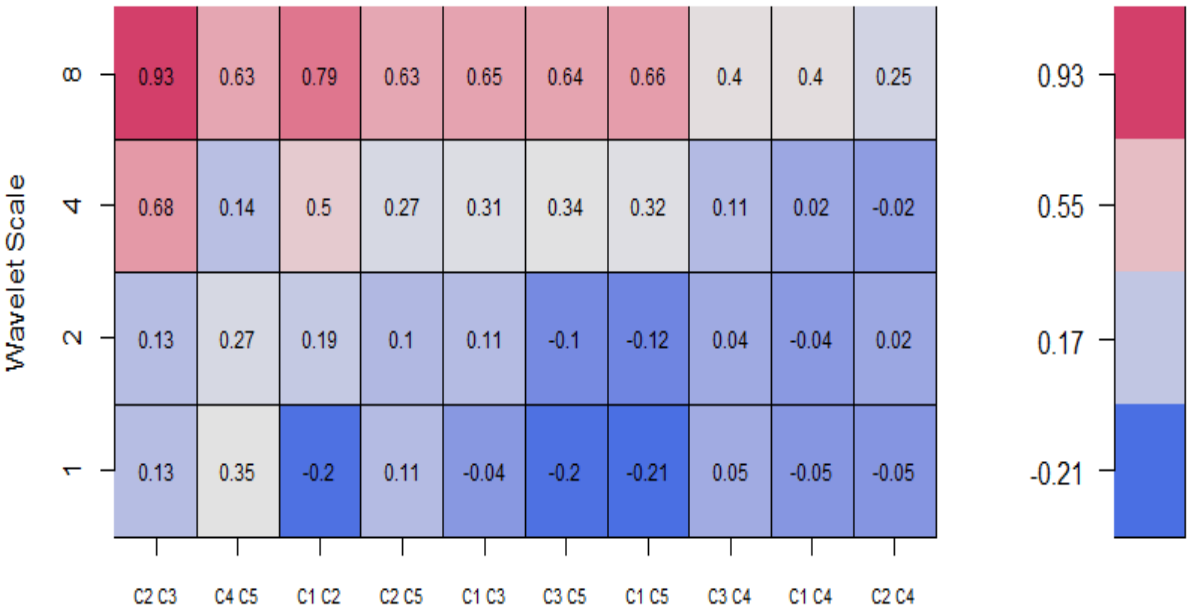
Note: the wavelet coherency heat-map gives the multi-scale correlation. The 5% significance level estimated from Monte Carlo Simulations is designated by white contour. The red (blue) colours signify region with high (low) coherency. The coherence power colour bar shows the power of coherence coefficient. MPR denotes nominal monetary policy interest rate.

In addition, the analysis of the coherency plots for the Tbill-Saving rate and Interbank-Saving rate pairs reveal somewhat larger and denser islands of significant white contours for the former than the latter pair across time-scale and historical time interval. This surmises a relatively stronger correlation between Tbill and saving deposit rate than that of Interbank and saving deposit rate in Ghana over the sample period. In synthesis, the coherency plots generally suggest time-scale dependent correlation among the money market rates in Ghana.

Figure 4.5 presents the level and direction of interlinkages for the money market rates in Ghana across wavelet time-scales. Consistent with the preceding coherency plots, the interactions among the wholesale and retail interest rates are much stronger at the medium to longer time-scales (see several reddish shades in scale levels 4 & 8). The very low correlations are observed at the intra-month and shorter time-scales for both figures. Notably, some negative correlations are recorded at the intra-month to short scales (i.e. up to 8months) across the linkages among the wholesale and retail money market interest rates. However, the extent of interlinkages

increases across time-scale. Although the magnitude of interaction among the whole money market rates appears to high from the medium to longer time scales with a range of 50%-93%, the onward linkages between the latter market and the lending rate remains low (up to 40%). However, the link between the wholesale market rates and savings deposits rate is comparatively higher with a ranging between 27% and 66% at the medium to longer time horizons. This multiscale observation thus contradicts the static correlation results in Figure 4.1 which shows relatively greater interactions between lending rate and wholesale markets rates than that of saving deposit rate and the latter market. Nevertheless, the correlogram heat-maps generally surmise a relatively feeble policy transmission among the money market rates in Ghana, as the bivariate interactions between wholesale and retail interest rates are broadly moderate.

Figure 4.5: Scaled-Dependent Correlation of Money Market Rates in Ghana



Note: The heat-map gives the correlation levels over trading scales. The degree of correlation ranges from weak (deep blue) to perfect or strong (deep red) correlation. C1, C2, C3, C4, and C5 represent returns of MPR, 91-

Day Treasury Bill Rate, Interbank Rate, Lending Rate and savings Deposits Rate respectively. Wavelet scales 1, 2, 4 & 8 on the vertical axis denote 2~4 months, 4~8 months, 8~16 months & 16~32 months respectively.

Based on the highest to lowest scaled-dependent correlations in Figure 4.5, we then rank the money market rates and Table 4.2 displays the scale-dependent correlation ranking for the money market interest rate in Ghana over the sample period. It is evident from the table that the leading money market interest rate is a linkage between the two retail rates (i.e. lending and saving rates) at both the intra-month (i.e. 2-4 months frequency) and the shorter time scales (i.e. 4-8 month frequency), while the MPR-savings pairs recorded the least interaction. However, the dynamics change significantly at the medium to longer time scales. It is obvious from the table that the interaction between the 91-day Treasury bill and Interbank rate assumes the pole position (1st position) at both the medium and longer time scales, followed by MPR-Tbill pair. At both scales, the interlinkages between the wholesale interest rates and savings deposits rate were generally ranked between 3rd and 6th positions. In contrast, the linkages between lending rate and all the wholesale market rates placed below 6th position, reinforcing relatively stronger co-movements between savings deposits rates and the wholesale market rates than that of the latter and lending rates in the context of Ghana. This reinforces the perceived (particular downward) stickiness of the lending interest rate in Ghana.

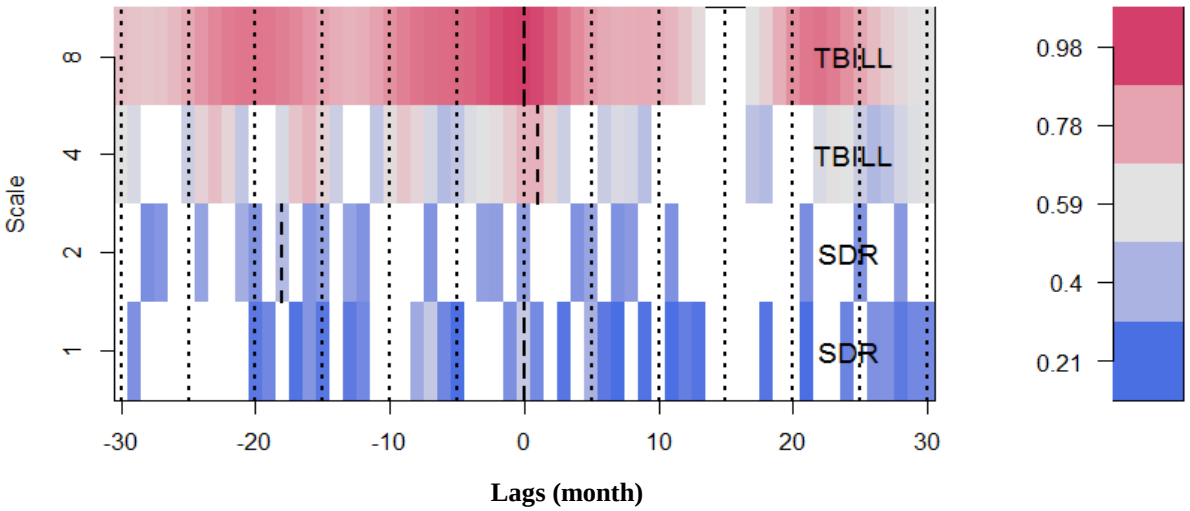
Table 4.2: Scale-dependent correlation ranking

Rank	2~4 months	4~8 months	8~16 months	16~32 months
1	LENDR-SDR [**0.35**]	LENDR-SDR [**0.27**]	TBILL-INTB [**0.68**]	TBILL-INTB [**0.93**]
2	TBILL-INTB [**0.13**]	MPR-TBILL [**0.19**]	MPR-TBILL [**0.50**]	MPR-TBILL [**0.79**]
3	TBILL-SDR [**0.11**]	TBILL-INTB [**0.13**]	INTB-SDR [**0.34**]	MPR-SDR [**0.66**]
4	INTB-LENDR [**0.05**]	MPR-INTB [**0.11**]	MPR-SDR [**0.32**]	MPR-INTB [**0.65**]
5	MPR-INTB [**-0.04**]	TBILL-SDR [**0.10**]	MPR-INTB [**0.31**]	INTB-SDR [**0.64**]
6	TBILL-LENDR [**-0.05**]	INTB-LENDR [**0.04**]	TBILL-SDR [**0.27**]	TBILL-SDR [**0.63**]
7	MPR-LENDR [**-0.05**]	TBILL-LENDR [**0.02**]	LENDR-SDR [**0.14**]	LENDR-SDR [**0.63**]
8	MPR-TBILL [**-0.20**]	MPR-LENDR [**-0.04**]	INTB-LENDR [**0.11**]	INTB-LENDR [**0.40**]
9	INTB-SDR [**-0.20**]	INTB-SDR [**-0.10**]	MPR-LENDR [**0.02**]	MPR-LENDR [**0.40**]
10	MPR-SDR [**-0.21**]	MPR-SDR [**-0.12**]	TBILL-LENDR [**-0.02**]	TBILL-LENDR [**0.25**]

Notes: The ranking is based on the scale-dependent correlation estimates in Figure 4. The ranks are associated with the strength of correlation between market rates, ranging from highest rank or rank 1 (for highest correlation) to lowest rank or rank 10 (for lowest correlation). The respective correlation coefficients are placed under the pairs in square bracket. In situations where there is tie in the coefficients under a scale, the subsequent scales coefficients are used to split markets. In such case, the market with the smallest coefficient in the subsequent scale is given a higher rank in the tie scale. Moreover, the preceding scales coefficients are used to split a tie at the 16~32 day. MPR denotes nominal monetary policy interest rate; INTB is Overnight interbank interest rate; SDR is savings rate; TBILL is 91-Day Treasury bill rate and LENDR is average lending rate.

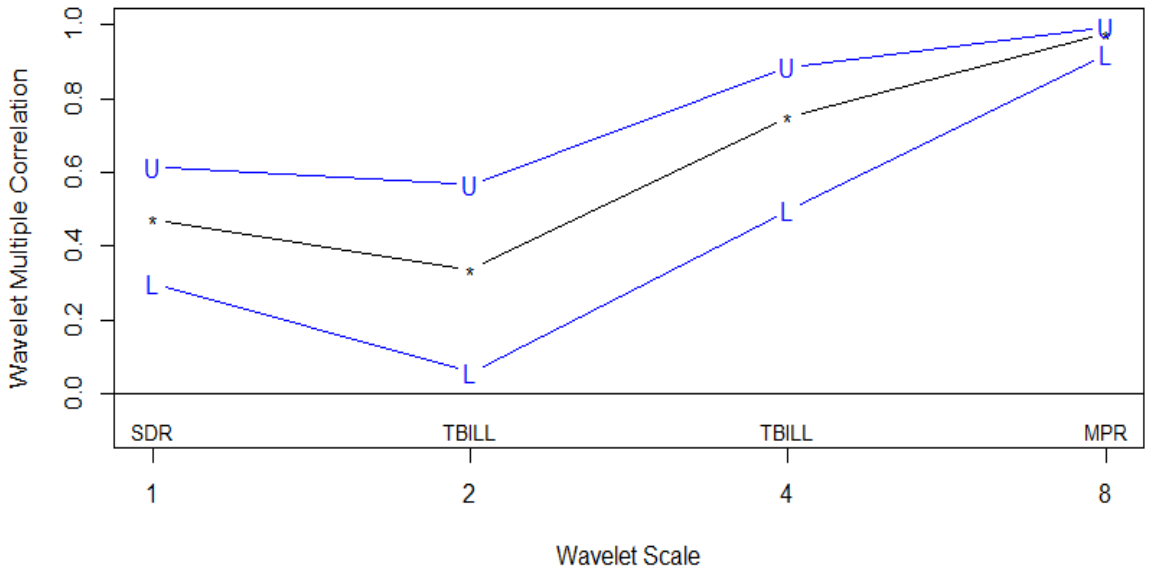
Figure 4.6 presents multiple cross correlation for all the money market interest rates, while Figure 4.7 illustrates the multiple normal correlation of the same variables. Both figures clearly buttress a medium to high interlinkages at the medium to longer time-scales. Also consistent with the bivariate correlation analysis (in Figure 4.2), The multiscale cross correlation heat-map unveils potential lead of savings deposit rate in money market at the intra-month to short time, while the 91-day Treasury bill rate is a potential leading interest rate at the medium-to-longer time-scale. This is further reinforced by the normal multiple correlation, although it proffers potential lead property for 91-day Treasury bill from short-to-longer time-scales.

Figure 4.6: Wavelet Multiple Cross Correlation of Money Market Interest Rate



Note: MPR denotes nominal monetary policy interest rate; INTB is Overnight interbank interest rate; SDR is savings rate; TBILL is 91-Day Treasury bill rate and LENDR is average lending rate.

Figure 4.7: Wavelet multiple correlations for all money market interest rates



Note: MPR denotes nominal monetary policy interest rate; INTB is Overnight interbank interest rate; SDR is savings rate; TBILL is 91-Day Treasury bill rate and LENDR is average lending rate.

Further sub-market analysis of multiple correlation of money market interest rate at time-frequency domain, as exhibited in Figures 4.8, supports a general weak correlation between the wholesale and retail markets interest rate at the intra-month to shorter time-scale but a moderate-to-high interconnectedness at the medium to longer time-scale. It also reveals a slight elevated interconnectedness of wholesale market rate with savings deposit rate than that of the former with lending rate (see Figure 4.8 chart C-F) across time-scales, consistent with multiscale correlation ranking in Table 4.2.

Figure 4.8: Sub-market analysis of multiscale multiple correlation

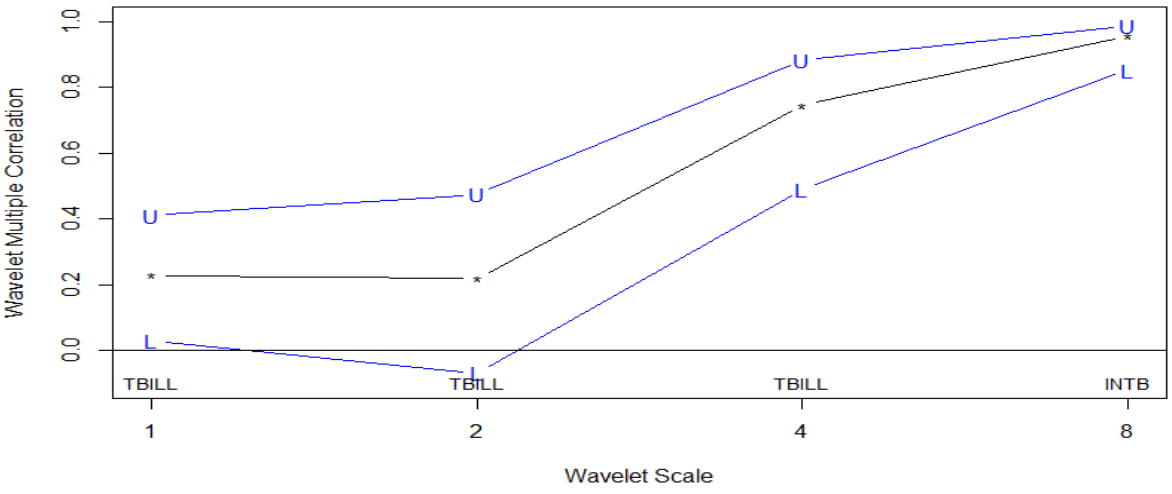


Chart A. Cross Correlation of MPR, TBILL, INTB & SDR

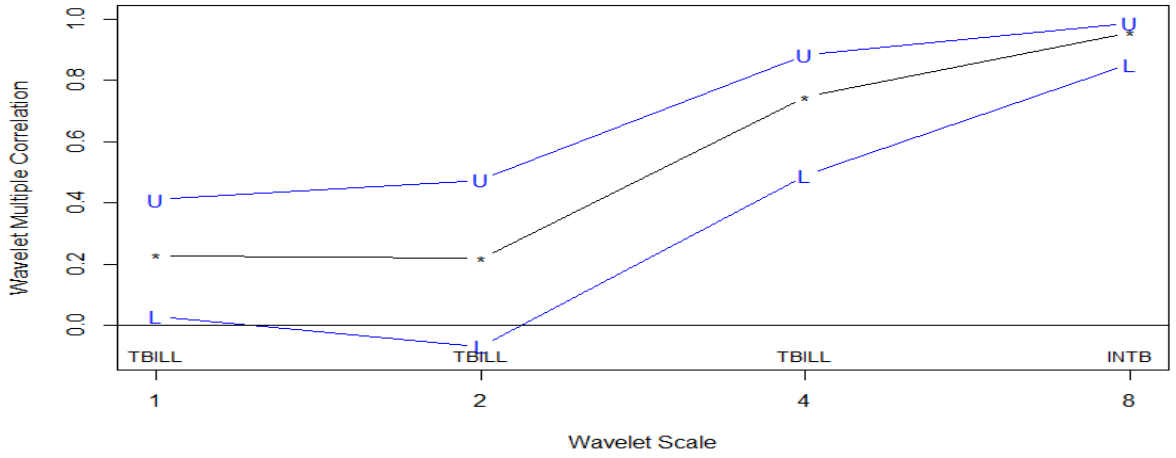


Chart B. Cross Correlation of MPR, TBILL, INTB & LENDR

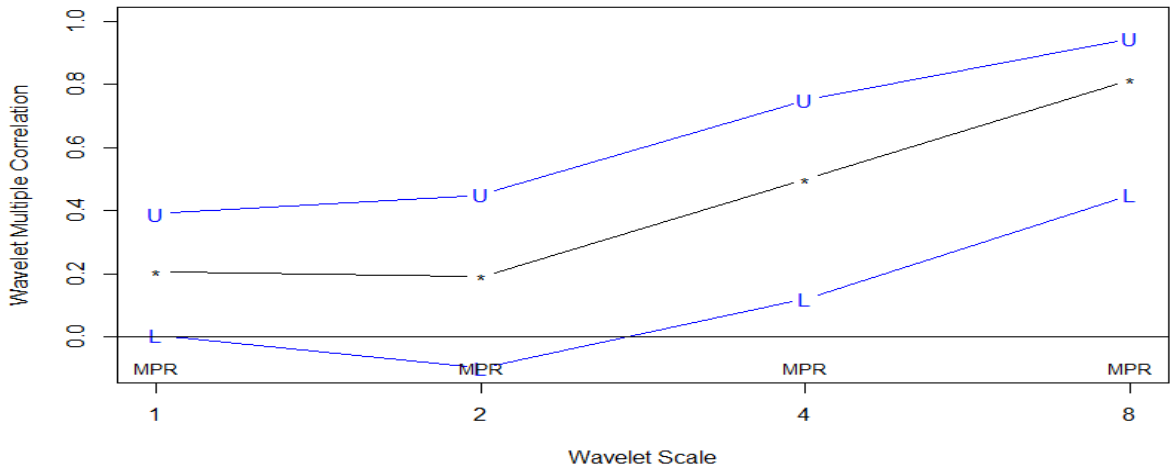


Chart C. Cross Correlation of MPR, TBILL & LENDR

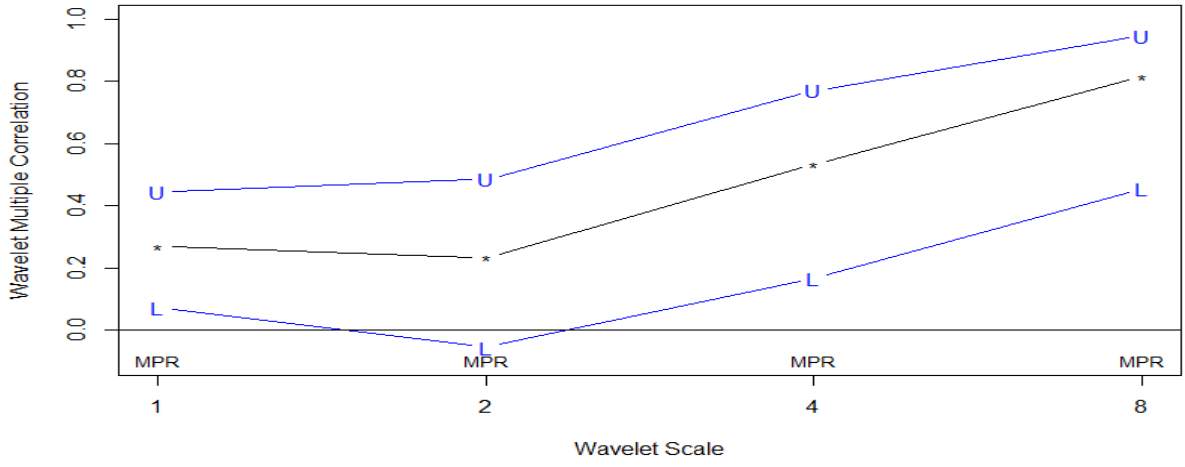


Chart D. Cross Correlation of MPR, TBILL & SDR

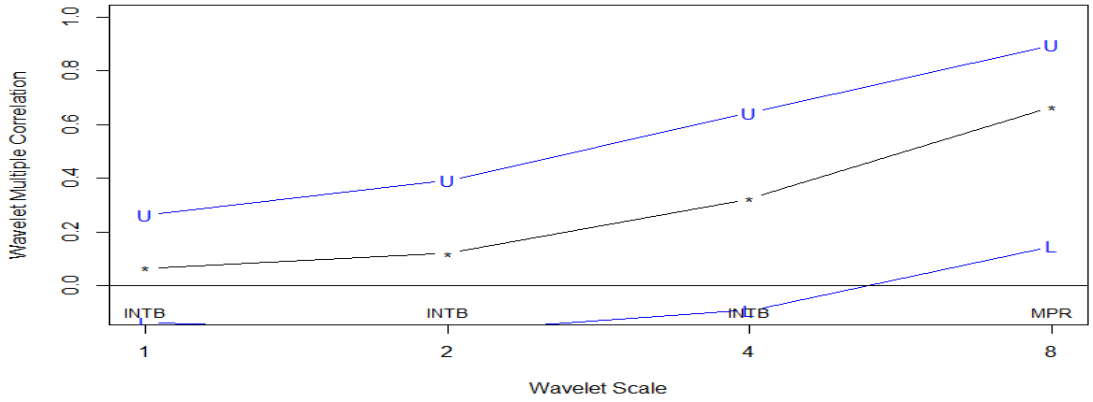


Chart E. Cross Correlation for MPR, INTB & LENDR

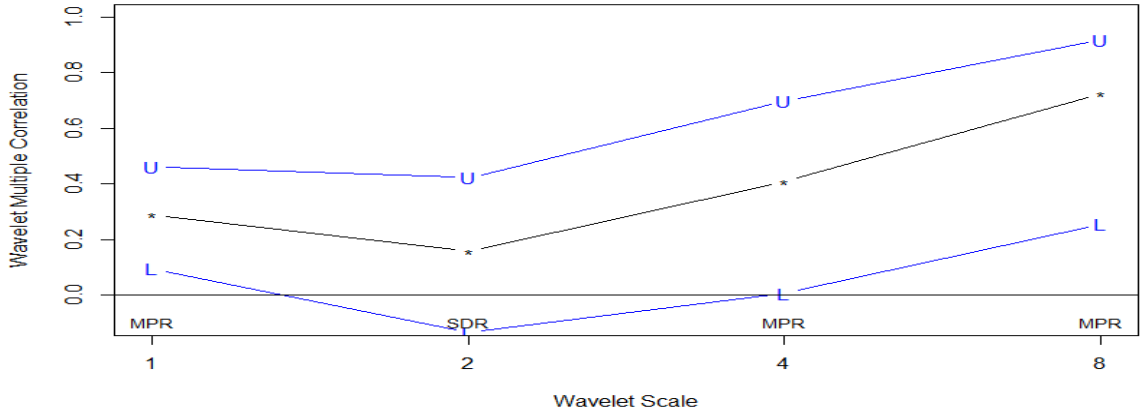


Chart F. Cross Correlation for MPR, INTB & SDR

Note: MPR denotes nominal monetary policy interest rate; INTB is Overnight interbank interest rate; SDR is savings rate; TBILL is 91-Day Treasury bill rate and LENDR is average lending rate.

We cannot forcefully infer that the policy interest rate effectively serves as a leading rate for the money market across time-scale due to less conspicuous positional black arrows from the coherency plots. In view of this, we further explore both linear and nonlinear causality tests to vividly decipher the lead/lag relationships among the money market interest rates in Ghana.

4.3.1.3 In-Sample Linear/Nonlinear Causality Analysis of MMRs

Table 4.3 presents results from parametric causality analysis based on Toda-Yamamoto lead/lag test at levels (full sample), Granger causality as well as instantaneous causality tests for the multi-scales data. The full sample analysis shows strong linkages among the money market interest rates in Ghana, consistent with the static correlation at historical time interval. This is clearly illustrated by the general significant chi-square estimates (at least 10 alpha level), reinforcing a dual linear causal relationships among the money market interest rates at

levels. The notable exceptions however are for the MPR-Lending rate, MPR-Saving rate, Tbill-Interbank and Tbill-Lending rate pairs which exhibit significant unidirectional causal links at levels. Specifically, the chi-square estimates at levels unveil that MPR lags in its respective pairings with Lending and Savings rates, while the Tbill rate lags in its respective pairings with Interbank and Lending rates.

Consistent with the coherency plots, the chi-square estimates for the time-scale causality estimates in Panel A and B of the table clearly demonstrate increasing significant linkages among the money market interest rates along time scale. Conspicuously, the chi-square estimates reveal no significant linear link for MPR-Tbill pair at the intra-month scale (1-4 months), while single-to-dual linkages are noticed from the short-to-long run horizon for the latter pair with MPR lagging. In contrast, the Chi-square estimates show unidirectional causal link for the MPR-Interbank pair at both the intra-month and longer time scales with MPR lagging. However, the link for the pair becomes dual at the short-to-medium time scale. Contrary to the level analysis, the chi-squared estimates reveal dual causal linkages for the Tbill-Interbank rate pair and this is statistically significant across time scales. Nevertheless, the magnitudes of the Chi-square estimates show that Tbill rate strongly leads interbank rate at the intra-month-to-shorter time scales while its lags at the medium-to-longer time scale. The observed dynamic causal linkages among the wholesale money market interest rates suggest that BOG systematically considers that state of both the overnight interbank rate and short-term interest rate on government bonds in positioning the policy interest rate (MPR). There is also an apparent feedback effect of policy interest rate on the other wholesale interest rate (interbank and Tbill rates), although this is time scale dependent. Besides, the leading effect of Tbill on interbank rate is conceivably intuitive as a commercial bank is probably willing to lend funds to its competitor or counterpart bank in the overnight credit market if and only if the latter would accept an interest rate at least equal to or over the risk free rate (i.e. interest rate on government bond).

Regarding the retail rates, the Chi-square estimates reveal that MPR-Lending rate pair has no significant linear link at the intra-month scale, but the link increases from single to bidirectional from the short to longer time scale with MPR as a leading variable. This is in contrast with the level analysis which detected a single link for the pair with lending rate as the leading variable. On the other hand, the estimates for the MPR-Savings rate pair show a unidirectional linear

link at the intra-month scale with saving deposit rates as a lead variable. Their causal link however becomes bi-directional at the short to longer time scales. MPR generally lags behind Savings rate as magnitudes of the chi-squared estimates for the linear causality from MPR to Saving rate are relatively smaller than that of reverse causation across times scale, except for the medium time horizon. Besides, the linkages between other wholesale market rates (Tbill and Interbank rate) and retail rates (lending and Savings rate) demonstrate that Tbill-Savings and Interbank-Saving rate pairs have dual causal relationships at time scale, consistent with the level results. Further analysis of the magnitudes of the chi-square estimates reveals that Savings deposit rate leads both the interbank and Tbill rates at intra-month to shorter scale and across all time scales respectively. This is intuitively plausible as commercial banks price in cost of private funds (including saving deposit rates) when charging interest rate on the limited loanable funds at the overnight interbank and government bond markets.

We however observed divergent causal linkages for the Tbill-Lending rate and interbank-Lending rate pairs across time scales, when compare with the level analysis. On one hand, the chi-square estimates show both single and dual causal relationships between T-bill and lending rate at the intra-month and longer time scales respectively, with T-bill rate as the leading variable, contradicting the results from the level analysis. This is conceivable as commercial banks are only willing to lend funds to the private sector at the risk free rate (i.e. interest rate on government bond) plus a mark-up. On the other hand, there is a unidirectional link for Interbank-Lending pair at the intra-month to shorter time-scale with the latter as a leading variable. The causal link for the pair however changes to bi-directional at the medium to longer time-scales, with lending rate leading at the longer scale. Thus, the lending rate significantly influences the overnight interbank rate and vice-versa as commercial banks have to choose between providing fund to its counterpart (or competitive) banks or to the private sector.

Table 4.3: Parametric (linear) causality estimates for money market interest rates in Ghana

Estimated measures: Chi-Square Statistics										
			Granger Causality Test				Instantaneous Causality Test			
Macro-Data	Linkage	Full Sample	Time-Scales				Time-Scales			
			D1	D2	D3	D4	D1	D2	D3	D4
MPR-TBILL	MPR≠>TBILL	14.2[A]	3.00[A]	4.28[A]	4.88[A]	2.61[A]	3.57[A]	13.72[A]	7.24[A]	7.78[A]
	TBILL<≠MPR	30.1[A]	1.81[B]	1.34	1.48[C]	1.78[A]				
MPR-INTB	MPR≠>INTB	15.1[A]	2.35[B]	2.08[A]	1.02	3.62[A]	0.29	8.97[A]	8.52[A]	25.99[A]
	INTB<≠MPR	11.6[A]	1.52	0.64	1.16	2.15[B]				
MPR-LENDR	MPR≠>LENDR	1.8	1.29	1.24	0.51	2.24[A]	0.75	0.47	12.30[A]	0.50
	LENDR<≠MPR	17.3[A]	0.7	0.72	0.89	1.21				

MPR-SDR	MPR≠>SDR	3.7	1.12	1.24	2.55 A	2.36 A	0.92	0.47	7.49 A	1.54
	SDR<≠MPR	13.6A	2.29A	0.72	2.56 A	1.48 B				
TBILL-INTB	TBILL≠>INTB	5.5	2.28A	4.59 A	5.00 A	3.21 A	7.17 A	2.86 C	0.49	19.90 A
	INTB<≠TBILL	67.9A	2.78A	1.41 C	1.28 B	1.51 B				
TBILL-LENDR	TBILL≠>LENDR	2.1	1.77B	2.34 A	1.40 C	3.68 A	0.6	3.27 C	7.21 A	0.43
	LENDR<≠TBILL	50.8A	1.99A	0.65	1.06	0.54				
TBILL-SDR	TBILL≠>SDR	23.7A	2.30A	3.96 A	4.50 A	3.54 A	1..47	0.21	1.02	2.70
	SDR<≠TBILL	33.1A	3.68A	1.16	1.09	2.76 A				
INTB-LENDR	INTB≠>LENDR	12.5A	1.59C	2.42A	2.07A	3.18 A	5.14B	0.35	0.32	11.07A
	LENDR<≠INTB	38.7A	0.26	0.89	1.03	2.35A				
INTB-SDR	INTB≠>SDR	11.6A	4.04A	2.49A	3.53A	1.71B	0.32	0.01	0.55	6.88A
	SDR<≠INTB	21.8A	1.00	1.57B	0.85	2.02A				
LENDR-SDR	LENDR≠>SDR	7.6A	1.51C	0.89	1.70A	0.63	8.37A	8.48A	10.78A	19.96A
	SDR<≠LENDR	2.6	1.63C	2.37A	1.97A	2.86A				

Note: Superscripts A, B & C denote 1%, 5% & 10% significant level respectively. MPR denotes nominal monetary policy interest rate; INTB is Overnight interbank interest rate; SDR is savings rate; TBILL is 91-Day Treasury bill rate and LENDR is average lending rate.

Nonetheless, there could also possibly be nonlinear interactions among the money market interest rates. This is supported by the DBS test results in Table 4.4 which illustrate a general rejection of a null of linearity of the residuals from the respective AR(1) models.

Table 4.4: DBS test on interest rate at multiscale

		Dimensions				
	Time scales	2	3	4	5	6
AR(1): MPR	D1	8.384[0.00]A	9.075[0.00]A	8.686[0.00]A	8.941[0.00]A	9.050[0.00]A
	D2	7.864[0.00]A	8.522[0.00]A	8.363[0.00]A	8.330[0.00]A	8.447[0.00]A
	D3	2.748[0.00]A	2.901[0.00]A	2.662[0.00]A	4.003[0.00]A	4.767[0.00]A
	D4	-0.362[0.72]	1.349[0.17]	1.913[0.05]C	2.342[0.01]B	2.344[0.02]B
AR(1): TBILL	D1	9.957[0.00]A	11.509[0.00]A	11.806[0.00]A	12.590[0.00]A	13.583[0.00]A
	D2	8.474[0.00]A	10.113[0.00]A	11.197[0.00]A	11.957[0.00]A	12.822[0.00]A
	D3	8.009[0.00]A	7.913[0.00]A	8.883[0.00]A	10.430[0.00]A	12.071[0.00]A
	D4	6.638[0.00]A	7.177[0.00]A	7.762[0.00]A	8.284[0.00]A	9.226[0.00]A
AR(1): INTERBANK	D1	6.861[0.00]A	9.831[0.00]A	11.305[0.00]A	12.615[0.00]A	13.914[0.00]A
	D2	6.309[0.00]A	8.652[0.00]A	9.713[0.00]A	10.824[0.00]A	11.717[0.00]A
	D3	9.045[0.00]A	10.141[0.00]A	11.096[0.00]A	12.353[0.00]A	13.519[0.00]A
	D4	8.473[0.00]A	8.358[0.00]A	9.087[0.00]A	9.554[0.00]A	10.171[0.00]A
AR(1): LENDING	D1	7.321[0.00]A	7.800[0.00]A	8.204[0.00]A	8.483[0.00]A	8.966[0.00]A
	D2	5.664[0.00]A	8.257[0.00]A	8.822[0.00]A	9.699[0.00]A	10.689[0.00]A
	D3	3.810[0.00]A	4.641[0.00]A	5.289[0.00]A	6.738[0.00]A	7.436[0.00]A
	D4	3.220[0.00]A	3.237[0.00]A	3.545[0.00]A	3.705[0.00]A	4.069[0.00]A
AR(1): SAVINGS	D1	8.995[0.00]A	9.594[0.00]A	9.956[0.00]A	10.111[0.00]A	10.009[0.00]A
	D2	8.233[0.00]A	10.550[0.00]A	11.180[0.00]A	11.674[0.00]A	11.976[0.00]A
	D3	4.532[0.00]A	4.855[0.00]A	5.075[0.00]A	6.145[0.00]A	6.720[0.00]A
	D4	2.442[0.01]B	1.878[0.06]C	1.506[0.13]	2.007[0.04]B	2.414[0.03]B

Note: the z-statistic is reported at various embedded dimensions. The p-values are reported in square brackets. The superscript A, B & C denotes 1%, 5% & 10% significant levels respectively. D1, D2, D3 and D4 denotes 2~4 months, 4~8 months, 8~16 months and 16~32 months respectively.

In view of that, Table 4.5 presents the T-statistics with the corresponding P-values from the pairwise nonlinear Granger causality test for the money market interest rate in Ghana over the sample period. On a whole, the table unveils general weak nonlinear interactions among the money market interest rates in Ghana, especially at levels. However, a close examination of the table reveals a weak single causal nonlinear effect from MPR to both T-bill and interbank rates at levels (at 10% significant level) and time-scales (short and very long scale for T-bill and only at very long time scale for interbank rate). While no significant nonlinear causal linkages were detected for MPR and the retail rates at levels, the scale analysis reveals a single nonlinear causal effect of MPR on lending rate at the medium to longer time-scales and on savings deposit rate at the short and medium time-scales.

Table 4.5: Nonlinear Granger Causality Estimates for Money Market Interest Rates in Ghana

Estimated measures: T-Statistic							
		Panel A					**Panel B**
Macro-Data	**Linkage**	**Returns: First Difference (Full Sample)**	**Time Scales**				**T-Y VAR Filtered Residuals (Full Sample)**
			D1	**D2**	**D3**	**D4**	
MPR-TBILL	MPR≠>TBILL	1.63^{C}	1.77^{B}	0.66	1.07	1.47^{C}	2.31^{B}
	TBILL<≠MPR	0.06	0.61	0.55	0.11	0.92	1.26
MPR-INTB	MPR≠>INTB	1.63^{C}	0.2	0.06	1.06	1.61^{C}	1.76^{B}
	INTB<≠MPR	0.13	0.84	0.61	0.27	0.22	1.41^{C}
MPR-LENDR	MPR≠>LENDR	0.92	1.22	1.12	1.43^{C}	2.08^{B}	1.47^{C}
	LENDR<≠MPR	0.97	0.88	1.03	0.95	0.44	0.96
MPR-SDR	MPR≠>SDR	0.51	0.81	1.92^{B}	0.84	1.59^{C}	1.37^{C}
	SDR<≠MPR	0.65	0.57	0.85	-1.55	0.46	1.23
TBILL-INTB	TBILL≠>INTB	1.19	1.83^{B}	1.71^{B}	1.74^{B}	2.61^{A}	2.33^{A}
	INTB<≠TBILL	0.21	1.18	1.80^{B}	1.62^{C}	1.29^{C}	2.19^{B}
TBILL-LENDR	TBILL≠>LENDR	1.63^{C}	1.26	1.82^{B}	1.29^{C}	2.12^{B}	2.08^{B}
	LENDR<≠TBILL	1.38^{C}	0.16	0.62	0.37	0.96	-0.02
TBILL-SDR	TBILL≠>SDR	0.33	1.41^{C}	1.86^{B}	0.79^{B}	0.99	1.86^{B}
	SDR<≠TBILL	1.55^{C}	0.43	0.21	0.96	1.42^{C}	2.04^{B}
INTB-LENDR	INTB≠>LENDR	1.26	0.11	1.09	0.49	1.25	1.74^{B}
	LENDR<≠INTB	0.57	0.9	0.81	0.76	1.15	0.94
INTB-SDR	INTB≠>SDR	0.27	0.53	1.04	1.89^{B}	0.95	0.10
	SDR<≠INTB	0.55	1.68^{B}	0.13	1.29^{C}	2.26^{B}	1.40^{C}
LENDR-SDR	LENDR≠>SDR	0.61	1.38^{C}	0.3	0.76	1.46^{C}	0.98
	SDR<≠LENDR	1.27	1.09	0.93	0.72	1.24	1.29^{C}

Note: *Superscript A, B & C denote 1%, 5% & 10% significant level respectively. D1, D2, D3 and D4 denote time-scales for 2~4 months, 4~8 months, 8~16 months and 16~32 months respectively. MPR denotes nominal monetary policy interest rate; INTB is Overnight interbank interest rate; SDR is savings rate; TBILL is 91-Day Treasury bill rate and LENDR is average lending rate.*

4.3.1.4 Out-of-Sample Volatility Spillovers Among MMRs

For robustness, this section further examines the extent of influence of MPR on the money market by exploring relative volatility spillovers among MMRs at both time- and frequency-domains. This is mainly to ascertain the relative contribution to shock propagations among MMR utilizing generalized forecast error variance decomposition (GFEVD). Table 4.6 presents time-spectrum spillover estimates for MMR based on the Diebold-Yilmaz (2012) approach, while Table 4.7 exhibits the corresponding spillover dynamics at frequency-domain based on Barunik-Krehlik (2015) methodology.

Table 4.6: Volatility spillovers among money market rates at time-spectrum

	Monetary Policy Rate	91-Day T-Bill Rate	Interbank rate	Lending Rate	Savings Rate	Contribution from Others (CFO)	**CFO Ranking**
H = 10 Quarters ahead							
Monetary Policy Rate	73.99	15.97	1.14	8.79	0.10	5.2	**3**
91-Day T-Bill Rate	11.00	85.88	2.78	0.19	0.14	2.82	**5**
Interbank rate	10.28	19.70	62.57	7.40	0.06	7.49	**2**
Lending Rate	11.46	25.27	7.49	53.55	2.23	9.29	**1**
Savings Rate	6.60	12.00	1.94	3.28	76.18	4.76	**4**
Contribution to Others (CTO)	7.87	14.59	2.67	3.93	0.51		
CTO Ranking	**2**	**1**	**4**	**3**	**5**		
Contribution including own	81.86	100.47	65.24	57.48	76.69	**Spillover Index**	
Net Spillover (NS)	2.66	11.76	-4.81	-5.34	-4.25	**29.56**	
NS Ranking	**2**	**1**	**4**	**5**	**3**		
H = 50-Quarters ahead							
Monetary Policy Rate	54.54	27.06	4.51	13.71	0.18	9.09	**4**
91-Day T-Bill Rate	12.90	84.69	1.31	0.88	0.22	3.06	**5**
Interbank rate	18.44	41.15	23.38	16.63	0.40	15.32	**2**
Lending Rate	20.16	50.18	17.63	8.89	3.14	18.22	**1**
Savings Rate	12.06	26.06	6.38	8.80	46.69	10.66	**3**
Contribution to Others (CTO)	12.71	28.89	5.97	8.00	0.79		
CTO Ranking	**2**	**1**	**4**	**3**	**5**		
Contribution including own	67.25	113.58	29.35	16.89	47.48	**Spillover Index**	
Net Spillover (NS)	3.62	25.83	-9.36	-10.22	-9.87	**56.36**	
NS Ranking	**2**	**1**	**3**	**5**	**4**		
H = 100 Quarters ahead							
Monetary Policy Rate	52.19	28.32	5.02	14.25	0.21	9.56	**4**
91-Day T-Bill Rate	13.19	84.50	1.04	1.03	0.24	3.10	**5**
Interbank rate	19.48	44.12	17.99	17.95	0.47	16.40	**2**
Lending Rate	20.85	52.42	18.65	4.90	3.18	19.02	**1**
Savings Rate	12.87	28.26	7.16	9.72	41.99	11.60	**3**
Contribution to Others (CTO)	13.28	30.62	6.38	8.59	0.82		
CTO Ranking	**2**	**1**	**4**	**3**	**5**		
Contribution including own	65.47	115.12	24.37	13.49	42.81	**Spillover Index**	
Net Spillover (NS)	3.72	27.52	-10.03	-10.43	-10.78	**59.68**	
NS Ranking	**2**	**1**	**3**	**4**	**5**		

Note: the table shows the estimated spillovers from (along column) and to (along row) of various combinations of macroeconomic variables, estimated using the Diebold and Yilmaz (2012) methodology. The rankings 1 to 5 indicates highest to lowest spillovers to (or from) variable i within the estimated system.

Table 4.7: Frequency-domain spillovers table for money market rates

	Monetary Policy Rate	91-Day T-Bill Rate	Interbank rate	Lending Rate	Savings Rate	From ABS	From WTH	Ranking From WTH
Short Scale (H = 1 to 6 Months)								
Monetary Policy Rate	0.06	0.21	0.05	0.10	0.00	0.07	14.15	**4**
91-Day T-Bill Rate	0.09	0.08	0.01	0.01	0.00	0.02	4.48	**5**
Interbank rate	0.14	0.32	0.04	0.13	0.00	0.12	23.10	**2**
Lending Rate	0.15	0.39	0.15	0.20	0.02	0.14	27.36	**1**
Savings Rate	0.09	0.20	0.05	0.07	0.01	0.08	15.89	**3**
To ABS	0.09	0.23	0.05	0.06	0.01	0.44		
Ranking	**2**	**1**	**4**	**3**	**5**		**Overall**	
To WTH	17.96	43.56	10.06	12.15	1.24		**Connectedness**	
Ranking	**2**	**1**	**4**	**3**	**5**		**84.97**	
Net Spillovers (NS)	0.02	0.20	-0.07	-0.08	-0.08			
NS Ranking	**2**	**1**	**3**	**4**	**5**			
Medium Scale (H = 6 to 36 Months)								
Monetary Policy Rate	0.22	0.67	0.25	0.30	0.02	0.25	15.48	**3**
91-Day T-Bill Rate	0.07	0.13	0.02	0.04	0.00	0.03	1.72	**5**
Interbank rate	0.35	0.94	0.29	0.41	0.03	0.34	21.37	**2**
Lending Rate	0.47	1.34	0.56	0.62	0.05	0.48	30.16	**1**
Savings Rate	0.21	0.57	0.21	0.24	0.02	0.24	15.23	**4**
To ABS	0.22	0.70	0.21	0.2	0.02	1.35		
Ranking	**1**	**3**	**4**	**2**	**5**		**Overall**	
To WTH	13.58	43.74	12.88	12.42	1.32		**Connectedness**	
Ranking	**2**	**1**	**3**	**4**	**5**		83.95	
Net Spillovers (NS)	-0.03	0.67	-0.14	-0.28	-0.22			
NS Ranking	**2**	**1**	**3**	**5**	**4**			
Long Scale (H =10 to 100 Quarters)								
Monetary Policy Rate	51.91	27.44	4.72	13.85	0.18	9.24	9.44	**4**
91-Day T-Bill Rate	13.03	84.29	1.01	0.98	0.23	3.05	3.11	**5**
Interbank rate	18.99	42.86	17.66	17.41	0.43	15.94	16.29	**2**
Lending Rate	20.23	50.68	17.95	4.08	3.11	18.39	18.79	**1**
Savings Rate	12.57	27.5	6.90	9.40	41.95	11.27	11.52	**3**
To ABS	12.96	29.69	6.12	8.33	0.79	57.89		
Ranking	**2**	**1**	**4**	**3**	**5**		**Overall**	
To WTH	13.25	30.34	6.25	8.51	0.81		**Connectedness**	
Ranking	**2**	**1**	**4**	**3**	**5**		**59.15**	
Net Spillovers (NS)	3.73	26.65	-9.82	-10.06	-10.48			
NS Ranking	**2**	**1**	**3**	**4**	**5**			

Note: the table shows the estimated spillovers from (along column) and to (along row) of various combinations of macroeconomic variables, estimated using the Barunik and Krehlik (2015) methodology. To ABS and To WTH refer to absolute and within connectedness of the estimated system. Long scale refer to forecast horizon of beyond 36 months, medium scales for forecast horizon between 6 and 36 months, while short scale captures forecast period up to 6 months.

The time-domain result in Table 4.6 reveals an overall spillover index of 59.68%, surmising a moderate connectedness of money market rate in Ghana. However, the frequency domain analysis in Table 4.7 unveils moderate to high connectedness among the money market rates in Ghana, as the spillover index ranges between 59.15% and 84.97% although declining with frequency. Notwithstanding, both tables reveals that the monetary policy rate has a low-to-moderate influence on volatility dynamics of other money market rate (particularly lending and interbank rates) across both time and frequency domains. This is a reflecting of a generally weak signaling capability of policy rate in Ghana.

On the other hand, the directional and net spillovers rankings from both tables clearly reveal that the monetary policy rate and the 91-day Treasury bill rate are net transmitters of shocks to the systems, while interbank, lending and saving rates are net receivers of shocks from the system. It is also apparent that Treasury bill emerges as the largest transmitter and the least recipient of shocks to and from the system respectively, across all forecast horizons and analytical domains. This observation surmises an influential role of fiscal policy's debt management on domestic interest rate dynamics, an indication of fiscal dominance in Ghana (see Ekpo, Asiama and Akosah, 2014). On the other hand, lending rate is the largest receiver of shocks from the system, followed by interbank rate and this is equally consistent across forecast horizons and investigative domains.

4.3.2 Interest Rate Impact on the Real Economy

In this section, we ascertain the impact of interest rate on the real economy by examining the extent of co-movements and interlinkages among policy interest rate, exchange rate, output gap and inflation gap at both time- and multiscale domains. The empirical analysis is based on quarterly dataset (2002Q1-2017Q4).

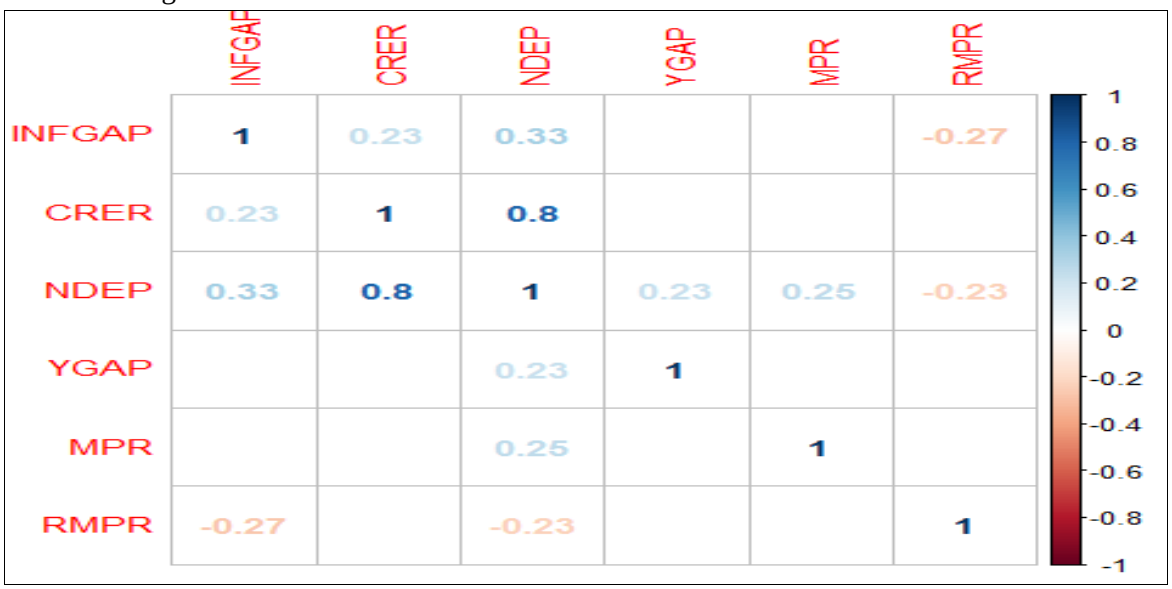
4.3.2.1 In-sample macro volatility spillovers at analytical domains

The in-sample spillover analysis begins with pairwise correlation outcomes at time-domain and this is exhibited in Figure 4.9. A closer glance at the scalogram in Figure 4.9 unveils general low-to-moderate interactions among the macro-variables in Ghana, with the exception of nominal and real exchange rate link. The figure further uncovers significant negative linkages

for the RMPR-INFGAP and RMPR-NDEP pairs, but shows positive significant correlations for the MPR-NDEP, NDEP-INFGAP, NDEP-YGAP and CRER-INFGAP pairs.

Although the correlation outcome at the time-domain is intuitive, it does not connote causation and there is also the penchant for the latter to conceal potential macro-linkages at the frequency domain. To overcome these problems, wavelet techniques are employed as they enable inferences at the time-frequency domain and also proffer lead/lag relationships between macro-pairs. Figure 4.10 displays pairwise wavelet coherence plots for selected key macro-variable at three time-scales, while Figure 4.11 presents wavelet multiple correlation (WMC) results for the linear combination of macro-variables. In particular, the application of WMC technique is to eschew possible spurious detection of correlation often associated with the simple pairwise wavelet scales (see, Das et al., 2018; Andries et al., 2016; Tiwari et al., 2013; Fernandez-Macho, 2012[44], etc.). The WMC essentially helps to decipher simultaneous macro-interconnectedness at the time-frequency domain.

Figure 4.9: Linear correlation matrix for the macro-variables at time-domain



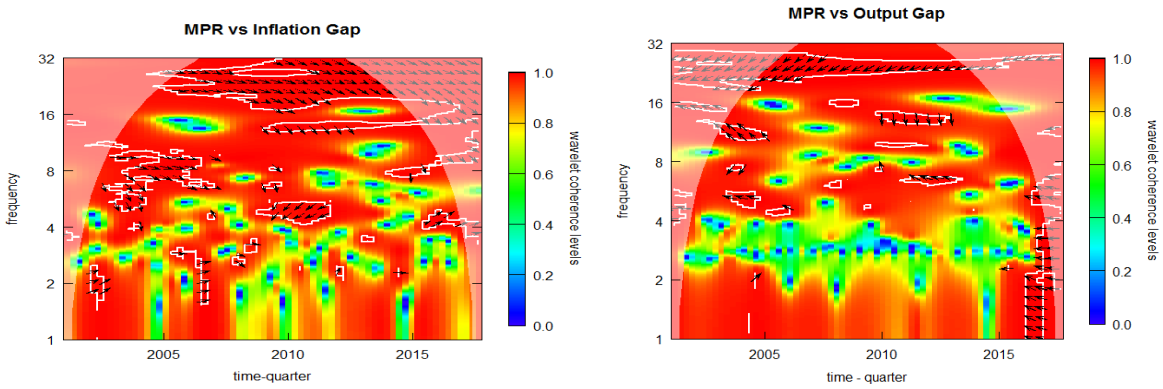
Note: The heat-map gives the static correlation levels over the aggregate time period which get stronger (or shows exact positive or inverse correlation) as the colour becomes warmer. A blank spot (or portion) with no digits denote insignificant correlation, while coloured digits shows statistical significant at 5%. However, the links for NDEP-RMPR, NDEP-YGAP and CRER-INFGAP are only statistically significant at 10% level. MPR and RMPR denote nominal and real monetary policy interest rate respectively; INFGAP is inflation gap; YGAP is output gap, NDEP and CRER represent nominal and real bilateral exchange rate respectively.

[44] The WMC measures the overall statistical relationships that may occur among a set of observations at different time-scales. It offers protection against the standard type 1 error (see Cohen et al., 2003) that may prevail in carrying out all possible pairwise comparisons in a multi-scale context.

In general, both figures unveil correlation range of 0.4 - 1.0, indicating a moderate-to-high macro-interdependence. It is however scale-dependent as correlations among the variables broadly intensify with scales. Particularly, the PWC analysis reveals somewhat stronger linkages at the medium-to-longer time-scale while the scalogram for WMC conspicuously points to robust correlations among the macro-variables at the longer time scale (8-16 quarters and beyond). By implication, monetary policy is rather more effective in the medium-to-longer run in Ghana.

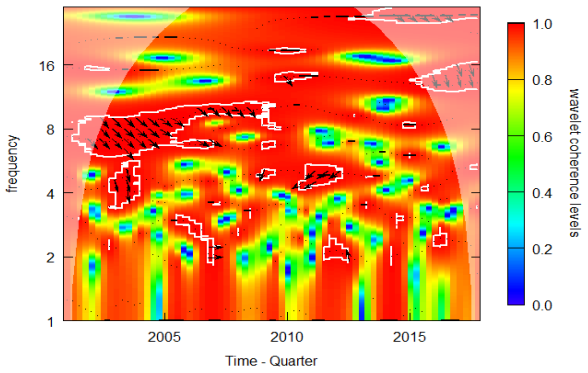
However, the lead/lag relationships from the pairwise scalograms (in Figure 4.10) are somewhat uncertain. In contrast, the WMC plots (in Figure 4.10) uncovers output gap and MPR as the potential leaders at the shorter scale (1-4 quarters) and medium scale (4-8 quarters) respectively, while exchange rate becomes a potential leader at the longer time horizon (8-16 quarters and beyond). The initial maximization of the correlation by output gap against the linear combination of other macro-variables and the subsequent potential dominance of MPR intuitively reinforce the general notion that monetary authority aptly reacts to looming aggregate demand pressures in order to rein in inflation.

Figure 4.10: Pairwise Wavelet Coherency (PWC) Plots for Macro-Interdependence[45]

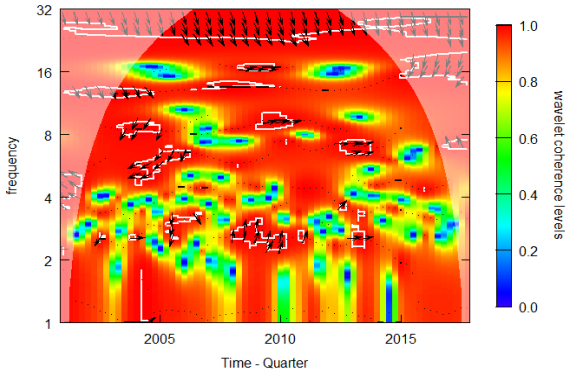


[45] Using 10% as inflation target (i.e. upper limit) to compute inflation gap across the dataset does not alter the empirical result drastically.

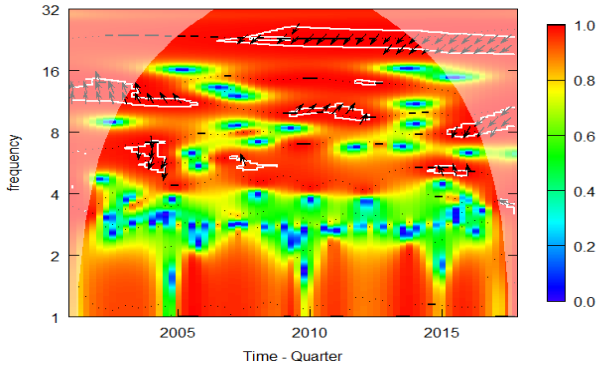
MPR vrs Nominal Depreciation



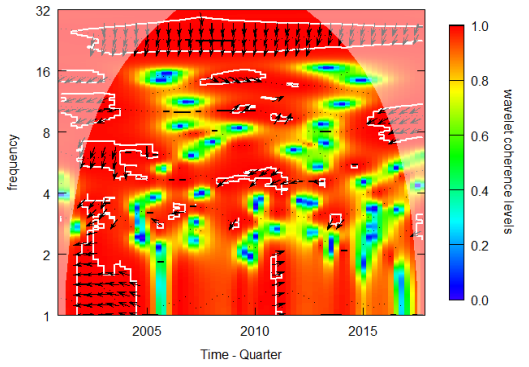
MPR vrs Change in RER



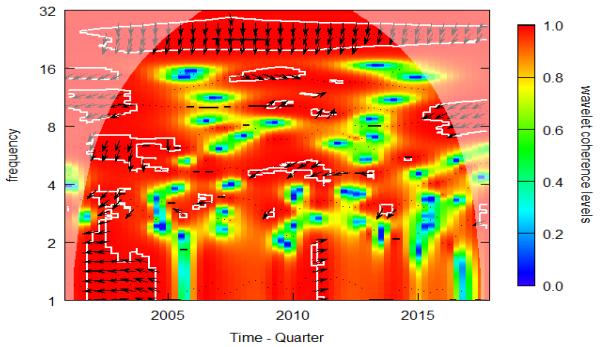
Inflation Gap vrs Output Gap



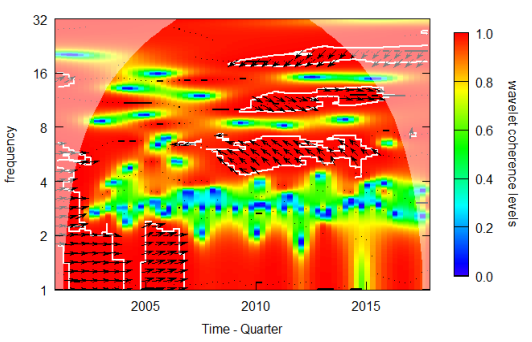
Nominal Depreciation vrs Inflation Gap

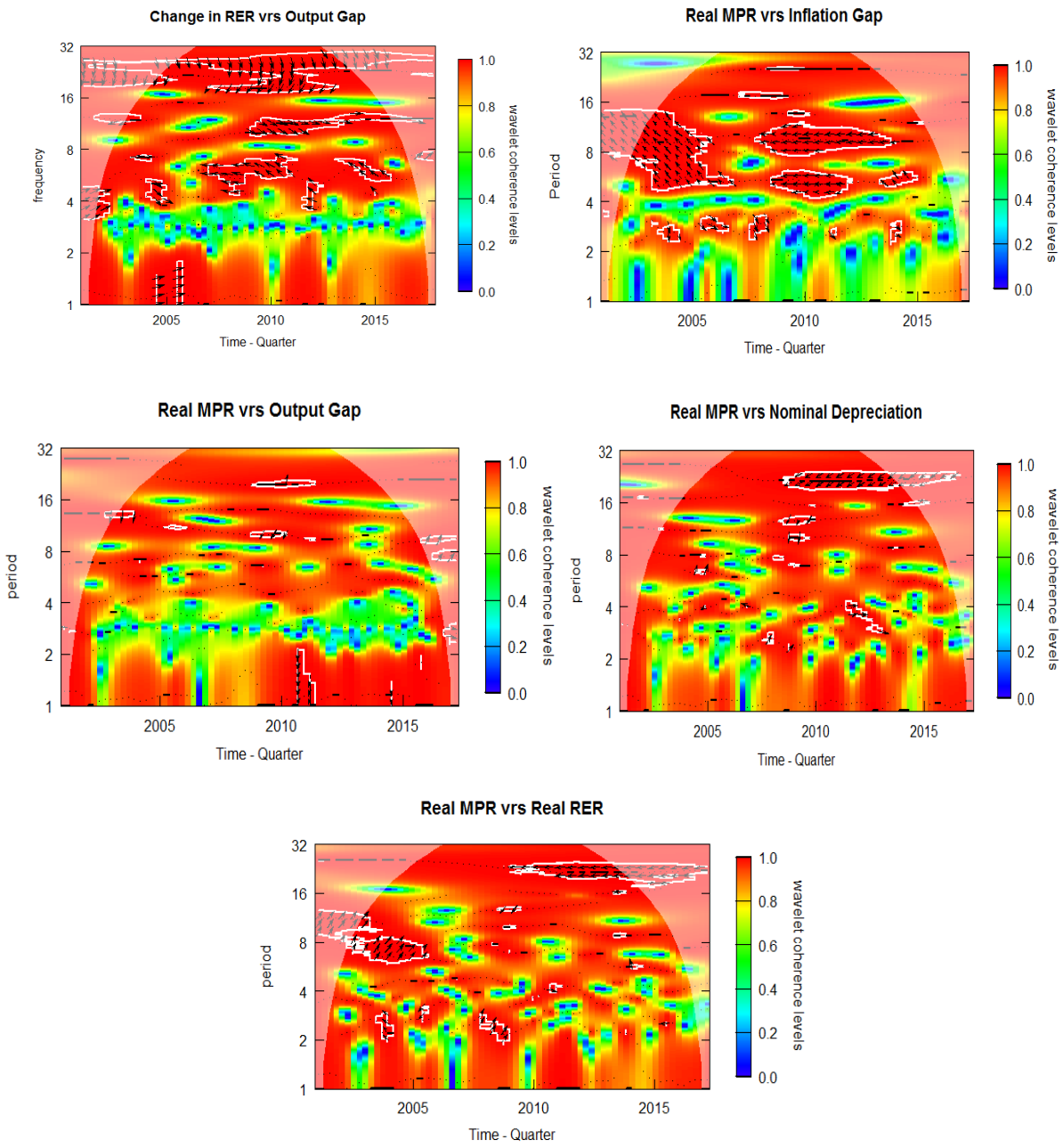


Change in RER vrs inflation Gap



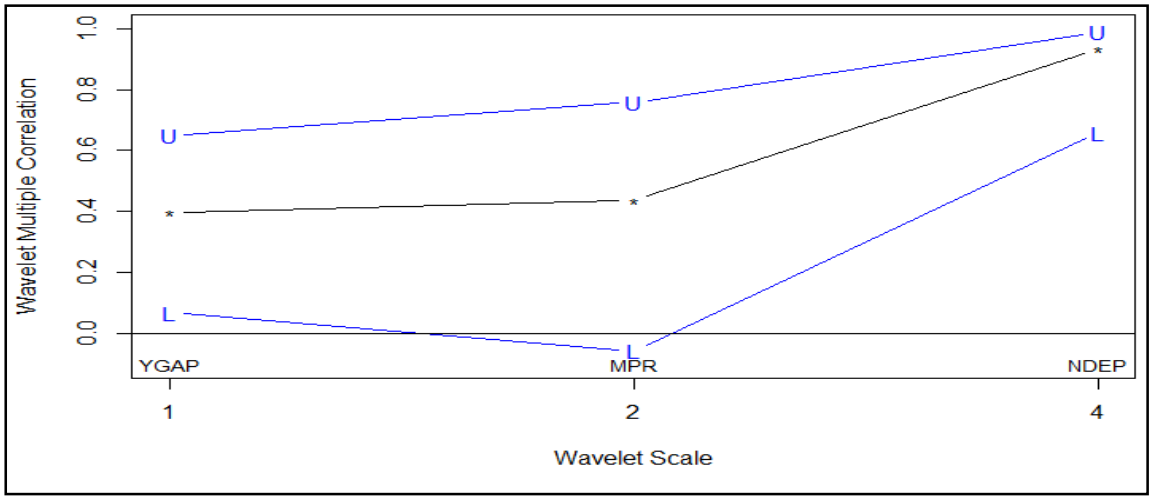
Nominal Depreciation vrs Output Gap



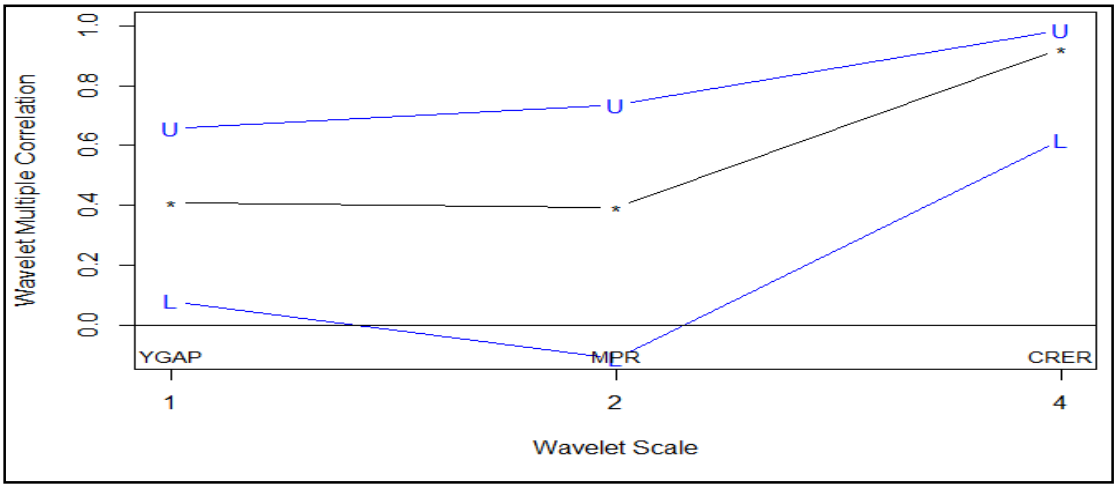


Note: the wavelet coherency heat-map gives the multi-scale correlation. The 5% significance level estimated from Monte Carlo Simulations is designated by white contour. The red (blue) colours signify region with high (low) coherency. The coherence power colour bar shows the power of coherence coefficient. MPR denotes nominal monetary policy interest rate; RER is real exchange rate.

Figure 4.11: wavelet multiple correlations (WMC) for the macro-variables.



A: Scale Correlation for MPR, INFGAP, YGAP & NDEP



B. Scale Correlation for MPR, INFGAP, YGAP & CRER

Note: The blue lines correspond to the upper and lower bounds of the 95% confidence interval. *MPR denotes nominal monetary policy interest rate; INFGAP is inflation gap; YGAP is output gap; NDEP and CRER represent nominal and real bilateral exchange rate respectively.*

4.3.2.2 In-sample Granger non-causality estimates at analytical domains

We are however of the view that in spite of warding off pairwise spurious outcomes, the WMC results tend to omit salient bivariate macro-interactions that may be critical for effective monetary policy implementation. As a result, Granger non-causality tests are further considered so as to sufficiently pinpoint the extent and direction of interdependence among the key macro-variables. After undertaking the appropriate treatment to ensure stationary of all the variables as required (see Table 4.1 for the unit root test results), Table 4.8 accordingly presents the empirical results of in-sample linear/parametric Granger non-causality tests for the macro-variables both at time- and multi-scale domains.

Table 4.8: In-sample linear causality test for macro interconnectedness

Linkage	Panel A	Panel B: Stationary Granger Causality		
	Full Sample	D1	D2	D3
MPR≠>INFGAP	0.21(0.64)	1.34(0.24)	4.63(0.00)^{A}	9.39(0.00)^{A}
INFGAP≠>MPR	2.80(0.09)^{C}	5.74(0.00)^{A}	2.15(0.07)^{C}	3.76(0.00)^{A}
MPR≠>YGAP	17.2(0.00)^{A}	0.72(0.73)	2.57(0.04)^{B}	9.12(0.00)^{A}
YGAP≠>MPR	8.70(0.19)	2.02(0.03)^{B}	0.86(0.48)	3.11(0.01)^{B}
MPR≠>NDEP	3.00(0.22)	1.07(0.38)	1.28(0.28)	1.36(0.25)
NDEP≠>MPR	1.1 (0.58)	1.13(0.34)	0.42(0.79)	0.97(0.42)
MPR≠>CRER	5.7 (0.05)^{C}	5.59(0.00)^{A}	2.70(0.03)^{B}	2.39(0.05)^{C}
CRER≠>MPR	0.98 (0.61)	2.21(0.07)^{C}	0.41(0.79)	1.57(0.18)
RMPR≠>INFGAP	65.0(0.00)^{A}	8.67(0.00)^{A}	8.53(0.00)^{A}	9.17(0.00)^{A}
INFGAP≠>RMPR	43.3(0.00)^{A}	14.29(0.00)^{A}	4.43(0.00)^{A}	3.07(0.01)^{B}
RMPR≠>YGAP	16.2(0.01)^{B}	11.09(0.00)^{A}	1.38(0.24)	10.09(0.00)^{A}
YGAP≠>RMPR	60.8(0.00)^{A}	1.94(0.14)	0.53(0.71)	2.19(0.07)^{C}
RMPR≠>NDEP	17.5(0.09)^{C}	2.91(0.02)^{B}	1.02(0.39)	1.23(0.30)
NDEP≠>RMPR	31.1(0.00)^{A}	0.72(0.57)	0.50(0.73)	2.05(0.09)^{C}
RMPR≠>CRER	5.8(0.67)	9.54(0.00)^{A}	5.79(0.00)^{A}	3.89(0.00)^{A}
CRER≠>RMPR	12.7(0.12)	1.828(0.12)	0.58(0.67)	2.21(0.07)^{C}
INFG≠>YGAP	17.5 (0.00)^{A}	1.19(0.31)	0.57(0.68)	2.87(0.02)^{B}
YGAP≠>INFG	33.2 (0.00)^{A}	3.79(0.00)^{A}	1.28(0.28)	3.48(0.01)^{B}
INFG≠>NDEP	4.60 (0.60)	0.37(0.82)	0.29(0.88)	0.43(0.78)
NDEP≠>INFG	1.50 (0.96)	2.97(0.02)^{B}	1.13(0.34)	4.14(0.00)^{A}
INFG≠>CRER	7.80 (0.00)^{A}	1.28(0.27)	0.70(0.59)	2.22(0.07)^{C}
CRER≠>INFG	5.40 (0.02)^{B}	2.91(0.02)^{B}	2.05(0.09)^{C}	3.23(0.01)^{B}
YGAP≠>NDEP	23.9 (0.00)^{A}	2.31(0.06)^{C}	1.18(0.32)	0.23(0.91)
NDEP≠>YGAP	10.6 (0.10)	7.34(0.000)^{A}	0.72(0.58)	4.78(0.00)^{A}
YGAP≠>CRER	11.8 (0.06)^{C}	5.25(0.00)^{A}	2.99(0.02)^{B}	1.38(0.24)
CRER≠>YGAP	2.90 (0.82)	1.27(0.28)	0.81(0.51)	1.61(0.17)

Note: Numbers in brackets are p-values; the superscripts A, B & C represent 1%, 5% & 10% significant levels respectively. D1, D2 & D3 denote scale 1 (2-4 quarters), scale 2 (4-8 quarters) and scale 3 (8-16 quarters and beyond); MPR is nominal monetary policy rate; RMPR is real monetary policy rate computed as $(1 + MPR)/(1 + inflation) - 1$. *NDEP and CRER are bilateral nominal depreciation and real exchange rate respectively for units of domestic currency per one US dollar. YGAP and INFG represent output gap and inflation gap respectively.*

At a glance, the table broadly unveils significant linear contemporaneous and lagged spillovers among the selected macro-variables. The full sample results (in Panel A) reveal either dual or single linear transmission links, with the exception of the NDEP-MPR and RMPR-INFGAP pairs. On a whole, the full-sample linear causal linkages can be categorized into two dynamic transmission conduits as follows: (i) YGAP↔INFGAP→MPR→YGAP and (ii) YGAP↔INFGAP↔RMPR↔YGAP→NDEP (CRER). These observed channels of linear causalities at time-domain reinforces that policy responds to aggregate demand pressures. In

other words, monetary policy exerts some notable influence on output growth in the short run and this is consistent with the findings of Awdeh (2018) for Lebanon.

For completeness, we further explore subsample analyses to capture macro interlinkages at multiple time-scales. Panel B of Table 4.8 shows lead/lag dynamics from the multi-scale linear Granger non-causality tests as the strength of macro- interconnectedness broadly varies across the time-scales. The multi-scale outcomes are broadly consistent with the full sample results, and hence, re-emphasizing that the monetary authority acts in response to aggregate demand and supply shocks in order to uphold price stability. Notably, the evidence of bi-directional linear macro spillovers becomes more apparent at the longest scale where the majority of the pairs show strong significant interconnectedness. Specifically, the multi-scale analysis uncovers that output gap leads inflation gap and both variables lead nominal MPR in their interdependence structure. In addition, it is equally discernible that exchange rate (particularly nominal) leads inflation and output gap in the shock transmission dynamics in Ghana. This is largely unsurprising due to the overreliance of imports for domestic economic activities and a sizeable proportion of imported (final and intermediate) goods in the consumer inflation basket in the economy. However, nominal/real exchange rate and real MPR have dual interlinkages with the latter as a leading variable while a significant feedback effect is visible at the longer time-scale. This observation, together with significant spillovers from exchange rate to inflation and output gap, buttresses the prerequisite to uphold exchange rate stability in order to inure general macroeconomic stability in Ghana.

Other interesting observations from Panel B are worth highlighting. A unidirectional linear causal effect is observed from output gap to real exchange rate across multi-scales. This is economically intuitive as increasing economic growth momentum enhances investor confidence which in turn attracts foreign inflows and invariable strengthens the domestic currency. Moreover, the lack of significant feedback from real exchange rate to output gap across multi-scale is inconceivable as conventional output gap equations feature a positive effect of the real exchange rate on the output gap. This is because movements in real exchange rate affect trade competitiveness with onward impact on net exports and hence output. Nevertheless, domestic economic activities depend heavily on the importation of intermediate and capital goods together with the fact that imported consumption goods form a sizeable proportion of the consumer basket in Ghana. Accordingly, exchange rate depreciation may

generate adverse wealth effect on financial balance sheet of households (especially for consumer with foreign denominated asset/liabilities) and also reduce the purchasing power of consumers (as higher cost of import is passed on to prices). Also, depreciation potentially makes domestic investments less attractive. Consequently, the plausible declines in both consumption and investments offset the positive gain in net export, supporting the insignificant feedback from real exchange rate to output gap in the Ghanaian context.

Nonetheless, the literature (for instance, Andries et al., 2016) asserts that the interpretation of linear correlation/causality results should be done with the utmost caution as such estimates may fail to adequately capture possible nonlinear linkages. As a consequence, we further explore possible nonlinear linkages in order to authenticate and hence, steer clear of potential biasedness in the preceding empirical results. In line with past studies (see Das et al., 2018), we first carried out DBS test[46] with a null hypothesis of linearity on the residuals of AR(1) process for the respective macro-variables. Table 4.9 presents the results for the DBS test. It is generally discernible from the table that the null hypothesis of independent and identical distribution *(i.i.d)* could not be accepted for the residuals of all the macro-variables across the dimensions for the full sample as well as the multi-scaled data. This favourable evidence of nonlinearity in the macro data engenders the risk of undependability of the preceding linear causality results. In view of this, the intent of performing nonlinear causality test to validate or complement the linear results is accordingly justified.

Table 4.9: DBS test results for full and multiscale macro-dataset

		Dimensions				
	Data Type	**2**	**3**	**4**	**5**	**6**
AR(1): MPR	Full Sample	2.659[0.00]^{A}	2.858[0.00]^{A}	3.913[0.00]^{A}	4.660[0.00]^{A}	5.142[0.00]^{A}
	D1	4.530[0.00]^{A}	4.885[0.00]^{A}	5.638[0.00]^{A}	6.198[0.00]^{A}	6.320[0.00]^{A}
	D2	3.122[0.00]^{A}	3.557[0.00]^{A}	3.906[0.00]^{A}	4.621[0.00]^{A}	5.032[0.00]^{A}
	D3	3.725[0.00]^{A}	3.584[0.00]^{A}	3.412[0.00]^{A}	4.260[0.00]^{A}	4.611[0.00]^{A}
AR(1): RMPR	Full Sample	3.795[0.00]^{A}	5.377[0.00]^{A}	6.418[0.00]^{A}	6.865[0.00]^{A}	7.188[0.00]^{A}
	D1	3.718[0.00]^{A}	5.243[0.00]^{A}	6.076[0.00]^{A}	7.158[0.00]^{A}	8.014[0.00]^{A}
	D2	5.411[0.00]^{A}	6.602[0.00]^{A}	7.598[0.00]^{A}	8.626[0.00]^{A}	9.475[0.00]^{A}
	D3	2.866[0.00]^{A}	3.631[0.00]^{A}	3.924[0.00]^{A}	4.937[0.00]^{A}	5.566[0.00]^{A}
AR(1): INFGAP	Full Sample	3.365[0.00]^{A}	4.527[0.00]^{A}	5.354[0.00]^{A}	5.880[0.00]^{A}	6.170[0.00]^{A}
	D1	3.088[0.00]^{A}	4.401[0.00]^{A}	4.777[0.00]^{A}	4.917[0.00]^{A}	5.513[0.00]^{A}
	D2	2.524[0.01]^{B}	4.459[0.00]^{A}	4.701[0.00]^{A}	4.728[0.00]^{A}	4.523[0.00]^{A}

[46] For details on DBS test, refers to Brock et al., (1996)

	D3	3.315[0.00]^{A}	4.282[0.00]^{A}	4.234[0.00]^{A}	4.729[0.00]^{A}	5.163[0.00]^{A}
AR(1): YGAP	Full Sample	8.886[0.00]^{A}	8.415[0.00]^{A}	8.610[0.00]^{A}	8.751[0.00]^{A}	9.436[0.00]^{A}
	D1	7.247[0.00]^{A}	8.589[0.00]^{A}	10.591[0.00]^{A}	12.120[0.00]^{A}	13.566[0.00]^{A}
	D2	2.592[0.00]^{A}	5.024[0.00]^{A}	7.240[0.00]^{A}	8.576[0.00]^{A}	9.456[0.00]^{A}
	D3	5.063[0.00]^{A}	5.735[0.00]^{A}	6.292[0.00]^{A}	7.006[0.00]^{A}	7.168[0.00]^{A}
AR(1): NDEP	Full Sample	6.053[0.00]^{A}	5.622[0.00]^{A}	5.810[0.00]^{A}	6.080[0.00]^{A}	6.156[0.00]^{A}
	D1	5.448[0.00]^{A}	5.707[0.00]^{A}	5.575[0.00]^{A}	5.990[0.00]^{A}	7.403[0.00]^{A}
	D2	2.469[0.01]^{B}	4.094[0.00]^{A}	5.248[0.00]^{A}	5.913[0.00]^{A}	6.670[0.00]^{A}
	D3	3.375[0.00]^{A}	2.519[0.01]^{B}	2.049[0.04]^{B}	3.537[0.00]^{A}	4.621[0.00]^{A}
AR(1): CRER	Full Sample	1.194[0.23]	1.530[0.12]	2.052[0.04]^{B}	3.054[0.00]^{A}	3.910[0.00]^{A}
	D1	1.928[0.05]^{C}	3.133[0.00]^{A}	2.829[0.00]^{A}	3.630[0.00]^{A}	5.448[0.00]^{A}
	D2	5.916[0.00]^{A}	6.344[0.00]^{A}	8.003[0.00]^{A}	9.138[0.00]^{A}	9.959[0.00]^{A}
	D3	3.173[0.00]^{A}	2.361[0.02]^{B}	1.906[0.06]^{C}	2.833[0.00]^{A}	4.414[0.00]^{A}

Note: the z-statistic is reported at various embedded dimensions. The p-values are reported in square brackets. The superscript A, B & C denotes 1%, 5% & 10% significant levels respectively. D1, D2 & D3 denote scale 1 (2-4 quarters), scale 2 (4-8 quarters) and scale 3 (8-16 quarters and beyond); MPR_t, $INFGAP_t$, $YGAP_t$, $NDEP_t$ and $CRER_t$ denote monetary policy rate, deviation of inflation from target, output gap, nominal and real exchange rate respectively, while $RMPR_t$ is real policy rate.

Table 4.10: Nonparametric Granger non-causality test for the macro-data

Direction	**Full Sample**	**D1**	**D2**	**D3**
MPR≠>INFGAP	0.39(0.34)	1.61(0.05)^{C}	1.68(0.04)^{B}	0.28(0.39)
INFGAP≠>MPR	0.93(0.17)	-1.15(0.87)	-0.44(0.67)	0.13(0.44)
MPR≠>YGAP	1.86(0.96)	1.61(0.05)^{C}	0.45(0.32)	-0.00(0.50)
YGAP≠>MPR	1.05(0.85)	-0.07(0.52)	0.79(0.21)	0.55(0.29)
MPR≠>NDEP	0.03(0.48)	0.88(0.19)	-0.96(0.83)	-0.37(0.64)
NDEP≠>MPR	-0.54(0.71)	-0.43(0.66)	0.87(0.19)	0.16(0.44)
MPR≠>CRER	-1.12(0.86)	-0.29(0.61)	-1.14(0.87)	0.28(0.39)
CRER≠>MPR	-1.38(0.91)	0.68(0.25)	0.94(0.17)	0.39(0.35)
RMPR≠>INFGAP	1.44(0.07)^{C}	1.51(0.06)^{C}	1.84(0.03)^{B}	2.07(0.02)^{B}
INFGAP≠>RMPR	0.41(0.34)	0.69(0.24)	0.36(0.36)	0.54(0.29)
RMPR≠>YGAP	0.81(0.21)	-0.83(0.79)	0.87(0.19)	-0.51(0.69)
YGAP≠>RMPR	-0.12(0.54)	0.06(0.47)	-0.12(0.55)	-0.23(0.59)
RMPR≠>NDEP	1.43(0.07)^{C}	-0.79(0.78)	-0.45(0.67)	0.26(0.39)
NDEP≠>RMPR	0.88(0.19)	-1.01(0.84)	-0.85(0.80)	0.56(0.29)
RMPR≠>CRER	1.06(0.14)	-0.42(0.66)	0.46(0.32)	0.66(0.25)
CRER≠>RMPR	0.97(0.17)	0.85(0.19)	-0.96(0.83)	0.66(0.25)
INFG≠>YGAP	0.70(0.24)	-0.44(0.67)	-1.21(0.88)	0.05(0.45)
YGAP≠>INFG	1.23(0.11)	1.24(0.11)	-0.58(0.72)	-0.22(0.59)
INFG≠>NDEP	0.62(0.27)	1.06(0.14)	-0.28(0.61)	1.04(0.15)
NDEP≠>INFG	-0.99(0.84)	-0.27(0.61)	0.58(0.28)	-0.83(0.79)
INFG≠>CRER	1.17(0.12)	0.08(0.46)	0.46(0.32)	0.28(0.39)
CRER≠>INFG	0.46(0.32)	-0.13(0.55)	0.11(0.46)	-0.58(0.72)
YGAP≠>NDEP	0.14(0.44)	-0.32(0.62)	0.20(0.41)	-1.02(0.85)
NDEP≠>YGAP	0.09(0.46)	-0.44(0.66)	-0.87(0.81)	-1.10(0.86)
YGAP≠>CRER	0.32(0.37)	0.45(0.32)	0.67(0.25)	-0.37(0.64)
CRER≠>YGAP	0.44(0.33)	0.05(0.48)	-0.17(0.56)	0.79(0.21)

Note: The p-values are reported in brackets. The superscript B & C denotes 5% & 10% significant levels respectively. D1, D2 & D3 denote scale 1 (2-4 quarters), scale 2 (4-8 quarters) and scale 3 (8-16 quarters and beyond); MPR, INFGAP, YGAP, NDEP and CRER denote monetary policy rate, deviation of inflation from target, output gap, nominal and real exchange rate respectively, while RMPR is real policy rate.

Considering the outcome of the DBS test, we proceed to perform an in-sample nonparametric (nonlinear) Granger causality test based on DP (2006) methodology. In doing so, we followed the protocols of DP2006 to set the lag length to 2, i.e. $l_z = l_w = 2$, and a bandwidth of 0.5 for all pairs. Table 4.10 presents the results for DP2006 test. At first glance, the table clearly unveils a general insubstantial evidence of nonlinear transmissions among the macro-data across time- and multi-scale domains. This surmises that the detected in-sample linear causal linkages at both time-spectrum and wavelet time-frequency domain (in Table 3.9) are broadly adequate for economic inferences in the context of Ghana.

Nonetheless, some isolated cases of significant nonlinear linkages are noticeable from the table. Particularly, the full sample analysis reveals significant unidirectional nonlinear interlinkages for macro-pairs RMPR-INFGAP and RMPR-NDEP (at 10% level) with RMPR as a transmitter. Thus, the real policy rate has dampening effect on inflation and also strengthens the domestic currency in nominal terms which is intuitively plausible. The nonlinear analysis unveils that the policy rate has significant nonlinear influence of both inflation and output gap at time-frequency domain. This observation is not surprising as the monetary policy transmission mechanism (MPTM) clearly demonstrates that policy interest rate affect both inflation and output via several conduits. In addition, the table reveals that the standard empirical analysis (in time-domain) has the tendency to overlook salient influence of policy interest rate on inflation gaps at frequency domain[47].

4.3.2.3 Out-of-sample macro volatility spillovers at analytical domains

We assert that the preceding in-sample analysis does not explicitly quantify the magnitude of spillovers and fails to reveal out-of-sample volatility spillovers among the macro-variables. In view of these limitations, this section explores the generalized forecast error variance decomposition (GFEVD) techniques to determine the relative contributions to forecast uncertainties by the selected macro-variables. Our preference for these approaches is mainly based on the fact that variance decomposition (VD) from a vector Autoregression (VAR) model proffers crucial information about how much of the future uncertainty of variable A is due to innovations to variable B. Therefore, VD is utilized to adequately capture system or macro interdependence/connectedness (Diebold and Yilmaz, 2012, 2009). By summing up

[47] Studies such as Aguiar-Conraria et al., (2008, 2012), Gallegati, et al., (2011) and Lynch and Zumbach (2003) underscore the importance of frequency domain analysis.

information in VD[48], one can quantify how the system is interconnected. For robustness, we apply both the Diebold and Yilmaz (2012) and Barunik and Krehlik (2015) methodologies which focus on time-domain and frequency-domain respectively.

Table 4.11 presents the magnitudes of directional, pairwise and total interconnectedness (spillovers) among real interest rate, inflation gap, output gap and real exchange rate at time domain based on the GFEVD methodology of Diebold-Yilmaz (2012) at different forecast horizons (H=10, 50 and 100 quarters). On the other hand, Table 4.12 present volatility spillovers among these macro-variables at frequency domain based on the GFEVD methodology of Barunik and Krehlik (2015) at different forecast horizons (H=10, 50 and 100 quarters). It is clearly evident from the table that average total connectedness among the macro-variable is about 50% for forecast horizon up to 10 quarters (H=10) and increases to about 68% with H=50 quarters ahead.

Table 4.11: Time-domain spillovers table for macro-data

	Real Policy Rate	Inflation Gap	Output Gap	Real Exchange Rate	Contribution from Others (CFO)	**CFO Ranking**
H = 10 Quarters ahead						
Real Policy Rate	47.64	19.11	12.72	20.53	13.09	**2**
Inflation Gap	25.57	50.29	1.85	22.28	12.43	**3**
Output Gap	59.06	3.01	33.45	4.47	16.64	**1**
Real Exchange Rate	26.98	1.28	2.81	68.93	7.77	**4**
Contribution to Others (CTO)	27.9	5.85	4.35	11.82		
CTO Ranking	**1**	**3**	**4**	**2**		
Contribution including own	75.54	56.14	37.8	80.75	**Overall Spillover**	
Net Spillover (NS)	14.81	-6.57	-12.29	4.05	49.92	
NS Ranking	**1**	**3**	**4**	**2**		
H = 50-Quarters ahead						
Real Policy Rate	28.68	11.86	9.22	50.25	17.83	**2**
Inflation Gap	27.71	32.32	9.12	30.85	16.92	**3**
Output Gap	44.78	9.29	9.54	36.40	22.62	**1**
Real Exchange Rate	27.12	8.4	7.81	56.67	10.83	**4**
Contribution to Others (CTO)	24.9	7.39	6.54	29.37		
CTO Ranking	**2**	**3**	**4**	**1**		
Contribution including own	53.58	39.71	16.08	86.04	**Overall Spillover**	
Net Spillover (NS)	7.07	-9.53	-16.08	18.54	68.2	
NS Ranking	**2**	**3**	**4**	**1**		
H = 100 Quarters ahead						
Real Policy Rate	35.12	11.21	8.31	45.37	16.22	**2**
Inflation Gap	31.63	21.18	7.49	39.69	19.7	**3**
Output Gap	46.64	9.98	8.21	35.16	22.95	**1**
Real Exchange Rate	27.21	7.66	6.73	58.40	10.4	**4**

[48] VD is closely related to recent network theory and the lately acclaimed measures of systemic risks, such as expected shortfall and CoVaR.

Contribution to Others (CTO)	26.37	7.21	5.63	30.06	
CTO Ranking	**2**	**3**	**4**	**1**	
Contribution including own	61.49	28.39	13.84	88.46	**Overall Spillover**
Net Spillover (NS)	10.15	-12.49	-17.31	19.65	69.27
NS Ranking	**2**	**3**	**4**	**1**	

Note: the table shows the estimated spillovers from (along column) and to (along row) of various combinations of macroeconomic variables, estimated using the Diebold and Yilmaz (2012) methodology. The rankings 1 to 4 indicates highest to lowest spillovers to (or from) variable i within the estimated system.

Table 4.12: Frequency-domain spillovers table for macro-data

	Real Policy Rate	Inflation Gap	Output Gap	Real Exchange Rate	From ABS	From Within
Short Scale						
Real Policy Rate	1.93	0.84	0.05	0.39	0.32	5.37
Inflation Gap	5.64	7.53	0.13	1.49	1.81	30.50
Output Gap	0.74	0.04	0.24	0.85	0.41	6.85
Real Exchange Rate	0.45	0.27	0.24	2.98	0.24	3.99
To ABS	1.71	0.29	0.10	0.68	2.78	
Ranking	**1**	**3**	**4**	**2**		**Overall Connectedness**
To WTH	28.68	4.82	1.74	11.48		**46.71**
Ranking	**1**	**3**	**4**	**2**		
Net Spillovers (NS)	1.39	-1.53	-0.30	0.45		
NS Ranking	**1**	**4**	**3**	**2**		
Medium Scale						
Real Policy Rate	29.21	5.64	3.49	11.92	5.26	9.88
Inflation Gap	21.15	6.20	3.21	10.60	8.74	16.40
Output Gap	41.50	7.08	6.32	21.41	17.50	32.85
Real Exchange Rate	21.61	2.91	1.92	18.90	6.61	12.41
To ABS	21.06	3.91	2.15	10.98	38.11	
Ranking	**1**	**3**	**4**	**2**		**Overall Connectedness**
To WTH	39.55	7.33	4.04	20.62		**71.54**
Ranking	**1**	**3**	**4**	**2**		
Net Spillovers (NS)	15.80	-4.83	-15.34	4.37		
NS Ranking	**1**	**3**	**4**	**2**		
Long Scale						
Real Policy Rate	3.97	4.73	4.77	33.05	10.64	26.08
Inflation Gap	4.85	7.45	4.16	27.60	9.15	22.44
Output Gap	4.40	2.87	1.66	12.90	5.04	12.36
Real Exchange Rate	5.15	4.49	4.57	36.52	3.55	8.71
To ABS	3.60	3.02	3.38	18.39	28.39	
Ranking	**2**	**4**	**3**	**1**		**Overall Connectedness**
To WTH	8.83	7.41	8.28	45.09		**69.60**
Ranking	**2**	**4**	**3**	**1**		
Net Spillovers (NS)	-7.04	-6.13	-1.67	14.84		
NS Ranking	**4**	**3**	**2**	**1**		

Note: the table shows the estimated spillovers from (along column) and to (along row) of various combinations of macroeconomic variables, estimated using the Barunik and Krehlik (2015) methodology. To ABS and To WTH refer to absolute and within connectedness of the estimated system. Long scale refer to forecast horizon of greater than 10 quarters, medium scales for forecast horizon between 4 and 10 quarters, while short scale captures forecast period up to 4 quarters.

A close examination of both tables conspicuously unveils that real policy rate and exchange rate as net transmitters of shock to the systems, while inflation and output gaps are net receivers of shocks from the system across analytical domains. The empirical estimates from the both analytical domains reveal that policy rate is the dominant transmitter of shock to the system in the short-to-medium run at time domain (and at the short run for frequency domain), while real exchange rate subsequently emerges as the largest propagator of shocks to the entire system (including own shocks) for longer forecast horizon for time domain (but at medium-to-longer forecast horizons for frequency domain). We also observe a strong dual linkage between real policy rate and exchange rate (at time domain) at least in the short run. The subsequent dominance of exchange rate shock in the system implies that exchange rate is a crucial transmission channel of monetary policy than interest rate in case of Ghana, particularly in the longer time horizon. This is an important observation given the fact that Ghana is classified as a managed float economy (see, IMF, 2014). This is consistent with Krušković (2018) who identified exchange rate as a very significant transmission channel than the interest rate both in emerging markets and Serbia.

Output gap is the largest receiver of shocks from the system, followed by inflation gap and this is consistent across forecast horizons. Notably, the effect of monetary policy shock on output outstrips that on inflation across forecast horizons, particularly at analytical time domain (see Table 4.11). This is intuitively plausible as policy decisions (or changes in policy instruments, either via interest rate or exchange rate) are initially targeted at the business cycle (aggregate demand pressures) and the onward effect on general prices (inflation), in line with the literature on monetary policy transmission mechanism. However, impact of exchange rate spillovers on inflation seems to be relatively stronger than that on output across forecast horizons in both time and frequency domains. Conceivably, adjustments in policy interest rate impact investment and consumption decisions of households with onward repercussions on aggregate demand (output). Likewise, the observed relatively stronger exchange rate spillovers to inflation are intuitively plausible as changes in the exchange rate impact firm's marginal cost of production with a consequential influence on prices.

Nevertheless, the directional spillover results also demonstrate that inflation shocks provide relatively higher explanation to variation in real policy rate than that emanating from output gap across the forecast horizon. Thus, monetary authority appears to put more weight on

upholding low and stable prices in policy rule response. It is however very conspicuous that interest rate shocks are relatively important for output, while exchange rate shocks wield predominant effects on inflation in the case of Ghana. Nonetheless, Table 4 reveals that the extent of spillover dynamics from policy rate to and from the targeted macro-variables (particularly output gap and inflation) appears to be moderate even in the long run, surmising an ineffective monetary policy transmission at frequency domain in the long run. Therefore, deliberate and coordinated policy efforts are warranted by the monetary and fiscal authorities to address inherent structural weaknesses, particularly related to the financial (banking) system, to accelerate and strengthen the onward policy response by the financial (banking) sector and the entire real sector economy

4.4 Conclusion

The Ghanaian economy is characterized by continuous and acute exchange rate volatilities alongside persistent and high consumer inflation. This places Ghana among the sub-Saharan African (SSA) with highest inflation and has ignited policy interest in the effectiveness of monetary policy rate regarding the extent of its pass-through to the real sector as well as the degree of exchange rate spillovers to other key policy targeted variables (inflation and output gap). Also, we want to know what drives inflation, output and exchange rate in Ghana. Giving the important role of fiscal policy in developing economies, it is critical to ascertain the impact of fiscal policy on monetary policy setting as fiscal deficit will affect the Treasury bill rate with implications on the money markets. In view of this, the current chapter of the thesis determines the effectiveness of monetary policy in two ways. First, it explores the signalling ability of policy interest rate in the money market by determining the extent of co-movements and connectedness among money market interest rates. Second, we investigate the policy rate-real sector nexus as well as the influence of exchange rate in domestic macro-dynamics and interest rate setting in Ghana. In this case, we appraise the co-movements and volatility spillovers among key macroeconomic policy variables (such as inflation, output gap, exchange rate and policy interest rate) at both time- and multi-scale domains.

Adopting a more systematic approach, we explore several versions of VAR frameworks alongside wavelet coherency and multiple correlation analyses. Specifically, we employ the conventional parametric (or linear) Granger non-causality tests together with the Diks and Panchenko (2006) nonparametric and nonlinear Granger non-causality test to uncover lead/lag

transmissions among the macro-variables. In addition to linear and nonlinear causality tests, the macro-spillovers are further examined using versions of the GFEVD approaches by Diebold and Yilmaz (2012) and Barunik and Krehlik (2015). The application of these several estimation techniques in this thesis is principally to ensure robust estimates and inferences.

In general, we unveil scale-dependent interconnectedness among the macro-variables. On one hand, both the wavelet coherency and multiple correlation analyses reveal strong macro co-movements at the longer time-scale but low-to-moderate interdependence at the short-to-medium scales. This empirical evidence is largely consistent with the Granger non-causality test as bi-directional linear macro-linkages become more apparent at the longest scale where majority of the pairs show strong significant interconnectedness. Basically, we notice that the dynamic interactions among the macro-variables are predominantly linear for the sample period as no substantial nonlinear transmissions were observed across time- and multi-scale domains. The Granger non-causality analysis reveals that nominal/real exchange rate and real MPR exhibit dual linear interlinkages. It is also discernible that exchange rate (both real and nominal) and output gap leads inflation gap in the shock transmission dynamics across multi-scales. While significant direct feedback from the inflation to real exchange rate is observed to occur only at the longer time-scale, no such evidence of direct feedback was noticed from the former to nominal exchange rate across time-scales. In addition, the multi-scale analysis unveils that both output gap and inflation gap lead nominal MPR in their interdependent dynamics, consistent with the general notion that monetary authority reacts to aggregate demand and supply shocks.

On the other hand, the analysis of generalized forecast error variance decomposition (GFEVD) reveals that both real policy rate and exchange rate are net transmitters of shocks to the system, while inflation and output gaps are net receivers of shocks from the system. Output gap is the largest receiver of shocks from the system, largely via real policy rate shocks and this is consistent across forecast horizons. However, we find that the policy interest rate and exchange rate emerge as the largest propagator of shocks to the system at the shorter and longer forecast horizons respectively. Analogous observation is apparent from the pairwise net spillovers between real policy rate and real exchange rate with the former emerging as a net shock transmitter (receiver) to (from) the latter at the shorter (longer) forecast horizon respectively.

The empirical observation indicates the capacity of the monetary policy instrument to effectively impact real economic variables and robustly accentuates the important influence of real exchange rate in domestic macroeconomic dynamics. Yet, the extent of spillover dynamics from policy interest rate to and from money market rates and the targeted macro-variables (particularly output gap and inflation) appears to be moderate even in the long run, surmising a weaker monetary policy transmission. This empirical observation accordingly warrants deliberate policy efforts to address inherent structural weaknesses, particularly related to the financial (banking) system, to hasten and intensify onward policy response by the financial (banking) sector and the entire real sector economy.

Another notable observation is the dominant shock transmission from the 91-day Treasury bill rate (i.e. short-term yield on government bond) to the money market interest rate across time and frequency spectrums. By implication, fiscal policy tends to exert an important influence of interest rate settings in Ghana which suggests an evidence of fiscal dominance. This warrants a deliberate and continuous policy harmonization between monetary and fiscal authorities to curtail fiscal surprises that engender heightened volatility in government yields with onward repercussions on other money market rates.

CHAPTER FIVE

Macroeconomic Policy Reaction Function for Ghana:

Time-Frequency Evidence from the Conditional Mean and Quantile Approaches

5.0 Introduction

Following the seminal work of Taylor (1993), the monetary policy reaction function has developed in a linear framework, disregarding possible asymmetries of central bank preferences. The typical Taylor rule commonly emanates from two assumptions: a solution of linear quadratic preference and a linear Philips curve (see Svensson, 1997; Chevapatrakul and Paez-Farrell, 2014; Guney, 2018; among others). The first assumption purports symmetric policy response to inflation and output irrespective of their trajectories from the desired levels. Even though the widely computed Taylor rule[49] tend to reasonably illuminate monetary policy well in most economies, the literature documents varying degree of rule- and discretionary-based models that have characterized operations of central banks (including US Federal Reserve) over time (see, Greenspan, 1997; Wolters, 2012). This reflects that central banks across the globe appear not to strictly adhere to a certain policy rule[50]. The presumed symmetric weights on positive and negative shocks (gaps) implied by the quadratic loss function have recently been questioned by several practitioners and researchers on grounds that it has little support beyond analytical flexibility (see, Blinder, 1996; Mishkin and Posen, 1997; Goodhart, 1999; Cukierman, 1999; Orphanides and Wilcox, 2002).

Several justifications for sporadic deviations from symmetric and linear policy rule have well been enunciated by economic theory and empirical research. Recent studies have provided theoretical foundations for asymmetry in the reaction function of monetary authorities. For instance, studies including Cukierman and Muscatelli (2008), Surico (2007) and Gerlach (2000) have shown that asymmetric central bank preference can result in a nonlinear policy reaction function. Cukierman (2000, 2002) has suggested that while credible central banks are opposed to negative output gaps, and to deviations in inflation from the target, they are not equally averse to positive output gaps. A possible explanation for this behaviour is that,

[49] Example of research that have estimated country specific coefficients are Taylor (1993), Nelson (2000), Surico (2002, 2007), Takats (2012), Naraidoo and Raputsoane (2010), de Sa and Portugal (2015), etc.
[50] See Rudebusch (1995), Svensson (1999, 2003, 2005), Clarida et al., (2000), Bernanke (2004) for discussion of the simple Taylor rule.

although most central banks are regarded as independent, if they are accountable to elected officials, their interventions may be influenced by the business cycle. Aside nonlinear Taylor rule, Schaling (1999, 2004) and Dolado et al (2005)[51] argue that asymmetric policy response may also arise if the economy is nonlinear. Similar evidence of nonlinear policy rule stem from model uncertainty (see, Tillmann, 2010; Meyer et al., 2001) and fear of the zero lower bound of interest rate (see, Adam and Billi, 2006; Kato and Nishiyama, 2005). Consequently, recent analysis on monetary policy reaction function (MPRF) have shifted from linear quadratic frameworks, as it is deemed as needlessly restrictive, to nonlinear reaction functions. Also, the debate regarding the inclusion or not of interest rate smoothing in the standard Taylor rule equally remains rife in the extant literature (see, Clarida et al., 2000; Rudebusch, 1995).

Ghana, in May 2007[52], emerged as the second African economy after South Africa but the first developing nation to adopt inflation targeting (IT) monetary policy framework[53]. Given its institutional weaknesses (such as feeble fiscal profile, continuous monetary financing of fiscal deficit, underdeveloped finance system), Ghana became a test case for the IT implementation in a developing economy. Like other IT central banks in small-open economies, the monetary policy committee (MPC) in Ghana sets the short-term interest rate after considering the balance of risks from both domestic and external sources to inflation and economic growth (employment). In addition, the central bank of Ghana has increased its channels of communication with the general public[54] to help shape private agent's formation of inflation expectation and hence, rein in inflation. This is particularly based on the recognition that increased policy transparency[55] does not only boost monetary policy effectiveness and

[51] Dolado et al (2005) extended the work of Schaling (1999, 2004) by including an intrinsic weight on output stabilization in the objective function of the monetary authorities.

[52] While some authors refer to the official announcement to date the adoption of IT (see Kwakye, 2012), Bawumia et al. (2008) assert that even though formal announcement was made in May 2007, Inflation Targeting was launched in the latter part of 2002.

[53] Abradu-Otoo et al., (2003) found unstable link between the monetary aggregates (i.e. the then instruments for monetary policy) and the inflation rate. This implies that monetary aggregates were no longer effective nominal anchor that the central bank can use to pin down economic agent's inflation expectation at or around the target inflation level.

[54] Little and Romano (2009) assert that institutional elements contributing to transparency range from central bank independence to the makeup of the policy-setting body. Accordingly, key policy documents for CBG are published at the Bank's website: www.bog.gov.gh

[55] According to Amato and Shin (2003), the actions of central bank and the information it publicly provides create a common powerful focal point for the information processing decisions of economic agents. Using a panel of emerging economies, Papadamou et al. (2015) find monetary policy transmission mechanism to be more effective under high policy transparency.

credibility but is also perceived as the crucial component of accountability in the era of central bank independence (see Haldane, 2017; Al-Mashat et al., 2018).

Despite more than a decade of practicing IT framework, Ghana's consumer inflation remains persistently high and above the medium-term inflation target of 8±2%. Ghana is still placed among the top ten African economies with higher inflation (see, International Monetary Fund, October 2019). The economic agents' inflation expectation has always exceeded the actual inflation (see Figure A2 in Appendix A). The monetary policy environment in Ghana is classified as less transparent (notably, Geraats, 2002; Dincer and Eichengreen, 2014; Naszodi et al., 2016). Ironically, Bleaney et al (2020) assert that the conduct of monetary policy in Ghana is consistent with other IT economies in the long run. The ensuing question then is what underlies the persistent inflation in Ghana? Cukierman et al., (1992) linked the high and embedded inflation inertia in Ghana to lack of legal independent of the central bank to keep the fiscal authority in check (i.e. weak institutions). Indeed, the Bank of Ghana (BOG) is still obliged by law to finance fiscal deficit up to 5% of the previous year's fiscal revenue, a clear indication of fiscal dominance in Ghana (see, Akpan et al., 2014; Bleaney et al. 2020). The relegation of monetary policy to fiscal necessities encourages private economic agents to consider that the Bank's promise to control inflation is incredible. Accordingly, the inflationary pressures of a fiscal origin may induce formal and informal indexation mechanisms in the private sector, and thus, complicating the tasks of the central bank (Bleaney et al., 2020). Consequently, Others studies (e.g. Kovanen 2011; Kwakye, 2010) attributes the poor performance of BOG in controlling inflation to inefficient interest rate transmission mechanism owing to underdeveloped banking/financial system as a contributing factor to the imbedded inflation inertia in Ghana. Monetary policy has an impact on real activity if the retail market deposit and lending interest rates respond to changes in the policy interest rate. This effect takes place via the impact of monetary policy on wholesale interbank and Treasury bill interest rates. Kovanen (2011) articulates an apparent lack of responsiveness in the lending interest rate at the retail level to changes in the policy interest rate in Ghana. In addition, exchange rate management has not been a smooth one in Ghana due, in part, to the overdependence of imports for domestic economic activities and the recurrent fiscal excesses. The Ghanaian economy is indeed exposed to recurrent exchange rate risk, often resulting in higher prices via imported inflation (see Loloh, 2014). Even though inflation remains high, the general macroeconomic outcomes have

improved during the IT regime compared to the previous regimes in Ghana (see Appendix 3Ai)[56].

The broad motive of this chapter is to empirically describe how the central bank has conducted monetary policy in Ghana given the numerous domestic and external constraints. Accordingly, the specific objectives of this chapter are in six-folds. First, it ascertains whether monetary policy in Ghana can be more precisely described by either (i) the standard linear Taylor rule, or (ii) an augmented linear rule including exchange rate or (iii) a nonlinear augmented threshold rule at both historical time interval and time-frequency domain. Second, we ascertain whether the BOG strictly adheres to the Taylor principles amidst regular and official sterilized purchases/sales of foreign exchange. This is premised on the strand of the literature that a flexible market-determined exchange rate is a precondition for successful adoption of IT (see, Masson et al, 1997; Mishkin and Savastano, 2001; Mishkin and Schmidt-Hebbel, 2002; and McCallum, 2007). In contrast, other studies (including Airaudo et al., 2016) also show that tight management of exchange rate (via direct official sterilized purchases/sales of foreign exchange) is pivotal for successful IT implementation and outcomes in Least Developed Economies (LDCs including Ghana) with sufficiently high degree of substitutability between domestic and foreign currencies. Notwithstanding, the overwhelming evidence is that interventions are costly and ineffective in such LDCs. Third, we determine the relative weights monetary policy attaches to inflation and output gaps in Ghana in bid to ascertaining policy preferences across business cycles of booms and downturns and at different time-scales. Fourth, the chapter ascertains the nature of the Philips curve faced by BOG based on how the latter responds to expected spill-overs from aggregate demand (output gap) to inflation at different time-scales. Fifth, we determine the importance and extent of policy inertia at different time-scales. Sixth, to evaluate the relevance of exchange rate dynamics in Ghana's monetary policy (Taylor) rule across time-scales and quantiles, amid the notion that exchange rate plays pivotal role in small open economies. Besides the exchange rate, we present several alternatives to the baseline specification that permit the central bank to respond to other foreign and domestic variables other than inflation and output due to Ghana's peculiar open economy characteristics. Seventh, the appointment of the central bank governors under the IT regime has broadly coincided with the political cycles in Ghana. Therefore, we further scrutinize

[56] Bleaney et al (2020) assert that IT regime has kept inflation much lower in most countries than in Ghana.

whether monetary policy preferences have differed substantially across political regimes. The rationale is that there is a general monetary policy easing stance during political regime 1 (PR1) and a broadly tightening stance during political regime 2 (PR2), as depicted by Appendix 5Aiv. For robust inferences, our analysis employs novel time- and time-frequency domain methodologies to thoroughly examine Ghana's MPRF at different time-scales and quantiles.

In this chapter, we thus estimate several linear and nonlinear (augmented, contemporaneous and forward-looking) Taylor rules using GMM as well as Frequentist and Bayesian Quantile approaches at historical time-interval and multiscale (time-frequency) domain. Additionally, this paper estimates a threshold autoregressive (TAR) specification to ascertain whether policy reaction to inflation and output gaps (or exchange rate) differs during low and high inflation regimes[57]. The use of quantile regression in this chapter helps to decipher policy reaction to output and inflation dynamics across the entire distribution of policy interest rate but not only the mean response. Such perspective is important as Ghana has high and rigid interest rate environment (Kwakye, 2010) which perhaps impedes the extent of policy aggression to positive deviation of inflation from its target. The chapter thus has an advantage over recent notable papers including Bawumia et al. (2008) and Bleaney et al. (2020) which examined the conduct of monetary policy in Ghana. Both papers exclusively estimated a linear augmented Taylor rule for Ghana using conventional conditional mean estimation techniques. But, the latter approach has been criticized that it fails to account for possible relationships at the tails, median and other parts of the response distribution (Koenker and Bassett, 1978).

While the empirical analysis of MPRF is not new, much of the literature has hovered around the advanced and emerging economies with predominantly free floating exchange rate regime (including North and Latin America, Europe and Asia). The literature on this topic focusing on developing and frontier IT economies (including Africa) with other forms of exchange rate regimes (example, pegged or tightly managed exchange rate regime) is woefully scanty. With Ghana as the second longest practicing IT economy in Africa (after South Africa) and also classified as a managed float IT economy (see IMF, 2016), it is of interest to consider how the interest rate setting compares with the empirical findings on other IT countries across the globe.

[57] Our preference for TAR is that it endogenously estimates the threshold value and hence, more appropriate to capture asymmetries in the conduct of monetary policy than the markov regime switching models which treat regimes change as exogenous (Atanasova, 2003; Castro 2011; Caporale et al. 2018; among others).

The chapter offers a number of cogent contributions to the macroeconomic literature on frontier and developing economies. Even though other recent papers (including Miles and Schreyer, 2012; Chevapatrakul and Paez-Farrell, 2014; Wolters, 2012; and Chevapatrakul et al., 2009) have also considered central bank reaction to inflation and output gap for the entire distribution of interest rate using frequentist quantile regression method, none of these studies has offered perspective on monetary policy dynamics within time-frequency (multiscale) domain. This is despite the fact that the relevance of time-frequency analysis is highly articulated in the extant literature[58]. To the best of our knowledge, the chapter is the first to specifically analyse MPRF using time-frequency domain techniques with Bayesian inferences. Thus, this chapter differs considerable as none of the previous studies has explored tailed MPRF at time-frequency domain with Bayesian inferences[59]. Second, the use of a more novel technique like Maximal Overlap Discrete Wavelet Transform (MODWT)[60] with Debauches least asymmetric filter of length (LA8) to obtain wavelet time-scale coefficients for the analysis of MPRF at the short, medium and long runs is a contribution worth mentioning. Another notable contribution is the application of Marginal Posterior Inclusion Probability (MPIP) based on Markov Chain Monte Carlo (MCMC) simulations to determine the relevance of a predictor variable in the MPRF. Furthermore, only few empirical studies (notably, Shortland and Stasavage, 2004; Akyurek et al. 2011; Miles and Schreyer, 2012; Akdogan, 2015; Davis and Presno, 2017; Caporale et al. 2018; among others) have addressed the issues of nonlinearity and/or threshold effect in monetary policy rule for developing and emerging economies. Nevertheless, the chapter has added advantage over the preceding studies as it uses a more robust method. This paper extends the analysis of monetary policy conducts in an area not yet explored in the empirical literature as it is the first paper to investigate the conduct of monetary authority within time-frequency domain with Bayesian quantile inference. Last but not the least, the empirical findings are

[58] Aguiar-Conraria, et al., (2008, 2012) argued that monetary authority may simultaneously operate at more than two time-scales (i.e. short and long run) and may particularly be interested in cyclical behaviour of macro-variables across multiple time-scales. Studies (including Gallegati, et al. 2011; Lynch and Zumbach, 2003) also assert that economic and financial processes can be the results of decisions of heterogeneous agents with different time or investment horizons.

[59] When several sets of variations occur in the distribution of the response variable, the conditional mean regression model may unsuccessfully reveal the complete relationship between the response variable and its predictors. The quantile regression techniques overcome this inherent glitch of the standard conditional mean estimators. Besides, Section 3.1 also illustrates the merits of Bayesian quantile inference (implemented via MCMC) over the standard quantile regression.

[60] See Section 3.4 for the overriding advantages of MODWT over DWT.

meant to provide a benchmark for the parameterization of a monetary policy rule in the New Keynesian (NK) models for Ghana and across similar small-open developing economies.

5.1 Relevant Literature on Monetary Policy Rule

5.1.1 Conceptual Framework and Empirical Literature

The estimation of central bank reaction function originated with Taylor (1993, 1999) and was further advanced by Clarida et al (1998, 2000). The fundamental idea is that the central bank set the policy interest rate (i_t) in response to deviation of inflation (π_t) from target ($\bar{\pi}_t$) and output (y_t)from potential ($\bar{y}_t$). The target interest rate is assumed to be determined as follows:

$$\bar{\imath} = \theta_\pi \tilde{\pi}_t + \theta_y \tilde{y}_t \tag{5.1}$$

$\tilde{\pi}_t = (\pi_t - \bar{\pi}_t)$ is CPI inflation; $\tilde{y}_t = (y_t - \bar{y}_t)$ denotes output gap. The positive parameters ζ_π and ζ_y measure interest rate sensitivity to current and/or expected inflation deviation from target, output deviation from potential and exchange rate respectively. The critical point is that the magnitude of parameter θ_π is key. If $\theta_\pi > 1$, the target rate adjusts to stabilize inflation, as well as output (given $\theta_y > 0$). Thus, when inflation increases, the central bank, if it desires to lower aggregate demand and output, needs to raise the real interest rate because what matters to aggregate demand is real but not the nominal interest rate. With $\theta_\pi < 1$, the authority rather accommodates changes in inflation. Thus, the estimated parameter θ_π offers a vital standard for assessing a central bank's policy rule (Clarida, et al, 1998).

The baseline Taylor rule has been criticized that it does not allow central banks to smooth interest rate movements (see, Goodfriend, 1991; Clarida et al., 2000; Rudebusch, 1995). The usual defenses for interest rate smoothing by central banks include fear of unsettling capital markets, loss of credibility from abrupt large policy changes, and the need for consensus building to support a policy change, etc (McCallum, 1999; Clarida et al. 1998, 1999). Consequently, the literature advocates that the actual interest rate tends to adjust slowly and is assumed to be a weighted average of its lagged and the target interest rate:

$$i_t = (1 - \rho_i)\bar{\imath} + \rho_i i_{t-1} + \varepsilon_t \tag{5.2}$$

where $0 < 1 - \varpi_i \leq 1$ represents the speed of adjustment. Substituting (5.1) into (5.2) yields:

$$i_t = \beta + \rho i_{t-1} + (1 - \rho_i)\left[\theta_\pi \tilde{\pi}_t + \theta_y \tilde{y}_t\right] + \mu_{1,t}, \tag{5.3}$$

Equation (5.3) is the baseline linear rule with smoothing parameter. $\rho_i \epsilon [0,1]$ captures the degree of interest rate smoothing; $\beta = (1-\rho_i)\xi$ and $\xi = \bar{\imath} - \theta_\pi \bar{\pi}_t$ where $\bar{\imath}$ is long run equilibrium nominal interest rate; $(1-\rho_i)$ is the speed of adjustment.

Studies (see, Clarida et al. 1998[61], 2000; Gorter et al. 2008) have argued that in the presence of sizeable lags and uncertainty about the transmission mechanism of monetary policy, it is appropriate to allow nominal interest rate to react not only to the current inflation gap but also to expected future deviations of inflation from its target. Therefore a numbers of studies (e.g. Clarida et al, 1998, 2000; Castro, 2011; Caporale et al. 2018; Bleaney et al. 2020; among others) have utilized some versions of a forward-looking Taylor rule as follows:

$$i_t = \beta + \rho_i i_{t-1} + (1-\rho_i)\left[\theta_{1,\pi}\tilde{\pi}_t + \theta_{2,\pi}E_t\tilde{\pi}_{t+j} + \theta_y \tilde{y}_t\right] + \mu_t, \qquad (5.4)$$

E denotes the expectation operator and subscript t indicates that expectations are based on the information set available in period t.

The linear Taylor rule suggests a symmetric policy response to negative and positive deviations of inflation and/or output from target. Taylor (1993) showed that the conduct of monetary policy in the US during the 1980s and early 1990s could be described in a clearly specified linear rule. Subsequent studies (including Taylor, 1999; Orphanides, 2002) find that the standard Taylor rule broadly describes monetary policy behaviour of the Federal Reserve, while others (such Bernanke, 2004; Siegfried, 2010; Taylor, 2013) argued that the adoption of such rule has had significant impact on the performance of the US economy.

However, the validity of the simple linear rule has been tested for other countries and time periods. The recent consensus points to nonlinear and/or threshold effects in the Taylor rule for some economies (e.g. Taylor and Davradakis, 2006; Martin and Milas, 2013; Caglayan et al. 2016). The nonlinear policy reaction function is argued to be as a result of asymmetric central bank preference or objectives (e.g. Gerlach, 2000; Favero et al. 2000; Taylor and Davradakis, 2006; Surico, 2007; Cukierman and Muscatelli, 2008; Martin and Milas, 2013; Castro, 2011; Ahmad, 2016), nonlinear macroeconomic relationships (e.g. Schaling, 1999, 2004; Robert-

[61] Using a forward looking version of Taylor's reaction function, Clarida et al. (1998) estimated monetary policy reaction functions for France, Germany, Italy, Japan, the UK, and the US. The authors report a forward looking behaviour in the policy setting of the central banks of those countries, given their reactions to anticipated inflation. They argue that, based on the outcomes of their investigation, a policy of fixing exchange rates is almost certainly inferior to an inflation targeting one.

Nobay and Peel, 2003; Dolado et al. 2005), fear of the zero lower bound of interest rate (e.g. Adam and Billi, 2006; Kato and Nishiyama, 2005; Orphanides and Wilcox, 2002). In addition to possible asymmetries in the reaction function, another important issue with regard to the conduct of monetary policy is uncertainty (see, Meyer et al., 2001; Leitemo and Soderstrom, 2008; Tillmann, 2010; Dai and Spyromitros, 2012; Guney, 2018; among others). Studies on uncertainty have generally examined its impact via inflation and output on the coefficients of the optimal monetary policy rule. These studies show that the policymaker should respond less to movements in a variable that has higher uncertainty. That is, an increase in inflation uncertainty reduces the optimal inflation coefficient, and increases the output-gap coefficient in a Taylor rule, and vice versa (e.g. Martın and Mılas, 2009; Rudebusch, 2001; Smets, 1999; among others). Other studies have considered the effect of inflation uncertainty on interest rates. On one hand, studies (e.g. Frankel and Lown, 1994; Jorda and Salyer, 2003; among others) found a negative relationship between inflation uncertainty and nominal interest rates based on the loanable funds theory or on the arguments of market frictions. On the other hand, studies (e.g. Chan, 1994; Fama, 1975; Markowitz, 1952; among others) rather found positive relationship between inflation uncertainty and nominal interest rates based on the portfolio theory, the Fisher hypothesis and term structure theory.

More recently, some studies have advocated for an augmented Taylor rule by including other relevant variables that affect the conduct of monetary policy especially in the open economies. According to Clarida et al. (1998, 2000), such practice allows the central bank to take various relevant variables into account when forming its forecast. For instance, additional variables included in the Taylor rule along with inflation and output gaps are exchange rate[62] (e.g. Clarida et al. 1998; Ball, 1999; Svensson, 2000; Dolado et al; 2005; Leitemo and Soderstorm, 2005; Aizenman et al. 2011; Miles and Schreyer, 2012; Akyurek et al., 2011; Akdogan, 2015; Airaudo et al. 2016; Caporale et al., 2018; Bleaney et al., 2020; among others), foreign interest rate (e.g. Clarida et al. 1998; Akyurek et al., 2011), asset price and financial variables (e.g. Bernanke and Gertler, 1999, 2001; Cecchetti et al. 2000; Driffill et al. 2006; Castro, 2011; among others) and monetary aggregates (see, Clarida et al. 1998; Fendel and Frenkel, 2006; and Surico, 2007b).

[62] Ball (1999) argued that including exchange rate in the Taylor rule reduces the variance of the CPI inflation. Debelle (1999) also assert that such augmented rule reduces the unpredictability of output and inflation.

In terms of econometric methodology, the majority of the empirical literature estimates Taylor rules (linear) using the conventional estimation techniques (like GMM, ARDL, logit/probit) that fit a single conditional mean regression curve to the mean part of the response distribution (notable Taylor, 1993; Clarida et al. 2000; Surico, 2003, 2004, 2007; Nelson, 2000; Dolado et al. 2005; Naraidoo and Raputsoane, 2010; Filosa, 2011; Garcia et al. 2011; Takáts, 2012; de Sa and Portugal, 2015; Shrestha and Semmler, 2015; Caporale et al. 2018; Bleaney et al., 2020; among others).

Some studies have also fitted a nonlinear Taylor rule using techniques such as markov switching, threshold GMM regression, smooth transition regression (STR), asymmetric exponential smooth transition autoregressive (AESTAR) models (including, Caporale et al. 2018; Akdogan, 2015; Jawadi et al. 2014; among others). On a whole, these empirical studies have shown evidence of nonlinearity (and threshold effect), policy inertia and the important role of exchange rate in interest rate setting especially in emerging and developing economies (see, Caporale et al. 2018).

On the other hand, empirical studies on Ghana has rather focused on monetary policy effectiveness via the interest rate transmission channel including Abradu-Otoo et al. (2003); Acheampong (2005); Ghartey (2005); Kovaren (2011); Fukac and Baldini (2014); Akosah and Dasah (2014); and Akosah (2015). Indeed, none of these studies specifically estimated MPRF for Ghana. For instance, Acheampong (2005) examined the bank interest rate channel of monetary policy transmission in Ghana for the period September 1994-February 2014. The study concluded that policy shift has some impact on lending rate decisions of the banks but no significant effect on the borrowing rate. Ghartey (2005) also examined the impact of monetary policy on the term structure of interest rate in Ghana during 1994-2004 and reported a significant effect of monetary policy rate on Treasury bill interest rate.

Kovaren (2011) also examined the interest rate pass through of monetary policy in Ghana with dataset spanning the period 2005-2010 using Vector Autoregressive (VAR) framework and simulation techniques. He found a relatively strong short term response of wholesale market interest rate (interbank and treasury bills) to changes in monetary policy rate, but a delayed long term response of the former (interbank rate) to changes in the latter. In addition, Fukac et al (2014) also examined inflation and monetary policy transmission in Ghana during 2007-

2012 and found reduced-form evidences that the interest rate transmission mechanism is now central to keeping inflation in check. They however found a limited signalling ability of monetary policy rate to other money market rates in 12-ordered Vector Auto-Regression (VAR) model.

Using the structural VAR framework, Akosah and Dasah (2015) explored the effectiveness of monetary policy in dampening exchange market pressure induced by fiscal excesses in Ghana over the period 2000Q1-2014Q1. They found sterilization interventions to be more effective than interest rate as a monetary policy tool in moderating tensions in foreign exchange market. Also, utilizing a battery of statistical and econometric techniques, Akosah (2015) examined the effectiveness of monetary policy transmission mechanism in Ghana over the period 2002M1 – 2014M12. The study finds monetary policy rate (MPR) to be fairly effective in signalling the money market interest rates in both the short run and long run, but the effect remains incomplete (that is, not one-to-one) even in the long run. In addition, the study identifies a hierarchy of short-term money market rates in Ghana is identified as follows: Monetary Policy Rate, Treasury bill rate, Interbank rate and retail rates (preferably, lending rate), which emphasized the predominant role of Treasury bill interest rate in the interest rate transmission channel in Ghana. The study further unveils that monetary authority responds positively and contemporaneously to output and inflationary pressures. He finds inflation to be driven mostly by interest rate shock over the medium to long term, while exchange rate shock exerts relatively larger influence on inflation in the short term. In contrast, output was observed to be driven largely by credit and assets prices shocks.

Bleaney et al (2020) investigated whether poor conduct of monetary policy is responsible for the persistently high inflation in Ghana under the IT regime. They estimated several versions of linear policy reaction functions using ordinary least squares (OLS) and ordered logit/probit regression methods. They find that interest rates in Ghana respond in the theoretically recommended manner to inflation shocks in the long run along with high policy inertia.

Other recent empirical studies have however estimated the Taylor rule using frequentist quantile regression (FQR) technique, developed by Keonker and Bassett (1978). Given the set of predictors, the FQR method allows several regression curves to be fitted through many parts of the distribution of a response variable. The spike in this direction is due to the limitation that

the conventional regression models fail to account for possible relationships at the tails, median and other parts of the response distribution. Therefore, if the dynamic links for policy interest rate against inflation and output gaps differ at the tails, these conditional mean estimates may not provide the complete picture of policy response to aggregate demand and supply shocks in the economy. Notable studies in this area include Chevapatrakul and Paez-Farrell, (2014), Wolters, (2012), Chevapatrakul et al., (2009) and Miles and Schreyer (2012).

For instance, Chevapatrakul and Paez-Farrell (2014) employed versions of quantile regressions (2SQR and Bootstrapping Quantile regression) to estimate monetary policy rule for three small open economies including Australia, Canada and New Zealand. Their study spans the beginning of inflation targeting for each economy (i.e. June 1991 for Australia and New Zealand, and January 1993 for Canada) to the end of December 2007. They find evidence of asymmetric interest rate response for all the three economies. Specifically, they find that monetary policy across the selected countries react more aggressively to inflation when interest rate are high than when they are low. Besides, more weight is placed on positive deviations of inflation from its target than negative deviations. On the contrary, the interest rate response to output gap is largely symmetric and small across the selected economies.

Using real-time data, Wolters (2012) also employed standard and inverse quantile regression techniques (IVQR proposed by Chernozhukov and Hansen, 2005) to estimate MPRF for the US Federal Reserve over the period 1969Q4 – 2005Q4. The study unveils clear evidence of nonlinear relationship between the interest rate, inflation, output gap and the lagged interest rate. The study also detects significantly high interest rate smoothing by the US Fed for the sample period. More so, the study found policy parameters to fluctuate significantly and systematically over the conditional distribution of the Fed fund rate.

In addition, Chevapatrakul, Kim and Mizen (2009) employed two-stage quantile regression to estimate the MPRF for the US and Japan based on respective data span October 1979 – September 2005 and May-1979 – January 1999. They find that both countries upheld the Taylor principle and also respond aggressively to inflation at the higher quantiles. In general, they also find evidence of more aggressive policy response to inflation in Japan compared to the USA. Yet, they find no detectable evidence of increasing aggression when approaching the zero lower bound in both countries. However, their model did not include lagged interest rate to ascertain

possible interest rate inertia. Besides focusing predominantly on the USA and other advanced economies, these quantile estimates have primarily concentrated on time-domain analysis (only two time scales). Consequently, they provide virtually no information about the frequency at which the macroeconomic interactions occur[63], implying a dearth of studies that precisely evaluates and quantifies MPRF using more than two time-scales.

Miles and Schreyer (2012) also examined the policy rules for the central banks of four Asian countries, namely Thailand, Malaysia, Korea and Indonesia using quantile regression analysis. They found evidence of nonlinearities but some cross-country differences. Particularly, they found that central bank in Indonesia does not respond to the output gap in the lower quantiles (20th and 40th), while the monetary authorities in Korea respond to it in both lower and higher quantiles. Their study also found that only the central banks of Malaysia and Indonesia react to exchange rate fluctuations.

Another stream of researches (notably Aguiar-Conraria et al, 2008, 2012) have applied novel technique that analyses dynamic relationship between interest rate, inflation and output gaps at the time-frequency domain. The recent surge in time-frequency analysis in finance and economic literature is premised on the view that preceding analysis only focus on macroeconomic interaction change over time (i.e. short run and long run) which overlook the informational value of frequency domain analysis (i.e. how signal or relationship is distributed over a range of frequencies). Aguiar-Conraria, et al., (2008, 2012) argued that monetary authority may simultaneously operate at more than two time-scales and particularly interested in cyclical behaviour of macro-variables across multiple time-scales. In addition, economic and financial processes can be the results of decisions of heterogeneous agents with different time or investment horizons, justifying the relevance of time-frequency analysis (see Gallegati, et al, 2011; Lynch and Zumbach, 2003). Therefore, time-domain analysis does not provide the complete picture of interactions between policy and macroeconomic variables. Although Aguiar-Conraria et al (2008, 2012) applied wavelet technique to examine the causal links between interest rate and macroeconomic variables, their study did not specifically quantify the magnitude of response of policy rate to macroeconomic shocks.

[63] It is well acknowledged that monetary authority may simultaneously operate at more than two timescales (see, Aguiar-Conraria, et al., 2008, 2012; Gallegati, et al, 2011).

Notwithstanding, the bulk of the preceding MPRF studies have extensively focused on time-domain analysis, and had overlooked the dynamic interaction of policy interest rate and macroeconomic shocks in frequency-domain. Besides, no MPRF study at time-frequency spectrum is apparent in the extant literature on Ghana. Consequently, the thesis is unique as it provides both the direction and magnitude of policy responses to macroeconomic shocks in historical time-interval and time-frequency domain. In addition, the focus on frontier/developing economies contributes to the extension of the literature on asymmetric and time-frequency domain analysis to the frontier and developing IT economies. Besides, this chapter differs substantially from the preceding works of Chevapatrakul et al, (2009), Wolters, (2012) and Chevapatrakul and Paez-Farrell, (2014) which focused solely on versions of Frequentist QR. This is because the thesis explores versions of Bayesian QR with wavelet multi-resolution framework (time-frequency domain), an approach which is generally acclaimed to be robust. To the best of knowledge, this is the first attempt in the extant empirical literature to employ versions of Bayesian quantile techniques alongside wavelet multi-resolution framework for the estimation of MPRF.

5.2 Empirical Taylor Rule Investigated

5.2.1 Linear Taylor Rule

Assuming that the actual interest rate tends to adjust slowly and is assumed to be a weighted average of its lagged and the target interest rate, we estimate a baseline linear rule with smoothing parameter as:

$$i_t = \beta + \rho i_{t-1} + (1-\rho_i)\left[\theta_\pi \tilde{\pi}_t + \theta_y \tilde{y}_t\right] + \mu_{1,t}, \quad (5.1)$$

where $\rho_i \epsilon [0,1]$ captures the degree of interest rate smoothing; $\beta = (1-\rho_i)\xi$ and $\xi = \bar{\imath} - \theta_\pi \bar{\pi}_t$ where $\bar{\imath}$ is long run equilibrium nominal interest rate; $(1-\rho_i)$ is the speed of adjustment. $\tilde{\pi}_t = (\pi_t - \bar{\pi}_t)$ denotes CPI inflation deviation from target; $\tilde{y}_t = (y_t - \bar{y}_t)$ denotes output gap. The positive parameters θ_π and θ_y measure interest rate sensitivity to current and/or expected inflation deviation from target, output deviation from potential and exchange rate respectively. The critical point is the magnitude of parameter θ_π is key. If $\theta_\pi > 1$, the target rate adjusts to stabilize inflation, as well as output (given $\theta_y > 0$). Thus, when inflation increases, the central bank, if it desires to lower aggregate demand and output, needs to raise the real interest rate because what matters to aggregate demand is real but not the nominal interest rate. With $\theta_\pi < 1$, the authority rather accommodates changes in inflation. Thus, the estimated parameter θ_π

offers a vital standard for assessing a central bank's policy rule (Clarida, et al, 1998). Due to the presence of sizeable lags and uncertainty about the transmission mechanism of monetary policy (e.g. Clarida et al, 1998, 2000; Castro, 2011; Caporale et al. 2018; Bleaney et al. 2020; among others), we also estimate an alternative forward-looking Taylor rule as follows:

$$i_t = \beta + \rho_i i_{t-1} + (1 - \rho_i)\left[\theta_{1,\pi}\tilde{\pi}_t + \theta_{2,\pi}E_t\tilde{\pi}_{t+j} + \theta_y\tilde{y}_t\right] + \mu_t, \quad (5.2)$$

E denotes the expectation operator and subscript t indicates that expectations are based on the information set available in period t.

Following the recent studies, we include additional variables that are considered to affect the conduct of monetary policy in Ghana. In this case, we first consider whether the Bank of Ghana takes US monetary policy as external constraints and this is done in two ways. We first introduce changes in cedi/US dollar into the BOG reaction function to account for imported inflation. The related issue is that the MPC in Ghana meets every two months (i.e. bimonthly) to determine the positioning of interest rate. We consider that the exchange rate may react to the interest rate decision after the meetings of the MPC. Therefore, we use lagged (instead of current) exchange rate in the Taylor rule as in Bleaney et al (2020). We then consider the US federal fund rate in the monetary policy reaction function for Ghana. Lastly, we examine the influence of monetary aggregate in the policy rule using the deviation of broad money growth from trend (HP trend) as Ghana is predominantly a cash-based economy. Then equation (4) based on current inflation becomes

$$i_t = \beta + \varpi_i i_{t-1} + \zeta_\pi\tilde{\pi}_t + \zeta_y\tilde{y}_t + \zeta_{\mathrm{x}}\mathrm{x}_{i,t} + \mu_t, \quad (5.3)$$

$\mathrm{x}_{i,t}$ is vector of other variables relevant; ζ_{x} denotes the sensitivity of interest rate to other relevant variables included in the Taylor rule besides inflation and output gaps; β, ϖ, and ζ_π are composite parameters. All parameters are expected to be positive. Using expectation in Equation (5.3) becomes:

$$i_t = \beta + \varpi_i i_{t-1} + \left[\zeta_{1,\pi}\tilde{\pi}_t + \zeta_{2,\pi}E_t\tilde{\pi}_{t+j} + \zeta_y\tilde{y}_t + \zeta_{\mathrm{x}}\mathrm{x}_{i,t}\right] + \mu_t, \quad (5.4)$$

where $\mathrm{x}_{i,t}$ is a vector of other relevant variables for the conduct of monetary policy in Ghana.

5.2.2 Nonlinear Taylor Rule

The preceding linear Taylor rule purports symmetric policy response to inflation and output irrespective of their trajectories from the desired levels. However, several studies have provided theoretical foundations for asymmetry in the reaction function of monetary

authorities. In addition, more recent studies (e.g. Taylor and Davradakis, 2006; Surico, 2007; Cukierman and Muscatelli, 2008; Aguiar and Martins, 2008; Martin and Milas, 2013; Castro, 2011; Ahmad, 2016; Caporale et al. 2018, among others) have given empirical evidences for nonlinearities and threshold effects in the reaction of monetary authority to inflation and output gaps. Given the escalating evidence of likely nonlinearities in the reaction function of central banks, we consider possible nonlinearities in the monetary policy reaction function for Ghana. Consequently, we first consider the possibility that monetary policy reaction differs at different phases of output and inflation gaps. This is carried out by splitting latter datasets into positive and negative deviations from target (or potential) level.

However, the chapter initially estimates a nonlinear monetary policy rule in a fashion derived by Dolado et al., (2005)[64]:

$$i_t = \alpha + \tau_i i_{t-1} + \zeta_\pi \tilde{\pi}_{t+p} + \zeta_y \tilde{y}_t + \zeta_\Gamma \Gamma_t + \zeta_{y\pi}\left(\tilde{\pi}_{t+p}\tilde{y}_t\right) + \mu_{1,t}, \tag{5.5}$$

where ζ_s are policy response parameters; $\tilde{\pi}_t$ is inflation deviation from target; $\tilde{y}_t$ is output gap; Γ_t is a predetermined/exogenous variable possibly capturing other determinants of interest rate setting in open economies (see, Ball, 1999); $\mu_{1,t}$ is an independent and identically distributed

[64] For detailed derivation of equation (5.2), interested readers are kindly referred to Dolado et al (2005). Assuming a quadratic per-period loss function in inflation and output performance, $L(\tilde{\pi}_t, \tilde{y}_t) = \left[\frac{1}{2}(\tilde{\pi}_t^2 + \lambda \tilde{y}_t^2)\right]$ and a fixed discount rate (φ), they assume policy makers objective in period t is to minimize the expected present discounted values of the per-period losses:

$$E_t \sum_{p=0}^{\infty} \varphi^p \; L(\tilde{\pi}_{t+s}, \tilde{y}_{t+s}) \tag{a}$$

subject to the following two equations describing the evolution of the economy:

$$\pi_{t+1} = \pi_t + \gamma f(y) + \varepsilon_{\pi,t+1} \tag{b}$$

with

$$f(y) = [\tilde{y}_t + \omega \tilde{y}_t^2]; \quad \tilde{y}_t > -{}^1\!/_2\, \omega$$

and

$$\tilde{y}_{t+1} = \vartheta \tilde{y}_t - \psi r_t + \phi \Gamma_t \; + \varepsilon_{y,t+1}, \tag{c}$$

with

$$r_t = i_t - \pi_{t+1};$$

where E_t is the conditional expectation operator, φ and $\vartheta \in [0,1)$ while $\varepsilon_{\pi,t+1}$ and $\varepsilon_{y,t+1}$ are zero-mean normally distributed shocks. Equation (a) is the accelerationist AS or Philips curve where output enters in a nonlinear way. Equation (b) becomes linear when $\omega = 0$ but yields a convex (concave) Philips curve when $\omega > 0$ ($\omega < 0$). Equation (c) is an aggregate demand function (IS curve) where output gap has an AR (1) process but also depends on real interest rate (r_t), exogenous economic variables (Γ_t) and interaction of expected inflation and the output gap. The model assumes real interest rate to affect output gap with a one-period lag and also impact inflation (in a nonlinear fashion) with a two-period lag, as in Christiano et al., (1999). Although Schaling (1999, 2004) also applied nonlinear Philips curve, he assumed zero weight for output stabilization (i.e. $\lambda = 0$) in the policy objective function (i.e. a pure inflation targeting). While Svensson (1997) has a loss function with intrinsic weight on output stabilization, he rather assumed a linear Philips curve.

(iid) error term. The constant (i.e. $\alpha = \bar{r} + \bar{\pi}$) in the empirical policy rule corresponds to the sum of the long-run real interest rate and the inflation objective in equation (5.5).

The empirical application of the policy rule derived by Dolado et al (2005) in the Ghanaian context is motivated by two main factors. First is the inclusion of an exogenous term, (Γ_t) which allows for the introduction of other key variables, preferably exchange rate volatility (or changes) to capture the small-open economy characteristics of Ghana. Second motivation is the interaction term in (5.5) which can intuitively be interpreted as an asymmetric policy response to output gap spillovers to expected inflation. The modified nonlinear Taylor rule in (5.5) resembles the linear one except the interaction term. The economic intuition behind the interaction term is simple. Given the extent of persistence (serial correlation), a positive output gap at time t is likely to remain positive at time $t+1$ and this will results in higher inflationary pressures at time $t+2$. In the case of linear Taylor rule, the policy maker is expected to increase interest rate by ζ_π. Nevertheless, if the Philips curve is convex[65] ($\zeta_{y\pi} > 0$) then the future inflationary pressures induced by the higher output gap will turn out to be larger than in the linear case. With a looming higher inflationary pressures depicted by the interaction term ($\tilde{\pi}_{t+p}\tilde{y}_t$), the policymaker is expected to react more aggressively. On the contrary, if the future inflationary pressure is expected to be lower in the case of concave Philips curve than in the linear Taylor rule, then monetary authority responds by increasing interest rate marginally ($\zeta_{y\pi} < 0$).

Nevertheless, the implied quadratic loss function in equation (5.5) suggests that monetary authorities symmetrically (evenly) weight positive and negative deviations of inflation and output from their respective targeted values. Studies including Clarida et al (1999), Woodford (1998, 1999 and 2000), Rotemberg and Woodford, (1999), Di Bartolomeo et al (2016) and among others have presented a theoretical justification for this approach[66]. But, the hypothesis that the coefficients of policymaker's loss function may not be identical across different states of the macroeconomy has also received mammoth interest in the contemporary macroeconomic literature. First, the presumed symmetric weights on positive and negative shocks implied by

[65] Convexity can be described by the traditional Keynesian assumption that nominal wages are flexible upwards but rigid downwards, so that inflation is an increasing function of the output gap (see, Tambakis, 2009).
[66] Besides, several studies including King et al. (2016) have also proposed quadratic objective function as a way of evaluating alternative targeting schemes and drawn implicit policy recommendations.

the quadratic loss function have been questioned by several practitioners at the policy committees of various central banks on the ground that it has little support beyond analytical flexibility[67]. Besides, studies such as Schaling (2004), Dolado et al. (2005) and Garcia-Iglesias et al., (2013) argue that the asymmetry in central bank can stem from the existence of a nonlinear (convex) Philip curve. In view of this, some researchers[68] have explored innovative mechanisms to reflect the asymmetric preference of monetary policy preference to inflation and output deviation from the respective desired levels. Following the literature, we also explore potential asymmetric policy response to output gap and inflation deviation from target by utilizing equation (5.6):

$$i_t = \alpha + \tau_i i_{t-1} + \zeta_{\pi p}\tilde{\pi}^{+}_{t+p} + \zeta_{\pi n}\tilde{\pi}^{-}_{t+p} + \zeta_{yp}\tilde{y}^{+}_{t} + \zeta_{yn}\tilde{y}^{-}_{t} + \zeta_{\Gamma}\Gamma_t + \zeta_{y\pi}Z_t + \mu_{2,t}, \quad (5.6)$$

where $\zeta_{\pi p}$ and $\zeta_{\pi n}$ represent relative policy response to positive ($\tilde{\pi}^{+}_{t+p}$) and negative ($\tilde{\pi}^{-}_{t+p}$) inflation gap respectively; ζ_{yp} and ζ_{yn} represent relative policy response to positive ($\tilde{y}^{+}_{t}$) and negative ($\tilde{y}^{-}_{t}$) output gap respectively; Z_t denotes the interaction terms $(\tilde{\pi}_{t+p}\tilde{y}_t)$; $\mu_{2,t}$ is similarly an independent and identically distributed (iid) error term. $p \in [-1, 4]$ such that $p = -1$ implies a "backward looking" Taylor rule as it does not explicitly allow for monetary policy responses to expected current or future output gap and inflation while $p \geq 1$ implies "forward looking" Taylor rule as it explicitly permits for monetary policy responses to expected current or future output gap and inflation (see, Clarida et al, 1998; Nelson, 2000).

The corresponding time-frequency specifications of equations (5.5) and (5.6) are as follows:

$$(s_j)i_t = (s_j)\alpha + \tau_i(s_j)i_{t-1} + \zeta_{\pi}(s_j)\tilde{\pi}_{t+p} + \zeta_{y}(s_j)\tilde{y}_{t+p} + \zeta_{\Gamma}(s_j)\Gamma_t + \zeta_{z}(s_j)Z_t + \mu_{1,t}, \quad (5.7)$$

$$(s_j)i_t = (s_j)\alpha + \tau_i(s_j)i_{t-1} + \zeta_{\pi p}(s_j)\tilde{\pi}^{+}_{t+p} + \zeta_{\pi n}(s_j)\tilde{\pi}^{-}_{t+p} + \zeta_{yp}(s_j)\tilde{y}^{+}_{t+p} + \zeta_{yn}(s_j)\tilde{y}^{-}_{t+p} + \zeta_{\Gamma}(s_j)\Gamma_t + \zeta_{z}(s_j)Z_t + \mu_{2,t}, \quad (5.8)$$

where s_j denotes wavelet time-scale data; $j = 1,2,3$ with 1 denoting shorter time-scale, 2 for medium time-scale and 3 for longer time-scale. The specifications in equations (5.7) and (5.8) thus imply that each Taylor-type rule yields the estimates for MPRF at the short run, medium run and long run.

[67] Notable studies include Blinder (1996), Mishkin and Posen (1997), Goodhart (1999), Cukierman (1999) and Orphanides and Wilcox (2002), etc.

[68] These include Varian (1974), Nobay and Peel (1998), Schaling (1999, 2004), Ruge-Murcia (2003), Surico (2007), Cukierman and Muscatelli (2008), Horvath (2008), Aguiar et al., (2008), Naraidoo and Raputsoane (2010), Klose (2011), Kobbi (2013), Komlan (2013), Garcia-Iglesias et al. (2013), de Sa and Portugal (2015) among others)

5.3 Estimation Techniques

5.3.1 Conditional Mean Estimation Method

Let v_t denotes a vector of instruments known when i_t is set (i.e. $v_t \epsilon\, \Omega_t$). Equations (5.1) to (5.8) then imply the set of orthogonality conditions:

$$E(\mu_{g,t}) = 0, \tag{5.9}$$

$$E\left(\mu_{g,t}\, v_t\right) = 0, \qquad g \in (1,2,3,4,5,6,7,8) \tag{5.10}$$

Equations (5.9) and (5.10) provide the basis for the estimation of the parameters $(\tau_i, \zeta_\pi, \zeta_y, \zeta_\Gamma, \zeta_z, \zeta_{\pi p}, \zeta_{\pi n}, \zeta_{yp}, \zeta_{yn})$ using Generalized Method of Moments (henceforth, GMM), with an optimal weighting matrix that accounts for possible serial correlation in $\mu_{g,t}$ for $g = 1,2,3,4,5,6,7,8$. Next, a Hansen test is employed to test the validity of the over-identification restriction. In addition, we carried out endogeneity test on key variables including inflation gap, output gap and exchange rate in order to satisfy equation (5.10). As often applied in the empirical literature, the lags of the selected macroeconomic variable were chosen as instruments for this analysis. For robustness, however, we adopt a systematic approach by fitting several models using (i) the level and wavelet time-scale datasets based on either aggregated or segregated datasets, and (ii) models with and without lagged interest rate.

5.3.2 Quantile Regression Approach

The conventional generalized linear models fit a single conditional mean regression curve to the mean part of the response distribution in a bid to establishing a relationship between response variable and its predictors. In a situation whereby several sets of changes exist in the distribution of the response variable, the conditional mean regression model may fail to display the entire relationship between the response variable and its predictors. In view of this limitation, Keonker and Bassets in the 1970s introduced quantile regression (QR) techniques as an alternative approach to the conventional conditional mean regression model. Given a set of predictors, the QR method allows for several regression curves to be fitted through many parts of the distribution of a response variable.

Consider T observations $\{i_t\}_{t=1,..,T}$ of the monetary policy interest rate conditional on the inflation deviation from target $(\tilde{\pi}_t)$ and output gap $(\tilde{y}_t)$. The conditional α^{th} quantile function

of i_t given i_{t-1}, $\tilde{\pi}_t$, and $\tilde{y}_t$ in the baseline model (5.1) represented by $\Gamma_\alpha(i_t|i_{t-1}, \tilde{\pi}_t, \tilde{y}_t)$, is defined as

$$\int_{-\infty}^{\Pi_\tau(i_t|i_{t-1},\tilde{\pi}_t,\tilde{y}_t),} g_{i_t|i_{t-1},\tilde{\pi}_t,\tilde{y}_t}(i_t|i_{t-1}, \tilde{\pi}_t, \tilde{y}_t) = \tau, \quad (5.11)$$

where $g_{i_t|i_{t-1},\tilde{\pi}_t,\tilde{y}_t}(i_t|i_{t-1}, \tilde{\pi}_t, \tilde{y}_t)$ is the conditional quantile function (density) of the response variable, i_t, at time t given i_{t-1}, $\tilde{\pi}_t$, and $\tilde{y}_t$; $\tau \in [0, 1]$. When $\tau = 0.5$, equation (5.11) is simply the conditional median function of i_t given $\tilde{\pi}_t$ and $\tilde{y}_t$. The parameters ϖ_τ $\zeta_{y,\tau}$ and $\zeta_{\pi,\tau}$ are allowed to vary with α and measure the degree of responsiveness of i_t (the policy interest rate) to i_{t-1}, $\tilde{\pi}_t$, and $\tilde{y}_t$ respectively when i_t is located at the τth quantile of the conditional distribution. For a fixed value of α, the parameters ϖ_τ, $\zeta_{\pi,\tau}$, and $\zeta_{y,\tau}$ are estimated through minimization:

$$\min_{\varphi_\tau,\beta_\tau,\theta_\tau,} \sum_{t=1}^{T} \rho_\tau \left((w_j) i_t - \left[\beta_\tau + \varpi_\tau(w_j) i_{t-1} + \zeta_{\pi,\tau}(w_j) \tilde{\pi}_{t|t} + \zeta_{y,\tau}(w_j) \tilde{y}_{t|t} \right] \right) \quad (5.12)$$

Where w_j for $(j = 1, 2, 3)$ is similarly defined as the wavelet decomposed time scale series based on MODWT with asymmetric filter (LA8). So for QR analysis based on the level dataset, $w_j = 1$ and it disappears from equation (5.12). The loss function $\rho_\tau(\varepsilon)$ is defined as

$$p_\tau(\varepsilon) = \varepsilon\left[\tau - I_{(\varepsilon \leq 0)}\right] \quad (5.13)$$

and the model's residuals, $I_{(\varepsilon \leq 0)}$, are formulated as an indicator function taking two values:

$$I_{(\varepsilon \leq 0)} = \begin{cases} 1 & for\ \varepsilon \leq 0 \\ 0 & otherwise \end{cases} \quad (5.14)$$

According to Keonker and Hallock (2001), $\rho_\tau(\varepsilon)$ effectively imposes different weight on positive and negative residuals and when $\tau = 0.5$ it is the median estimator.

The BQR has also been documented in the recent researches but its empirical application for policy dynamics remains scanty (see, Yu and Moyeed, 2001; Boako et al, 2015; among others). Our preference of BQR at the expense of the frequentist approach is motivated by the following factors; (i) BQR provides precise estimations which properly account for parameter uncertainty; (ii) BQR does not hinge on approximations to the asymptotic variances of the estimators; (iii) it inherently corrects for model complexity in terms of model selection; and (iv) although the QR formation does not have a standard prior distribution, the Bayesian technique implemented through the Markov Chain Monte Carlo (MCMC) method adequately extract the marginal and joint posterior distributions of unknown parameters (see, Yu and

Moyeed, 2001). According to Yu and Moyeed (2001), the minimization of the loss function, $p_\alpha(\varepsilon)$, in (4.13) is largely akin to the maximization of the likelihood function which is obtained by putting together independently distributed asymmetric Laplace densities. Thus, given the response variable, $i_t = \{i_1, i_2, i_3, \dots, i_n\}$ and the posterior distribution of ψ, we express the density function, $\Gamma_\alpha(i_t|i_{t-1}, \tilde{\pi}_t, \tilde{y}_t, x_t)$, of the beta coefficients at the chosen nine quantiles, ψ^α, as

$$\Gamma_\alpha(i_t|i_{t-1}, \tilde{\pi}_t, \tilde{y}_t: \alpha) \propto L(i_t|i_{t-1}, \tilde{\pi}_t, \tilde{y}_t).\, p(\psi) \tag{5.15}$$

where $p(\psi)$ is the prior distribution of ψ and $L(i_t|i_{t-1}, \tilde{\pi}_t, \tilde{y}_t)$, denotes the likelihood function and is given by

$$L(i_t|i_{t-1}, \tilde{\pi}_t, \tilde{y}_t) = p^n(1-p)^n \exp\left\{-\sum_{t=1}^{n} p\left(i_t - \left[i_t|i_{t-1}, \tilde{\pi}_t, \tilde{y}_t\right]'\psi^q\right)\right\} \tag{5.16}$$

Due to the shorter sample size, we exclude $\alpha < 30th$ in the analysis. Therefore, in this chapter, the lower quartile entails $\alpha \in (30, 40)$, the median encompasses $\alpha = (50th, 60th)$ and the upper quartile covers $\alpha \geq 75th$ in a bid to establishing a more dynamic policy response function for Ghana.

The BQR estimates based on equation (5.11) assumes no endogeneity problem even though it is widely agreed that macroeconomic variables such as interest rate, output gap inflation and exchange rate are highly interrelated. For instance, a high pass through of exchange rate to prices in Ghana is highlighted by Loloh (2014) and Akosah (2015). Therefore, the inclusion of exchange rate in equation (5.3) introduces endogeneity problem, causing bias in the quantile estimators $\hat{\beta}_\alpha$, $\hat{\theta}_\alpha$ and $\hat{\gamma}_\alpha$ (see, Kim and Muller, 2008). In addition, the literature clearly underscores inflationary pressures emanating from aggregate demand (see, Dolado et al. 2005). Against this background, we apply the two-stage quantile regression (2SQR) methodology proposed by Kim and Muller (2008) and Powell (1983) to address potential endogeneity problems. In this approach, we first regress both inflation and output gap on a set of instruments and generate fitted values, $\breve{\pi}_t$ and $\breve{y}_t$ respectively using the generalized methods of moments (GMM) technique. Second, policy interest rate (i_t) is then regressed on the fitted values generated for both inflation and output gap from the first step using quantile regression technique; $i_t = f(\breve{\pi}_t, \breve{y}_t)$. Kim and Muller (2004) however show that the slope coefficients are unbiased while the intercept is biased. Consequently, we do not discuss the intercept in this chapter. However, due to the fact that the explanatory variables in the two-stage quantile regression are forecasted from the first-stage estimation instead of the true values, the standard

errors of the estimates may be biased. Therefore, we apply heteroskedasticity and autocorrelation consistent (HAC) covariance weighting matrix for the first-stage GMM estimation as well as MCMC for the second-stage Bayesian quantile estimation to ensure more robust standard errors.

Using spline quantile regression method, the corresponding conditional α^{th} quantile function of i_t given the baseline nonlinear rules are defined as

$$\int_{-\infty}^{\Pi_\tau(i_t|i_{t-1},\tilde{\pi}_t^+,\tilde{\pi}_t^-,\tilde{y}_t^+,\tilde{y}_t^-),} g_{i_t|i_{t-1},\tilde{\pi}_{t+p},\tilde{y}_{t+p}}(i_t|i_{t-1},\tilde{\pi}_t^+,\tilde{\pi}_t^+,\tilde{y}_t^+,\tilde{y}_t^-) = \tau, \quad (5.17)$$

where $\tilde{\pi}_t^+ = \tilde{\pi}_t(\pi^p)$; $\tilde{\pi}_t^- = \tilde{\pi}_t(\pi^n)$ $\tilde{y}_t^+ = \tilde{y}_t(y^p)$; $\tilde{y}_t^- = \tilde{y}_t(y^n)$ with π^p, π^n y^p and y^n represent knot dummy variables defined respectively as;

$$\pi^p = \begin{cases} 0 & if\ \tilde{\pi}_t < 0 \\ 1 & if\ \tilde{\pi}_t > 0 \end{cases}; \pi^n = \begin{cases} 1 & if\ \tilde{\pi}_t < 0 \\ 0 & if\ \tilde{\pi}_t > 0 \end{cases}; y^p = \begin{cases} 0 & if\ \tilde{y}_t < 0 \\ 1 & if\ \tilde{y}_t > 0 \end{cases}; \text{ and } y^n = \begin{cases} 1 & if\ \tilde{y}_t < 0 \\ 0 & if\ \tilde{y}_t > 0 \end{cases}$$

From equation (4.16), the parameters $\zeta_{\pi p}$ and $\zeta_{\pi n}$ represent the coefficients for policy reactions to positive ($\tilde{\pi}_t^+$) and negative ($\tilde{\pi}_t^-$) inflation gap respectively, while ζ_{yp} and ζ_{yn} denote the relative policy responses to positive ($\tilde{y}_t^+$) and negative ($\tilde{y}_t^-$) output gap.

5.3.3 Standard Threshold Regression

We note that equation (5.17) just determines whether there is an asymmetric policy response to either inflation gap or output gap, but does not specifically points to a particularly threshold level. Consequently, we later apply the standard threshold regression technique developed by Hansen (1999) which endogenously determines the threshold value of the chosen variable along with the other parameters in the model as follows:

$$i_t = \begin{cases} Z_t'\theta_1 + e_t & if\ \ q_t < \gamma_1 \\ Z_t'\theta_2 + e_t & if\ \ q_t \geq \gamma_1 \end{cases} \quad (5.18)$$

where Z denotes variables with regime-specific coefficients; q_t is the observable threshold variable which is inflation rate; γ is an optimal threshold value of the chosen q_t variable defining the high/low regime of the model and is estimated endogenously along with the other parameters (Martin and Milas, 2013); θ_1 and θ_2 denote low and high regime coefficients respectively; e_t is the error term. Following Hansen (1999, 2011), we combine the j individual regime specifications into a single equation by using an indicator function $I_j(q_t, \gamma) = 1(q_t \geq \gamma)$ which takes the value 1 if the expression is true and 0 otherwise:

$$i_t = \sum_{j=0}^{m} 1_j(q_t, \gamma) \, . \, Z_t' \theta_j + e_t \tag{5.19}$$

From equation (5.19), the optimal threshold value γ for the selected q_t and the coefficients θ_j are estimated by minimizing a sum-of-squares objective function (SSRs):

$$S(\theta, \gamma) = \sum_{t=1}^{T} \left(i_t - \sum_{j=0}^{m} 1_j(q_t, \gamma) \, . \, Z_t' \theta_j \right)^2 \tag{5.20}$$

We employ the global estimation of threshold method developed by Bai-Perron (1998) which compares the SSRs of all possible set of m threshold values. Due to the small sample size, we use a trimming percentage of 25 and a maximum of 1 threshold at 99% confidence level (i.e. 0.01% alpha level). We focus on a threshold response to inflation since central banks might respond more aggressively when inflation overshoot than when it undershoot its target (see, Chevapatrakul and Paez-Farrell, 2014; Akdogan, 2015; Caporale et al. 2018). For robustness, the following threshold Taylor rule specifications are also considered in this paper: (i) a simple rule (see, Taylor, 1993), (ii) a forward-looking rule (following Clarida et al. 1998, 2000), (iii) augmented contemporaneous rule including the lagged and current exchange rate (following Ball, 1999; Svensson, 2000; Taylor, 1999, 2001; Caporale et al, 2018; among others) and (iv) augmented forward-looking rule that includes the expected and current inflation gap as well as lagged and current exchange rate.

5.3.4 Marginal posterior inclusion probability (MPIP) technique

Since additional variables are included in equation (5.2), the marginal posterior inclusion probability (MPIP) technique is further utilized to assess the relevance of each variable in the monetary policy rule for Ghana. The Bayesian MPIP is a Marko Chain Monte Carlo (MCMC) generated ranking measure to see how much the data favours the inclusion of a particular variable j in the regression. Suppose we have a usual full normal linear model

$$y = Z\omega + v \tag{5.21}$$

where y is the $k \; x \; 1$ vetor of observed values of the response variable, Z is the $k \; x \; n$ $(n < k)$ full rank matrix of covariates, and ω is a $n \; x \; 1$ unknown coefficients vector; and v is the coordinates of random error vector, each assumed to be independent and normally distributed with mean 0 and common (known or unknown) variance σ^2. The usual least squares estimator

for equation (5.21) is expressed as: $\hat{\omega} = (Z'Z)^{-1}Z'y$. Given the full model (in equation 5.21), we consider selecting M_I from among sub-models using the following

$$M_I: y = Z_I\omega_I + v \tag{5.22}$$

where $I = l_1, l_2, \ldots l_n$ is the model index, l_i being either 1 of 0 a covariate Z_i is in or out of the model (or if ω_i is set equal to zero); Z_I comprises the columns of Z corresponding to the nonzero coordinates of I; and I is the corresponding vector of regression coefficients. Since the selected model is used to predict the future observation, y^*, we minimize a squared error loss in predicting y^* by $\hat{y}^*$ as:

$$L(\hat{y}^*, y^*) = (\hat{y}^* - y^*)^2 \tag{5.23}$$

Using Bayesian MCMC schemes, the overall posterior probability that variable i is in the model (i.e. the posterior inclusion probability) is given by

$$p_i \equiv \sum_{I:l_j=1} P(M_I|y), \tag{5.24}$$

If variable $\boldsymbol{j}$ exists, the median probability model $\boldsymbol{M_I^*}$ is defined to be the model consistent of those variables whose marginal posterior inclusion probability is at least $\mathbf{1/2}$. Precisely, $\boldsymbol{I}^*$ is defined by

$$I_j^* = \begin{cases} 1, & \text{if } p_i \geq \frac{1}{2} \\ 0, & \text{otherwise} \end{cases} \tag{5.25}$$

Following Barbieri and Berger (2004), we apply MCMC model scheme to determine the median probability model. In this case, a Markov chain is developed to move between the models and the posterior probability of a model is estimated by the fraction of the time that the model is visited by the chain. Therefore, the median posterior probability of a variable in a model is determined by the fraction of the time that each variable is present in the visited models. At the end of the MCMC simulations, those variables for which the fraction exceeds 1/2 are chosen. According to Barbieri and Berger (2004), determining the median probability model in this manner is computationally simpler than finding the highest posterior probability model. In the chapter, the MCMC method extracts the marginal and joint posterior distributions of parameters for the selected macro-variables based on bootstrapping with 50000 replications.

5.3.5 **Levels and Scaled (Transformed) Datasets**

We employed the same level and transformed quarterly datasets as in Chapter three, spanning the period 2001Q1-2017Q4[69], for the analysis of MPRF for Ghana. The choice of the variables is purely based on the literature on MPRF. The variables are nominal interest rate, consumer inflation gap[70], real GDP (or output) gap, changes in nominal and real bilateral exchange rate. Official monetary policy rate (MPR) is used as the nominal interest rate and is computed as quarterly average. The use of quarterly MPR is appropriate as the MPC meeting is generally bi-monthly. Therefore, our quarterly MPR reflects policy decisions from at least one of the six MPC meetings in a year, often slated for the months of January, March, May, July, September and November. Besides, the highest frequency for real GDP in Ghana is quarterly. With the exception of MPR, all the remaining variables are seasonally adjusted and are in logarithmic terms.

The time-frequency analysis in this chapter used the corresponding transformed quarterly datasets as in the previous chapter. As illustrated in Section 3.3.2 of the preceding chapter, the highest decomposition level for j is $j = \log_2(n) = \log_2(68) = 6$. This reflects 6 maximum levels of data points. Therefore, the periods associated with the desired wavelet coefficients of scale $\psi_j = 1, \ldots, 6$ respectively include 2~4 quarters (D1: 6months – 1year), 4~8 quarters (D2: 1-2year scale), 8~16 quarters (D3: 2-4year scale), 16~32 quarters (D4: 4-8 year scale), 32~64 quarters (D5: 8-16 year scale) and 64~128 quarters (D6: 16-32 year scale). Due to small sample dataset, we chose to examine MPRF at the first three time-scales (i.e. D1, D2 & D3). This is basically to proxy for policy reaction to macroeconomic shocks at the short-run, medium-run, and long-run respectively.

[69] The choice of the sample size is to cover both the transition (IT lite) and the full inflation targeting (IT) regimes from 2002 as well as easily availability of quarterly data. However, the inclusion of one-year (2001Q1-Q4) preceding the adoption of IT lite is just to ensure that the introduction of lagged variables (especially with respective to the instruments) still maintains a sizeable data sample for the estimation. Nevertheless, our empirical results show that the inclusion or otherwise of one-year dataset preceding the IT adoption does not affect the results.

[70] For robustness, we validate our empirical results using inflation target of 10% across the data span. The use of the upper limit of medium-term inflation target is broadly motivated by the fact that Ghana's headline inflation has consistently exceeded the medium-term target midpoint of 8%.

5.4 Analysis of Empirical Results and Inferences

In this section, we present the empirical results on conditional mean and quantile estimates for monetary policy rule in Ghana utilizing both levels and wavelet time-scale datasets. We however fitted several versions of Taylor rules including forward-looking", "backward-looking" "hybrid" (which nests the preceding two), and augmented Taylor rules with and without smoothing parameter.

5.4.1 Preliminary Analysis

The preliminary analysis of the data unveils that all the series are stationary at levels, I(0) processes, with the exception of MPR which exhibited an I(1) process (see Appendix 5Ai). It is also conspicuous from Appendix 5Aii that both Bayesian Information Criterion (BIC) and Residual Sum of Squares (RSS) measures display signs of breaks (i.e. multiple regimes) in the selected macroeconomic dataset in their time variations, except for output gap (YGAP). However, it is argued that the BIC overestimates the breaks in the presence of serial correlation in the series (Bai and Perron, 2003a,b). For robustness, therefore, we further apply Bai and Perron's (1998, 2003a,b) tests for unknown multiple structural breaks to authenticate the findings based on Zeilies et al (2003). The table in Appendix 5Aiii presents both the Bai-Perron's sequentially and information criterion globally determined breakpoints tests. Both tests identify at most one breakpoint for output gap and nominal exchange but no discernible structural breaks for MPR (nominal and real), real exchange rate (i.e. CRER), inflation gap (INFGAP and actual inflation. In view of this, it is econometrically prudent to assess the effects of the detected structural breaks on policy rule in Ghana. To do this, we create a dummy variable which takes a value of zero (0) for periods before and after break dates, and a value of 1 for the exact break dates.

5.4.2 GMM estimates at Time- and Multiscale Domains

Tables 5.1 and 5.2 present the symmetric MPRF estimates for BOG at time-domain (ATD) and multiscale-spectrum respectively based on the aggregated datasets. On the other hand, Tables 5.3 and 5.4 report the corresponding asymmetric MPRF estimates for BOG at time-spectrum and multiscale domain respectively based on the segregated datasets. A close examination of the OLS estimations with structural break effect (see ATD1 in Table 5.1) clearly shows that the breaks could not substantially influence the dependence structure between policy interest rate (MPR) and its regressors. Consequently, we declined to account for structural breaks in the subsequent estimation of policy rule.

Table 5.1: Aggregated Time-Domain (ATD) Estimates for MPRF

Dependent Variable: MPR_t							
	ATD1	**ATD2**	**ATD3**	**ATD4**	**ATD5**	**ATD6**	**ATD7**
MPR_{t-1}	0.958		0.997	0.979	0.988	0.919	0.930
	[34.52]*		[21.24]*	[56.46]*	[54.83]*	[17.05]*	[14.13]*
C	0.272	18.25	-0.006	0.113	-0.230	0.833	0.849
	[0.49]	[1.57]	[-0.01]	[0.32]	[-0.76]	[0.94]	[0.74]
$INF_{gap,t}$	0.055	-0.68				0.101	0.078
	[2.99]*	[-0.18]				[3.19]*	[1.96]***
$INF_{gap,t-1}$			0.056				0.006
			[2.97]*				[0.15]
$INF_{gap,t+1}$				0.092	0.152	0.143	0.164
				[4.25]*	[10.17]*	[1.79]***	[1.74]***
$INF_{gap,t+2}$						-0.031	-0.051
						[-0.49]	[-0.82]
$INF_{gap,t+3}$						-0.071	-0.093
						[-0.75]	[-0.87]
$INF_{gap,t+4}$						0.047	0.040
						[0.75]	[0.53]
$Y_{gap,\ t}$	0.052	-0.01			0.037	0.028	-0.149
	[1.05]	[-0.008]			[0.81]	[0.29]	[-1.01]
$Y_{gap,\ t+1}$				-0.141			
				[-3.07]*			
$Y_{gap,\ t-1}$			0.204				0.259
			[4.55]*				[1.78]***
$Xdep_t$	0.031						
	[2.49]*						
Xdep_dummy	-0.025						
	[-0.39]						
Ygap_dummy	-0.339						
	[-0.54]						
ΔRER_t				0.030			
				[4.15]*			
$RS_{W,t}$				-0.255			
				[-7.21]*			
α				**0.043**	**0.012**		
				[4.26]*	**[1.93]*****		
Model Diagnostics							
Adj R-squared	0.97	0.12	0.91	0.95	0.94	0.93	0.92
S.E. of reg	1.05	4.30	1.16	0.99	1.04	1.07	1.12
Instrument rank		10	21	25	25	22	22
Prob(J-statistic)		{0.81}	{0.84}	{0.81}	{0.89}	{0.71}	{0.60}
Normality Test	{0.62}	{0.04}**	{0.02}**	{0.73}	{0.91}	{0.46}	{0.62}
Prob(CR)	>0.1^	< 0.01	>0.1	>0.1	>0.1	>0.1	>0.1
Prob(CSR)	>0.1	< 0.01	>0.1	>0.1	>0.1	>0.1	>0.1
ADF Test (Resid)	*{0.00}**	{0.03}**	*{0.00}**	*{0.00}**	*{0.00}**	*{0.00}**	*{0.00}**
Wald Test: χ^2 Stats for α = 0				(18.15)*	(3.74)***		
Serial Correl Test	{0.09}***						
Heteroscedasticity Test	{0.02}**						
Stability Test	{0.03}**						

Note: *, ** & *** denotes 1%, 5% & 10% alpha levels respectively. ^ means that significant at lag 1; RSW is US 3-month interest rate. ATD3 displays the estimates for "backward-looking" Taylor rule, while ATD6 and 7 provide the estimates for the "forward-looking" and "hybrid" Taylor rules respectively. CoR is correlogram of residuals for 1 to 16 lags; CoSR denotes correlogram of squared residuals for 1 to 16 lags. MPR_t denotes monetary

policy rate; $INF_{gap,t,}$ denotes inflation deviation from target; $Y_{gap,t,}$ is output gap; $Xdep_t$ is nominal exchange rate; RER_t denotes real exchange rate; and $RMPR_t$ is real policy rate. Xdep_dummy is a dummy for exchange rate break; Ygap_dummy represents break dummy for output gap; α is a coefficient of $INF_{gap,t+4}*Y_{gap,t}$.

Table 5.2: Multiscale-Aggregated GMM Estimates for MPRF

	Short Run				Medium Run				Long Run			
	SR1	**SR2**	**SR3**	**SR4**	**MR1**	**MR2**	**MR3**	**MR4**	**LR1**	**LR2**	**LR3**	**LR4**
$INF_{gap,t}$	0.020	0.008	0.007	0.010	0.165	0.161	0.161	0.133	0.101	0.110	0.107	0.103
	[1.81]***	[0.58]	[0.48]	[0.69]	[6.99]*	[10.25]*	[10.12]*	[7.52]*	[12.55]*	[8.68]*	[8.89]*	[6.99]*
$Y_{gap,t}$	0.307	0.302	0.296	0.108	-0.093	-0.100	-0.100	-0.130	0.067	0.038	0.034	-0.020
	[8.46]*	[7.16]*	[7.88]*	[1.16]	[-1.57]	[-1.71]***	[-1.77]***	[-1.48]	[2.08]**	[0.96]	[0.86]	[-0.47]
MPR_{t-1}	-0.306	-0.348	-0.344	-0.367	0.601	0.598	0.597	0.615	0.782	0.766	0.780	0.732
	[-5.34]*	[-5.82]*	[-5.89]*	[-6.04]*	[11.16]*	[10.30]*	[10.59]*	[11.87]*	[18.38]	[16.66]*	[17.77]*	[17.35]*
C	0.000	-0.004		0.003	0.013	0.003		-0.020	-0.023	0.075		0.009
	[0.00]	[-0.12]		[0.11]	[0.20]	[0.04]		[-0.25]	[-0.38]	[0.83]		[0.09]
α_1		0.063	0.066	0.058		-0.010	-0.011	-0.005		-0.001	-0.005	-0.005
		[2.19]**	[2.34]**	[2.07]**		[-0.89]	[-1.00]	[-0.34]		[-0.23]	[-0.95]	[-0.89]
$Xdep_t$				0.041				0.069				0.036
				[1.91]***				[2.25]**				[2.53]**
	Model Diagnostics											
Adj. R-squared	0.36	0.34	0.35	0.39	0.58	0.59	0.60	0.52	0.59	0.57	0.59	0.60
D-W stat	2.11	2.06	2.08	2.14	2.07	2.05	2.05	1.81	1.73	1.73	1.80	1.69
Instrument rank	13	14	14	15	14	15	15	15	17	15	15	15
J-statistic	12.22	11.77	11.96	11.84	11.35	10.76	10.79	10.46	11.69	9.65	11.12	9.46
Prob(J-statistic)	{0.201}	{0.226}	{0.287}	{0.222}	{0.331}	{0.376}	{0.461}	{0.314}	{0.554}	{0.471}	{0.433}	{0.396}
Normality Test	{0.974}	{0.934}	{0.930}	{0.832}	{0.360}	{0.331}	{0.327}	{0.537}	{0.163}	{0.313}	{0.560}	{0.296}
ADF Test (Residuals)	{0.00}*	{0.00}*	{0.00}*	{0.00}*	{0.00}*	{0.00}*	{0.00}*	{0.00}*	{0.00}*	{0.00}*	{0.00}*	{0.00}*
Wald Test: χ^2 Stats												
α_1=0		(4.82)*	(5.51)*	(4.32)*		(0.80)	(1.00)	(0.12)		(0.05)	(0.90)	(0.79)

Note: {} and ( ) denote p-values and chi-square statistic respectively; Superscript *, ** & *** represent 1%, 5% & 10 significant levels respectively. MPRt-1, denotes lagged monetary policy rate; INFgap,t, denotes deviation of inflation from target; Ygap,t, is output gap; α_1 is the coefficient of the interaction term for spillovers from current output gap to four-quarters ahead inflationary gap (Ygap,t*INFgap,t+4).

Table 5.3: Segregated Time-Domain (STD) Estimates of MPRF

	STD1	STD2	STD3	STD4	STD5	STD6	STD7
C	14.502[12.19]*	1.213[3.78]*	0.747[2.65]**	0.571[2.21]**	0.665[2.62]**	0.587[1.49]	0.217[0.41]
MPR_{t-1}		0.888[39.78]*	0.925[45.27]*	0.930[50.88]*	0.927[60.35]*	0.932[42.16]*	0.945[34.86]*
$PINF_{gap,t}$	0.590[5.48]*	0.193[17.61]*	0.188[12.97]*	0.176[15.94]*	0.178[14.56]*	0.181[11.28]*	0.191[5.73]*
$NINF_{gap,t}$	-0.539[-12.45]*	-0.051[-2.94]*	-0.038[-1.97]***	-0.021[-1.26]	-0.023[-1.27]	-0.022[-1.15]	-0.057[-1.72]***
$PY_{gap,t}$	-0.668[-2.55]*	-0.094[-1.83]***	0.007[0.06]	0.013[0.16]	-0.045[-0.70]	-0.044[-0.53]	0.565[2.18]**
$NY_{gap,t}$	-0.813[-2.07]**	0.046[0.89]	0.123[2.03]**	0.091[1.66]	0.201[2.98]*	0.129[2.34]**	0.214[2.11]**
$XDEP_t$	0.004[0.09]	0.006[0.78]	0.005[0.65]	0.009[1.38]	0.003[0.57]	0.008[1.14]	0.004[0.63]
α_{pp}			-0.012[-0.82]				-0.063[-1.79]***
α_{pn}				0.225[2.41]**			0.942[2.87]*
α_{np}					-0.069[-2.16]**		-0.062[-1.37]
α_{nn}						0.010[0.48]	0.024[0.64]
	Model Diagnostics						
Adjusted R-squared	0.247	0.964	0.965	0.962	0.966	0.964	0.957
S.E. of reg.	3.975	0.874	0.865	0.891	0.847	0.871	0.958
DW stat	0.601	1.629	1.757	1.686	1.849	1.789	1.885
Instrument rank	25	25	25	25	25	25	25
J-statistic	13.426	12.042	10.883	11.259	11.750	11.452	10.317
Prob(J-statistic)	{0.816}	{0.845}	{0.862}	{0.842}	{0.815}	{0.832}	{0.738}
Normality Test	{0.148}	{0.115}	{0.007}*	{0.001}*	{0.123}	{0.001}*	{0.448}
Prob(CoR); 1 to 16 lags	<0.1	>0.1	>0.1	>0.1	>0.1	>0.1	>0.1
Prob(CoSR); 1 to 16 lags	<0.1	>0.1	>0.1	>0.1	>0.1	>0.1	>0.1

Note: MPRt-1 denotes lagged monetary policy rate; PINFgap,t, denotes positive deviation of inflation from target (i.e. inflationary periods); NINFgap,t, denotes negative deviation of inflation from target (i.e. disinflationary period); PYgap,t, is positive output gap (period of economic boom); NYgap,t, is negative output gap (period of economic downturn); Xdept is nominal exchange rate depreciation; α_{pp} is the coefficient of interaction term for spillovers from economic boom cycle to four-quarters ahead inflationary (PYgap,t*PINFgap,t+4); α_{pn} is the coefficient of the interaction term for spillovers from economic boom cycle to four-quarters ahead dis-inflationary (PYgap,t*NINFgap,t+4); α_{np} is the coefficient of the interaction term for spillovers from downturn cycle to four-quarters ahead inflationary (NYgap,t*PINFgap,t+4); α_{nn} is the coefficient of the interaction term for spillovers from downturn cycle to four-quarters ahead dis-inflationary (NYgap,t*NINFgap,t+4). Superscript *, ** & *** denote 1%, 5% & 10% significance levels respectively. Prob(CoR) denotes probability value for correlogram of residuals for 1 to 16 lags; Prob(CoSR) denotes probability value for correlogram of squared residuals for 1 to 16 lags.

Table 5.4: Segregated Multiscale (Time-Frequency) Estimates for MPRF

	Short Run						Medium Run					
	SR0	**SR1**	**SR2**	**SR3**	**SR4**	**SR5**	**MR0**	**MR1**	**MR2**	**MR3**	**MR4**	**MR5**
C	**0.010**	**0.004**	**0.002**	**0.011**	**0.010**	**0.002**	**0.087**	**0.012**	**-0.003**	**0.046**	**-0.004**	**0.015**
	[0.45]	[0.15]	[0.07]	[0.38]	[0.35]	[0.06]	[0.62]	[0.13]	[-0.03]	[-0.52]	[-0.03]	[0.15]
$PINF_{gap,t}$	**0.064**	**-0.007**	**-0.009**	**-0.012**	**-0.012**	**-0.028**	**0.009**	**0.098**	**0.085**	**0.095**	**0.111**	**0.143**
	[1.80]***	[-0.31]	[-0.39]	[-0.47]	[-0.48]	[-1.05]	[0.08]	[5.01]*	[3.00]*	[4.06]*	[5.01]*	[3.34]*
$NINF_{gap,t}$	**0.015**	**0.011**	**0.019**	**0.010**	**0.017**	**0.022**	**0.142**	**0.093**	**0.096**	**0.103**	**0.072**	**0.074**
	[0.51]	[0.53]*	[0.99]	[0.45]	[0.82]	[1.20]	[0.56]	[1.63]	[1.53]	[3.07]*	[1.14]	[1.44]
$PY_{gap,t}$	**0.386**	**0.298**	**0.258**	**0.298**	**0.288**	**0.279**	**0.005**	**0.253**	**0.338**	**0.134**	**0.256**	**0.293**
	[7.57]*	[6.50]*	[6.65]*	[6.54]*	[6.35]*	[6.53]*	[0.01]	[1.95]***	[1.80]***	[1.72]***	[1.85]	[2.20]**
$NY_{gap,t}$	**-1.146**	**-0.222**	**-0.203**	**-0.199**	**-0.289**	**-0.387**	**-1.074**	**-0.327**	**-0.330**	**-0.285**	**-0.281**	**-0.190**
	[-2.93]*	[-1.12]	[-1.04]	[-0.36]	[-1.43]	[-1.46]	[-4.36]*	[-2.42]**	[-2.03]**	[-1.77]***	[-2.03]	[-1.18]
MPR_{t-1}		**-0.324**	**-0.339**	**-0.347**	**-0.339**	**-0.359**		**0.565**	**0.536**	**0.490**	**0.596**	**0.602**
		[-4.15]*	[-4.23]*	[-4.30]*	[-4.25]*	[-4.27]*		[4.58]*	[3.84]*	[3.61]*	[5.10]*	[5.96]*
α_{pp}			**0.038**						**0.047**			
			[1.81]***						[1.49]			
α_{pn}				**0.020**						**-0.047**		
				[0.86]						[-4.80]*		
α_{np}					**0.126**						**-0.041**	
					[1.32]						[-0.82]	
α_{nn}						**0.119**						**-0.173**
						[1.98]***						[-1.15]
Model Diagnostics												
Adj. R-squared	0.05	0.40	0.41	0.38	0.47	0.40	0.04	0.49	0.47	0.59	0.49	0.49
D-W stat	2.30	2.22	2.31	2.14	2.18	2.19	1.21	1.75	1.70	1.56	1.74	1.77
Instrument rank	13	20	21	21	21	21	8	22	23	23	23	23
J-statistic	8.02	13.07	13.43	13.27	13.08	13.03	4.54	13.05	11.91	13.04	12.22	11.94
Prob(J-statistic)	{0.431}	{0.521}	{0.492}	{0.506}	{0.520}	{0.524}	{0.208}	{0.669}	{0.686}	{0.670}	{0.728}	{0.747}
Normality Test	{0.898}	{0.543}	{0.733}	{0.433}	{0.526}	{0.583}	{0.001}*	{0.269}	{0.566}	{0.584}	{0.266}	{0.308}
ADF Test (Residuals)	{0.00}*	{0.00}*	{0.00}*	{0.00}*	{0.00}*	{0.00}*	{0.00}*	{0.00}*	{0.00}*	{0.00}*	{0.00}*	{0.00}*
Wald Test: χ^2 Stats												
α_{pp} **=0**			(3.27)***						(2.22)			

α_{pn}=0	(0.75)	(23.10)*
α_{np}=0	(1.74)	(0.67)
α_{nn}=0	(3.29)***	(1.32)

Table 5.4: Continuation……

	Long Run					
	LR0	**LR1**	**LR2**	**LR3**	**LR4**	**LR5**
C	**0.178**	**0.017**	**0.129**	**0.038**	**0.035**	**0.079**
	[1.26]	[0.27]	[1.92]***	[0.50]	[0.49]	[1.13]
$PINF_{gap,t}$	**0.407**	**0.305**	**0.273**	**0.301**	**0.268**	**0.315**
	[4.01]*	[11.65]*	[11.22]*	[11.39]*	[6.75]*	[11.41]*
$NINF_{gap,t}$	**-0.262**	**-0.099**	**-0.098**	**-0.096**	**-0.091**	**-0.118**
	[-3.75]*	[-5.68]*	[-4.33]*	[-4.06]*	[-4.00]*	[-4.93]*
$PY_{gap,t}$	**-0.032**	**0.169**	**0.166**	**0.174**	**0.226**	**0.134**
	[-0.23]	[3.51]*	[2.20]**	[2.95]*	[3.95]*	[2.59]**
$NY_{gap,t}$	**-1.038**	**-0.218**	**-0.152**	**-0.220**	**-0.225**	**-0.216**
	[-6.69]*	[-3.42]*	[-1.76]***	[-3.54]*	[-3.73]*	[-2.89]*
MPR_{t-1}		**0.626**	**0.648**	**0.638**	**0.648**	**0.603**
		[12.70]*	[13.02]	[13.57]*	[15.08]*	[10.43]*
α_{pp}			**0.026**			
			[2.78]*			
α_{pn}				**-0.006**		
				[-0.62]		
α_{np}					**0.047**	
					[0.84]	
α_{nn}						**-0.070**
						[-1.71]***
Model Diagnostics						
Adj. R-squared	0.21	0.70	0.67	0.71	0.70	0.69
D-W stat	1.39	1.98	1.87	1.94	1.92	1.99
Instrument rank	9	22	23	23	23	23
J-statistic	7.60	11.50	10.19	10.92	10.99	10.46
Prob(J-statistic)	{0.107}	{0.777}	{0.807}	{0.814}	{0.809}	{0.841}
Normality Test	{0.475}	{0.642}	{0.392}	{0.458}	{0.477}	{0.502}
ADF Test (Residuals)	{0.01}**	{0.00}*	{0.00}*	{0.00}*	{0.00}*	{0.00}*
Wald Test: χ^2 Stats						
α_{pp}=0			(7.74)*			
α_{pn}=0				(3.97)**		
α_{np}=0					(0.71)	
α_{nn}=0						(2.92)***

Note: The table presents GMM estimates for MPRF at time-frequency domain based on different economic cycle and trajectory of inflation gap (positive and negative deviations). MPR_{t-1} denotes lagged monetary policy rate; $PINF_{gap,t,}$ denotes positive deviation of inflation from target (i.e. inflationary periods); $NINF_{gap,t,}$ denotes negative deviation of inflation from target (i.e. disinflationary period); $PY_{gap,t,}$ is positive output gap (period of economic boom); $NY_{gap,t,}$ is negative output gap (period of economic downturn); $Xdep_t$ is nominal exchange rate depreciation; α_{pp} is the coefficient of interaction term for spillovers from economic boom cycle to four-quarters ahead inflationary **($PY_{gap,t}$*$PINF_{gap,t+4}$);** α_{pn} is the coefficient of the interaction term for spillovers from economic boom cycle to four-quarters ahead dis-inflationary **($PY_{gap,t}$*$NINF_{gap,t+4}$);** α_{np} is the coefficient of the interaction term

for spillovers from downturn cycle to four-quarters ahead inflationary ($NY_{gap,t}$*$PINF_{gap,t+4}$); α_{nn} is the coefficient of the interaction term for spillovers from downturn cycle to four-quarters ahead dis-inflationary ($NY_{gap,t}$*$NINF_{gap,t+4}$). Superscript *, ** & *** denote 1%, 5% & 10% significance levels respectively.

The empirical estimates in Tables 5.1-5.4 reveal that lagged interest rate could be an important missing variable in the OLS estimates. In all cases, the time-spectrum and multiscale estimates for the aggregate and segregated datasets unveil considerable evidence of high degree of interest rate inertia. This is not surprising given the fact that rates may remain constant (no change) for a while (i.e. central bank adopts a "wait and see" strategy). While the estimates at the time-spectrum (see Tables 5.1 & 5.3) clearly illustrate strong policy inertia, the multiscale analysis (in Tables 5.2 & 5.4) rather reveals anti-persistence of interest rate at the shorter time-scale, as the lagged interest rate assumes significant negative values which are highly implausible. However, the interest rate smoothing is clearly evident at the medium and longer time-scales (refer to Tables 5.2 & 5.4). But, the degree of policy inertia is relatively moderate for the asymmetric analysis at multiscale domain, particularly at the medium and long time-scales, with a range of 0.490 and 0.648 (see Table 5.4). This favourably compared with the range of [0.597 and 0.782] for the symmetric multiscale estimates (see Table 5.2) and that of [0.888 and 0.997] for the symmetric and asymmetric estimates at time-domain (see Tables 5.1 & 5.3). In addition, the time-domain analysis somewhat dampens the influence of both inflation and output gap on policy interest rate.

In addition, a close examination of the tables generally reveals divergent policy response (in terms of direction and magnitude) to inflation and output gaps across time-spectrum (see, Table 5.3) and at different time-scales (see Table 5.4), epitomizing asymmetric monetary policy rule for Ghana. The evidence that BOG, to some extent, considers business cycle dynamics in decision making process across both time- and multiscale domains is a reflecting of BOG's pursuit of flexible inflation targeting regime (FITR). However, it is equally apparent from the Tables 5.3 and 5.4 that monetary policy reactions to inflation and economic cycle dynamics are equally time-scale dependent. In terms of magnitudes, estimated policy parameters for output gap (either negative or positive gap) are broadly greater than that for inflation (either positive or negative deviation) at the short to medium scales. In the longer time scale, however, policy parameters for inflation gap are generally greater than that for output gaps. Similar strong policy aversion towards inflation gap is discernable at time-spectrum (see Table 5.3), supporting the overriding price stability objective of BOG in the long run.

Furthermore, the multiscale analysis (see Tables 5.2 & 5.4) reveals that the monetary authority is remarkably more aggressive during inflationary phase (positive inflation gap), especially at the medium to-longer time scale. This surmises a considerable medium-to-long run monetary policy aversion to positive inflation gap. Conversely, we noticed an insignificant short-to-medium scale response to negative inflation gap. However, policy easing cycle becomes more apparent for negative inflation gap at the longer time horizon.

Besides the observed asymmetric policy link between official interest rate and output gap at time-domain, the extent of policy response to economic cycles is also time-scale dependent. On one hand, although the authority broadly adopts tighter policy stance during economic expansion (positive output gap) as expected, the magnitude of response is relatively larger and statistically significant (1% alpha level) at the shorter scale. But, both the magnitude and level of statistical significance dwindle along the scales, epitomizing higher policy risk aversion to aggregate demand pressures at the shorter scale. This intuitively suggests that monetary authority attempts to dampen looming upward aggregate demand spillovers to inflation in the short run by responding aggressively and contemporaneously to economic boom cycles.

Similarly, we uncover a general time-scale dependent easing policy stance for economic downturn (in Table 5.4). For instance, while the shorter time-scale analysis shows a statistically insignificant (weak) negative policy response to economic downturn, the response rather becomes highly significant and broadly larger (in terms of magnitude) at the medium-to-long scales.

Despite a conspicuously favourable evidence of asymmetric (nonlinear) policy response to inflation dynamics, the magnitude of BOG's response to the latter across both time-spectrum and multiscale domain is woefully below the prescription of the Taylor rule (see Tables 5.1-5.4). This surmises that BOG has not systematically adhered to the Taylor principle by adjusting policy rate more than one-to-one in response to changes in inflation (especially when inflation is above target). The non-adherence of the Taylor principles can perhaps be linked to the direct and regular official interventions in the foreign exchange rate market by central bank of Ghana to moderate volatilities in the domestic currency[71]. Aside from the exchange rate, the observed passive policy reaction to inflation gap could partly be attributed to a sufficiently high

[71] Ghana is classified as a managed floater without a predetermined path for the exchange rate (IMF, 2016).

financially excluded (unbanked) or "hand-to-mouth" consumers in Ghana[72]. This is because changes in the policy interest rate do not directly impinge on large unbanked consumers, leading to a less effective monetary policy in Ghana[73].

Another salient observation, especially from Tables 5.2, 5.3 and 5.4, is that the interaction terms broadly point to an asymmetric (nonlinear) and multiscale-dependent policy response to spillovers from economic cycles to inflation. On one hand, we find nonlinear policy response to spillovers from positive output gap (economic boom cycle) to inflation. Basically, the estimates for the interaction terms uncover strong policy aggression towards spillovers from positive output gap to positive inflation gap than to negative inflation gap. By implication, there is a higher inclination for monetary authority to react forcefully to counter aggregate demand pressures if the source of the economic boom is likely to ooze inflationary pressures. Conversely, if policymakers do not perceive the source of economic growth or boom to trigger inflationary pressures, going forward, they may either adopt a "wait and see" strategy or raise interest rate marginally which perhaps is unable to dampen aggregate demand. Alternatively, we identify a general weak policy response to spillovers from economic downturns to expected inflation trajectory (either positive or negative gap). This finding reinforces nonlinear policy reaction to different economic cycles by BOG.

5.4.2.1 Robustness of the observed inflation bias

It is highly imperative to be absolutely certain that the observed divergent policy parameters, particularly for positive and negative inflation gaps, are not primarily due to how the inflation target is derived. This is to principally authenticate that the observed changing policy parameters are not rather attributable to potential structural break due to the two approaches to obtain the target for different time periods in the preceding analysis. In view of these concerns and for plausibility, we re-estimate the MPRF based on inflation gap defined as actual inflation minus a threshold (or target) of 10%. A number of factors motivated the choice of the alternative target value. First, the choice is conditional on BOG's long-standing policy desire for single-digit inflation[74]. Second, the 10% inflation threshold is consistent with the upper

[72] In a speech on December 5th 2017, the Vice President of the Republic of Ghana, Dr. Bawumia, avers that about 70 percent of unbanked consumers in Ghana. Available at: https://www.myjoyonline.com

[73] According to Bilbiie (2008), an inverted "Taylor principle" may possibly ensue if the proportion of the hand-to-mouth consumers is sufficiently high. In this case, the optimal policy may necessitate a passive monetary policy rule (see, Galí et al, 2004; Motta and Tirelli, 2010; Ascari et al., 2011; Colciago, 2011; and Yetman, 2017).

[74] See, https://www.bog.gov.gh/monetary-policy/press-releases/425-mpc-press-release-january-2003.

limit of the medium-term inflation target[75]. And lastly, Ghana's headline inflation has continuously exceeded the medium-term target midpoint of 8% for the IT period. Therefore, our alternative choice of a 10% inflation threshold is well justified.

Employing GMM estimation techniques at time-domain, Table 5.5 presents the segregated MPRF estimates for both the full sample (2002Q1-2017Q4) and sub-sample (2007Q1-2017Q4). The selection of the sub-sample was mainly based on the official announcement of the adoption of fully-fledged IT regime by BOG in 2007. Consistently, the empirical results in Table 5.6 clearly endorse the earlier findings of asymmetric (or divergent) policy responses to positive and negative inflation gap. Particularly and in line with earlier results, the table clearly reinforces that BOG's policy bias towards positive inflation gap (i.e. rising inflationary pressures). This additional observation, irrespective of how inflation target is defined, surmises that the earlier empirical findings are valid for economic and policy inferences. Moreover, there is also ample evidence that previous changes in policy rate strongly influence the current interest rate setting by the monetary authority in Ghana.

[75] See, https://www.bog.gov.gh/monetary-policy/press-releases/1910-mpc-press-release-sept2014.

Table 5.5: Alternative Estimates for MPRF at Time-Domain based on Inflation Target of 10%

	Full Sample (2002Q1-2017Q4)			Sub-Sample (2007Q1-2017Q4)		
	1	**2**	**3**	**4**	**5**	**6**
C	0.851[3.97]*	0.600[4.38]*	1.302[3.17]*	1.011[6.26]*	0.540[1.28]	1.004[2.72]*
MPR_{t-1}	0.950[71.26]*	0.969[128.39]*	0.938[42.61]*	0.945[76.14]*	0.979[42.61]*	0.944[44.05]*
ΔMPR_{t-1}	0.363[9.45]*	0.273[9.96]*	0.291[4.54]*	0.530[9.69]*	0.312[2.79]*	0.533[4.04]*
$PINF_{gap,t}$	0.102[4.01]*	0.079[7.96]*	0.178[3.34]*	0.094[2.38]**	0.172[1.90]***	0.081[1.01]
$NINF_{gap,t}$	-0.140[-0.75]	-0.129[-1.45]	-0.377[-0.94]	-0.206[-1.07]	-0.323[-0.65]	-0.088[-0.18]
$Y_{gap,t}$	0.031[1.40]	-0.204[-8.01]*		0.003[0.28]	-0.107[-1.67]	
$Y_{gap,t-1}$		0.285[9.73]*			0.151[2.15]**	
$Y_{gap,t+3}$		0.009[0.73]			-0.058[-1.97]***	
$PY_{gap,t}$			-0.120[-1.715]***			0.011[0.138]
$NY_{gap,t}$			0.118[2.656]**			-0.038[-0.350]
	Model Diagnostics					
Adj. R-squared	0.943	0.947	0.938	0.958	0.958	0.957
S.E. of regression	1.084	1.038	1.146	0.892	0.900	0.912
DW stat	2.074	2.174	2.251	2.154	2.036	2.156
Instrument rank	24	37	25	24	20	25
J-statistic	12.883	13.849	13.886	9.848	8.825	10.577
Prob(J-statistic)	{0.798}	{0.992}	{0.736}	{0.936}	{0.717}	{0.911}
Normality	{0.051}***	{0.078}***	{0.141}	{0.446}	{0.833}	{0.465}
Prob(CoR)	> 0.1	> 0.1	> 0.1	> 0.1	> 0.1	> 0.1
Prob(CoSR)	> 0.1	> 0.1	> 0.1	> 0.1	> 0.1	> 0.1
ADF Unit Root Test	{0.000}*	{0.000}*	{0.000}*	{0.000}*	{0.000}*	{0.000}*

Note: MPR_{t-1} denotes lagged monetary policy rate; ΔMPR_{t-1} denotes lagged changes in monetary policy rate; $PINF_{gap,t,}$ denotes positive deviation of inflation from target (i.e. inflationary periods). Here, we use inflation target of 10% which is the upper band of the medium-term target; $NINF_{gap,t,}$ denotes negative deviation of inflation from target (i.e. disinflationary period); $PY_{gap,t,}$ is positive output gap (period of economic boom); $NY_{gap,t,}$ is negative output gap (period of economic downturn); Superscript *, ** & *** denote 1%, 5% & 10% significance levels respectively. Values in squared and curly brackets are t-statistic and p-values respectively. Prob(CoR) is probability values for correlogram of residuals from 1 to 16 lags; Prob(CoSR) denotes probability values for correlogram of squared residuals from 1 to 16 lags.

5.4.2.2 Relevance of exchange rate in BOG's MPRF

The time-domain (level) estimates in Tables 5.1 and 5.3 point to an inconclusive relevance of nominal exchange rate in the MPRF for BOG. This is contradicted by the multiscale estimates which reveal a conspicuous significant impact of exchange rate on policy interest rate in Ghana (see Tables 5.2 & 5.4). In view of the inconclusive results regarding the relevance of exchange rate (real and nominal) in the MPRF for BOG, we further examine the relative performance of BOG's policy rule with and without exchange rate across time-spectrum and multiscale domain. In line with the literature, this approach would robustly enable us to determine whether the direct inclusion of exchange rate in BOG's policy rule is superfluous or not across both analytical domains. Accordingly, Table 5.6 presents both the static and dynamic forecasting performances of GMM estimates for BOG's policy rule with and without exchange rate at both time-spectrum and time-frequency domain using aggregated and segregated datasets. For robustness, this chapter follows the literature to apply competing forecasting performance criteria (see, Bentes, 2015; Patton, 2006, 2011; etc.). These include (i) mean absolute error (MAE), (ii) root mean squared error (RMSE) and (iii) Theil's inequality coefficient (TIC), defined as:

$$MAE = \frac{1}{n}\sum_{t=1}^{n}|i_t - \hat{\imath}_t| \tag{5.26}$$

$$RMSE = \sqrt{\frac{\sum_{t=1}^{n}(i_t - \hat{\imath}_t)^2}{n}} \tag{5.27}$$

$$TIC = \frac{\sqrt{\left(\frac{1}{n}\right)_{t=1}^{n}(i_t - \hat{\imath}_t)^2}}{\sqrt{\left(\frac{1}{n}\right)\sum_{t=1}^{n} i_t^2} + \sqrt{\left(\frac{1}{n}\right)\sum_{t=1}^{n} \hat{\imath}_t^2}} \tag{5.28}$$

where n is the number of forecasts and i_t and $\hat{\imath}_t$ are the observed and the predicted values of policy interest rate (MPR) at time t, respectively. According to this methodology, the best forecasting model is the one that produces the lowest prediction error. For robustness, we explore both in-sample and out-of-sample forecast performance of the competing models. As a common empirical practice in the literature, the out-of-sample period should not exceed 1/3 of the whole sample (see, Bentes, 2015). Therefore, we use 56 quarterly observations for the

in-sample GMM estimation and the remaining 12-quarters (2015Q1-2017Q4) for the out-of-sample forecast.

In general, it is clearly evident from Table 5.6 that the models with the nominal exchange rate unanimously yielded the lowest static in-sample prediction errors across both time-spectrum and time-frequency domain. While similar conclusion can be drawn for the dynamic in-sample forecasting performance across historical time-interval and for the aggregated time-frequency analysis, models with the least dynamic in-sample prediction errors are rather inconclusive for the segregated time-frequency analysis. On the other hand, the table indicates that out-sample forecasting performances of the competing models depend on (1) the type of dataset for the time-spectrum analysis and (2) the frequency under consideration. The out-sample prediction error for the aggregated dataset in the time-domain favours BOG's policy rule with the nominal exchange rate, while policy rule without exchange rate is preferred for the case of segregated level dataset. In contrast, the out-sample prediction error for the multiscale analysis preferred BOG's policy rule without exchange rate in the short-to-medium scale but with exchange rate in the longer scale irrespective of the type of dataset under consideration. In synthesis, the table broadly points to a non-trivial influence of exchange rate on BOG's policy rule. Consequently, the direct inclusion of the former in monetary policy rule is not necessarily superfluous in the context of Ghana at the long run.

Table 5.6: Forecast performance of BOG's policy rule with and without exchange rate

		In-Sample Forecast						Out-Sample Forecast		
		Dynamic			Static			Static		
		RMSE	MAE	TIC	RMSE	MAE	TIC	RMSE	MAE	TIC
		Panel A: Historical Time-Spectrum								
A: Aggregated Level Data										
	With Xdep	**2.8668**	**2.1862**	**0.0767**	**0.9896**	**0.7471**	**0.0255**	**1.1823**	**0.9596**	**0.0247**
	Without Xdep	3.3408	2.5487	0.0895	1.0539	0.7687	0.0271	1.3185	1.0258	0.0273
B: Segregated Level Data										
	With Xdep	**2.0593**	**1.6076**	**0.0539**	**0.8428**	**0.6727**	**0.0217**	0.9068	0.7427	0.0191
	Without Xdep	2.0601	1.6554	0.0541	0.8625	0.6874	0.0222	**0.8546**	**0.7008**	**0.0180**
		Panel A: Time-Frequency Domain								
A: Aggregated Scaled Data										
Short scale	*With Xdep*	**0.3728**	**0.3009**	0.4544	**0.3634**	**0.2856**	**0.4239**	0.4188	0.3700	**0.5569**
	Without Xdep	0.3907	0.3104	**0.4449**	0.3854	0.3057	0.4347	**0.3188**	**0.2549**	0.6687
Medium scale	*With Xdep*	**0.6735**	**0.4935**	**0.3923**	**0.6516**	**0.4943**	**0.3898**	0.5716	0.5192	**0.6231**
	Without Xdep	0.7137	0.5306	0.3934	0.6981	0.5303	0.4005	**0.4516**	**0.4073**	0.6276
Long scale	*With Xdep*	**1.2623**	**0.9541**	**0.5435**	**0.8733**	**0.6474**	**0.3442**	**0.4788**	**0.4155**	**0.3668**
	Without Xdep	1.3002	0.9842	0.5651	0.8947	0.6574	0.3483	0.5279	0.4676	0.4057
B: Segregated Scaled Data										

Short scale	*With Xdep*	0.3663	0.3021	0.4672	**0.3511**	**0.2809**	0.4195	**0.3551**	0.3008	0.5515
	Without Xdep	**0.3629**	**0.2957**	**0.4509**	0.3513	0.2819	**0.4123**	0.3577	**0.2893**	**0.4278**
Medium scale	*With Xdep*	**0.6440**	**0.4873**	**0.4043**	**0.6101**	**0.4802**	**0.3761**	0.5747	0.5097	**0.6184**
	Without Xdep	0.6758	0.4908	0.4296	0.6469	0.4872	0.4010	**0.4426**	**0.3972**	0.6365
Long scale	*With Xdep*	0.8729	0.6611	0.3262	**0.7220**	**0.5585**	**0.2675**	**0.5889**	**0.4973**	**0.4604**
	Without Xdep	**0.8141**	**0.6285**	**0.3154**	0.7388	0.5689	0.2730	0.7028	0.6289	0.5677

Note: Xdep is exchange rate depreciation; RMSE is root mean square error; MAE is mean absolute error; TIC denotes Theil's inequality coefficient.

5.4.2.4 BOG's policy preference and shifting political regimes

We further ascertain whether observed divergent monetary policy preferences could substantially be attributed to changing political regimes as the sample period encompassed two main shifts in political administrations with five (5) tenures of central bank governors as illustrated in Appendix 5Aiv. In this regard, the dataset is further segregated into political regimes 1 and 2 (henceforth PR1 & PR2 respectively). Based on Appendix 5Aiv, PR1 covers the period 2001-2008Q4 and 2017Q1-Q4, while PR2 spans the period 2009Q1 – 2016Q4. Since the changing policy preference is similar across time-spectrum and multiscale domain, we first investigate the effects of the political regimes on actual inflation and Appendix 5Bi present to results. It is conspicuous from the table in Appendix 5Bi that the changing political regimes have no significant impact on actual inflation in Ghana as the coefficient values for DUMPR are statistically indifferent from zero. We then proceed to explore possible effect of changing political regimes on interest rate setting in Ghana focusing only on the time-domain estimates. Table 5.7 reports the time-domain estimates of political-regime specific policy response parameters for BOG.

Table 5.7: Political Regime-Specific GMM Estimates at Time-Domain

	RGMM1	RGMM2	RGMM3	RGMM4	RGMM5	RGMM6
MPR_{t-1}		0.90[16.13]*		0.93[24.27]*		0.92[10.70]*
C	15.13[235.99]*	1.09[1.20]	14.38[606.64]*	0.64[1.09]	13.32[63.92]*	0.72[0.53]
INF_{gap}_PR2	0.49[4.88]*	0.20[4.19]*	0.52[190.31]*	0.18[2.83]*		
INF_{gap}_PR1	0.28[10.02]*	0.16[6.09]*	0.15[235.97]*	0.19[15.94]*		
Y_{gap}_PR2	-0.27[-1.69]***	0.03[0.42]	-0.31[-574.49]*	0.07[1.23]		
Y_{gap}_PR1	-1.30[-14.67]*	0.03[0.25]	-1.32[-484.13]*	0.08[1.26]		
Xdep_PR2			0.01[15.77]*	0.002[0.14]	0.06[2.08]**	-0.02[-0.89]
Xdep_PR1			0.35[97.71]*	-0.056[-1.93]***	0.15[4.55]*	-0.06[-1.82]***
$PINF_{gap}$_PR2					0.57[3.58]*	0.33[3.65]*
$NINF_{gap}$_PR2					1.63[1.34]	-1.29[-1.58]
$PINF_{gap}$_PR1					0.17[20.92]*	0.19[7.44]*
$NINF_{gap}$_PR1					-0.25[-4.32]*	0.17[1.15]
PY_{gap}_PR2					-0.15[-0.43]	-0.22[-1.54]
NY_{gap}_PR2					-0.12[-0.70]	0.35[2.25]**

PY_{gap}_PR1					-0.36[-2.83]*	0.12[0.62]
NY_{gap}_PR1					-1.98[-34.33]*	0.006[0.03]
	Model Diagnostics					
Adj. R-squared	0.62	0.95	0.65	0.95	0.69	0.93
D-W stat	0.62	1.88	0.65	2.03	0.97	2.06
SSR	273.97	35.97	239.49	35.77	197.06	40.57
Instrument rank	21	21	25	25	25	25
J-statistic	11.31	9.64	10.25	8.62	7.78	8.99
Prob(J-statistic)	0.79	0.84	0.92	0.95	0.90	0.77
Prob (CoR (lags ≤10))	< 0.01	> 0.1	< 0.01	> 0.1	< 0.05	> 0.1
Prob(CoSR (lags ≤10))	> 0.1	> 0.1	> 0.1	> 0.1^1	> 0.1^1	> 0.1
Normality	{0.000}*	{0.000}*	(0.981}	{0.022}**	{0.726}	{0.004}*

Note: ^1 means the Q-statistic for lag one is statistically significant. Values in {} denote p-values. _PR1 covers the period 2001-2008Q4 and 2017Q1-Q4 while _PR2 covers the period 2009Q1 – 2016Q4. Superscript *, ** & *** denote 1%, 5% & 10% significance levels respectively. CoR is correlogram of residuals for 1 to 16 lags; CoSR denotes correlogram of squared residuals for 1 to 16 lags.

The estimated parameters in the table robustly point to homogeneous (identical) policy reaction to inflation and output gaps by BOG across political regimes. We can thus conclude that the positioning of the interest rate by the MPC is purely influenced by the prevailing macro-fundamentals at the time of decision making but not by any political gestures from the fiscal authority. Notably, the table also reinforces that BOG assigns more weight to inflation across political regimes as the policy parameter for inflation gap (unlike output gap) is statistically significant in all models. There is however an unequivocal evidence of a singular policy aversion to positive inflation gap across political regimes, which is intuitively consistent with the price stability objective of BOG (i.e. strict policy preference for precautionary demand for price stability).

5.4.3 Quantile Estimates for MPRF

Here, we provide the salient highlights from the quantile estimates and compared with that of the GMM counterpart.

5.4.3.1 Evidence of Asymmetric Quantiles

We begin our analysis by testing for evidence of asymmetry in the policy reaction function for Ghana. According to Newey and Powell (1987), conditional symmetry entails that the average value of two sets of coefficients for symmetric quantiles around the median will equal the value of the coefficients at the median:

$$\frac{\beta(\alpha) + \beta(1-\alpha)}{2} = \beta(0.5) \tag{5.29}$$

We then estimate the median quantile and carry out the Newey and Powell joint test which has the null hypothesis of

$$H_0 = \frac{\beta(\alpha_i) + \beta(\alpha_{J-i-1})}{2} = \beta(0.5), \quad for\ i = 1, \dots, (j-1)/2 \tag{5.30}$$

with a restriction of $p(j-1)/2$. The corresponding Wald test is zero and the statistic is distributed as a $\chi^2_{p(j-1)/2}$. The paper applies the residual bootstrapping approach[76] with 100 replicates for the estimation of the asymptotic covariance matrix of the median quantile estimate. In addition, we carry out the Koenker and Bassett (1982) test for quantile slope equality to validate the preceding asymmetry test. This is based on the null hypothesis:

$$H_0 = \beta_1(\alpha_1) = \beta_1(\alpha_2) = \cdots = \beta_1(\alpha_j), \tag{4.30}$$

with $(p-1)(j-1)$ restriction on the coefficient and the corresponding Wald statistic is distributed as $\chi^2_{(p-1)(j-1)}$.

Table 5.8 presents the results for conditional symmetry and quantile slope equality tests based on equations (5.30) and (5.31) respectively.

Table 5.8: Tests for Symmetry and Quantile Slope Equality

Panel A: Newell and Powell (1987) Joint Test for Symmetric Policy Reaction Function

	Aggregated Data	**Segregated Data**
	Chi-Sq. Statistic [Prob]	***Chi-Sq. Statistic [Prob]***
Wald Test	10.552[0.0144]**	13.425[0.0038]*
Restriction: b(tau) + b(1-tau) - 2*b(0.5) = 0		
Panel B: Quantile Slope Equality Tests		
Wald Test	18.750[0.0009]*	26.839[0.0008]*
Restriction: b(tau_h) - b(tau_k) = 0		

Note: *&** denote 1% & 5% significant levels respectively.

It is evident that the computed Wald statistics reject the null of symmetry across quantiles in Panel A, implying a departure from symmetric to asymmetric policy reaction function for BOG. The test results in Panel B also unveil favourable evidence of changing slope coefficients across quantiles. This suggests further that the conditional mean estimates may not provide the full picture of policy reaction to inflation and output gap, especially at the tails.

[76] See Buchinsky (1995), He and Hu (2002) and Kocherginsky, He, and Mu (2005) for detailed exposition on bootstrapping techniques for the estimation of covariance matrix of the estimates require for the onward estimation of the sparsity nuisance parameter in quantile regression.

Due to the small sample size, this paper focuses on the estimated posterior means for seven (7) quantiles including 30th, 40th 50th, 60th, 75th, 80th and 90th. In this case, we proxy the lower quartile effects with the 30th and 40th quantiles. Next, we report quantile process estimates at both levels (i.e. time-domain) and wavelet time-scales (i.e. multiscale domain) dataset, the latter generated using MODWT with Debauchies' asymmetric filter of length 8 (LA8). We main discuss focuses on the results from the baseline method (i.e. Bayesian quantile). The result from an alternative method, Frequentist quantile approach, is only discussed when we identify striking differences with the baseline method.

5.4.3.2 Quantile Linear Taylor Rule Results at Levels (i.e. Time-Domain)

Panel A of Table 5.9 report the one-stage Bayesian quantile estimates for simple Taylor rule at levels (i.e. time-domain). Appendix 5Bii provides the corresponding estimates based on the alternative method. The posterior means for the linear one-stage Bayesian quantile estimates (henceforth L1SBQ) are computed using Markov Chain Monte Carlo (MCMC) with 50000 replicates. A key advantage for the Bayesian quantile approach over the FQ method is that the accompanying trace and density plots as well as residual autocorrelation functions (ACFs) ensure valid inferences for the former approach. For brevity, the figures in Appendix 5Ci and 5Cii display the trace plots and the residual autocorrelation functions (ACFs) respectively for some selected quantiles (the others are available upon request) in Table 5.9. It is clear that the fitted L1SBQ models are well-behaved and adequate for policy inferences. In addition, Panel A of Appendix 5Ei reports the estimated posterior means from the linear two-stage Bayesian quantile (L2SBQ) method at levels. We find that the L2SBQ results are broadly akin to those reported for the L1SBQ method in Table 5.10. Consequently, no significant evidence of endogeneity problem exists in the baseline model and thereby, the preceding estimates are appropriate for economic inferences.

Table 5.9: One-Stage Symmetric Bayesian Quantile estimates for policy rule at time-domain

Panel A: Baseline Contemporaneous Taylor Rule							
	30th	40th	50th	60th	75th	80th	90th
c	0.185	0.175	0.194	0.110	-0.086	-0.166	0.126
	[0.837]	[0.752]	[0.739]	[0.778]	[0.981]	[1.059]	[1.415]
i_{t-1}	0.950*	0.964*	0.976*	0.994*	1.028*	1.042*	1.055*
	[0.045]	[0.040]	[0.040]	[0.043]	[0.053]	[0.056]	[0.072]
$\tilde{\pi}_t$	0.098**	0.091**	0.084**	0.081**	0.087**	0.088**	0.087**
	[0.039]	[0.035]	[0.035]	[0.033]	[0.030]	[0.030]	[0.037]
$\tilde{y}_t$	0.038	0.050	0.059	0.080	0.113	0.121	0.131
	[0.071]	[0.074]	[0.078]	[0.082]	[0.096]	[0.106]	[0.151]

Cumulative Reaction							
$\tilde{\pi}_t$	***1.96***	***2.53***	***3.50***	***13.50***	***-3.11***	***-2.10***	***-1.58***
Panel B: Augmented Contemporaneous Taylor Rule (including Lagged Exchange rate)							
c	0.289	0.238	0.215	0.194	0.237	0.199	0.316
	[0.900]	[0.806]	[0.778]	[0.832]	[0.961]	[1.039]	[1.429]
i_{t-1}	0.936*	0.955*	0.969*	0.982*	1.001*	1.012*	1.035*
	[0.052]	[0.045]	[0.044]	[0.047]	[0.055]	[0.061]	[0.082]
$\tilde{\pi}_t$	0.083***	0.080**	0.076**	0.073**	0.074**	0.075**	0.079
	[0.045]	[0.038]	[0.036]	[0.034]	[0.033]	[0.033]	[0.042]
$\tilde{y}_t$	0.039	0.045	0.057	0.070	0.089	0.094	0.109
	[0.075]	[0.077]	[0.083]	[0.087]	[0.094]	[0.106]	[0.155]
Δe_{t-1}	0.013	0.011	0.013	0.016	0.020	0.021	0.022
	[0.020]	[0.017]	[0.018]	[0.018]	[0.020]	[0.023]	[0.036]
Cumulative Reaction							
$\tilde{\pi}_t$	***1.30***	***1.78***	***2.45***	***4.06***	***-74.0***	***-6.25***	***-2.25***

Note: i_{t-1} denotes lagged changes in monetary policy rate; $\tilde{\pi}_t$, denotes deviation of (aggregated) inflation from target; $\tilde{y}_t$, is output gap (overall); Δe_{t-1} denotes nominal exchange rate depreciation; Cumulative reaction is computed as $\frac{\zeta_\pi}{(1-\varpi_i)}$, where ζ_π is the coefficient of inflation gap; ϖ_i is the coefficient for i_{t-1}.

The linear time-domain estimates produce statistically significant coefficients for the smoothing parameter. The observed high level of central bank smoothing of interest rate in Ghana is consistent with the empirical literature for developing and emerging economies. For instance, Bleaney et al (2020) find similar high policy inertia for Ghana while Caporale et al. (2018) also find that the interest rate smoothing coefficients are close to unity in both regimes for Indonesia, Israel, South Korea and Turkey in the low inflation regime. The delays and lags in changing the monetary policy stance by the MPC are, in part, due to loss aversion. The latter is driven primarily by policy uncertainty about the true state of the economy at the time of decision making. Additionally, the MPC is unable to accurately determine if the previous policy action has already fully impacted the economy due partly to ineffective interest rate transmission mechanism in Ghana (see, Kovanen, 2011; Akosah, 2015). Therefore, the authority considers monetary inertia as a rational strategy to avoid tough 'stop-and-go' policies and the resultant negative macroeconomic spillovers (see, Masciandaro, 2017)[77].

The level coefficient for inflation gap is positive and significant across quantiles. In term of magnitudes, the estimated level coefficient for inflation gap is below unity across quantiles. This suggests the instant policy reaction to inflation is inconsistent with the prescription by the Taylor rule. However, the cumulative policy reaction to inflation gap is greater than one in the

[77] The observed high policy inertia in Ghana could conceivably be linked to the fact that the MPC follows a "consensus voting model" whereby interest rate decision is based on supermajority. As argued by Dal Bo (2006), such voting model leads MPC to act as a conservative central banker. Particularly, the supermajority rule alleviates concerns of time-inconsistency and ushers in a status quo bias in monetary policy decisions.

levels analysis (see Table 5.9), in line with Bleaney et al. (2020). Also the policy responds more strongly to inflation when interest rate is low than when they are high at time domain, contradicting the findings of Chevapatrakul and Paez-Farrell (2014) for Australia, Canada and New Zealand.

The estimate level coefficients for output gap implied by the baseline method are positive but insignificant across quantiles, in line with the findings of Bleaney et al. (2020). However, the alternative method yields slightly different outcome for both variables. The estimated level coefficient for the output gap is positive but significant only at the higher quantiles (see Appendix 5Di) in the alternative method. The linear rule suggests that the Bank of Ghana has placed rather more weight on controlling inflation relatively to output stabilization. The weak interest rate response to output gap could possibly be linked to increased output uncertainty as the authority is unable to adequately gauge to true state of the Ghanaian business cycle at the time of decision making.

Next, we then consider several versions of augmented and forward-looking linear Taylor rules at levels by including other important variables given the peculiar characteristic of Ghana. The estimates for the augmented linear Taylor rule at levels are reported in Panel B of Table 5.9 and Table 5.10. As a small open economy, we first consider whether the Bank of Ghana takes US monetary policy as external constraints and this is done in two ways. We first introduce changes in cedi/US dollar into the BOG reaction function to account for imported inflation. We then consider the US federal fund rate in the monetary policy reaction function for Ghana. In both cases, the simple rule wins as the external variables are statistically insignificant across quantiles in the baseline method (L1SBQ). The insignificant coefficient for exchange rate is in line the findings of Bleaney et al (2020) for Ghana. Indeed, the inclusion of the US federal fund rate does not alter the baseline estimates. But introducing exchange rate in the Taylor rule rather increases the variances of inflation and output gaps, contradicting the assertion by Ball (1999) and Debelle (1999) that the unpredictability of both latter variables are reduced in this way. Nonetheless, the coefficient for exchange rate is positive but significant only at the higher quantiles (see Appendix 5Bi) in the alternative method, even though the level of significant remains weak (at 10% alpha level).

Table 5.10: L1SBQ Time-Domain Estimates for Alternative Taylor Rules

Panel A: Augmented Contemporaneous Taylor Rule									
	30th	50th	75th	30th	50th	75th	30th	50th	75th
c	0.240	0.171	-0.108	0.150	0.206	0.071	0.159	0.250	0.231
	[0.870]	[0.763]	[0.993]	[0.857]	[0.756]	[0.994]	[0.919]	[0.843]	[1.084]
i_{t-1}	0.943*	0.976*	1.027*	0.950*	0.976*	1.021*	0.951*	0.975*	1.018*
	[0.068]	[0.059]	[0.080]	[0.046]	[0.041]	[0.053]	[0.047]	[0.042]	[0.054]
$\tilde{\pi}_t$	0.099**	0.083**	0.088**	0.098**	0.082**	0.081**	0.098**	0.085**	0.082**
	[0.039]	[0.034]	[0.031]	[0.039]	[0.034]	[0.031]	[0.040]	[0.034]	[0.031]
$\tilde{y}_t$	0.036	0.064	0.109	0.038	0.058	0.103	0.041	0.070	0.121
	[0.077]	[0.080]	[0.096]	[0.075]	[0.078]	[0.099]	[0.079]	[0.084]	[0.098]
π_{t-1}	0.002	0.002	0.004						
	[0.047]	[0.045]	[0.062]						
$\tilde{m}_t$				0.008	0.015	0.016			
				[0.033]	[0.029]	[0.034]			
i_t^*							-0.022	-0.013	-0.058
							[0.131]	[0.115]	[0.140]
Panel B: Forward-Looking Taylor Rule									
c	-0.034	0.040	-0.188	-0.229	-0.169	-0.416	1.017	1.070	1.455
	[0.900]	[0.838]	[1.075]	[0.893]	[0.760]	[0.980]	[1.079]	[0.902]	[1.114]
i_{t-1}	0.958*	0.997*	1.045*	0.964*	0.988*	1.039*	0.885*	0.911*	0.906*
	[0.048]	[0.045]	[0.058]	[0.047]	[0.040]	[0.052]	[0.073]	[0.061]	[0.078]
$\tilde{\pi}_t$	0.082	0.075	0.082	0.081**	0.077**	0.080**	0.166**	0.154**	0.154**
	[0.045]	[0.039]	[0.042]	[0.035]	[0.031]	[0.031]	[0.057]	[0.048]	[0.054]
$\tilde{y}_t$	0.054	0.083	0.121	0.029	0.052	0.090	-0.017	-0.013	0.003
	[0.081]	[0.083]	[0.104]	[0.081]	[0.075]	[0.089]	[0.115]	[0.108]	[0.124]
$\tilde{\pi}_{t+1}$	0.030	0.015	0.009						
	[0.041]	[0.037]	[0.045]						
$\tilde{\pi}_{t+3}$				0.064	0.050	0.039			
				[0.040]	[0.033]	[0.035]			
$\tilde{\pi}_{t+1}^{survey}$							-0.013	-0.005	0.044
							[0.114]	[0.100]	[0.130]
Panel C: Backward & Forward-Looking Taylor Rules									
c	-0.160	-0.211	-0.332	0.258	-0.011	0.028	0.063	-0.064	0.203
	[0.917]	[0.769]	[0.994]	[0.918]	[0.788]	[1.061]	[0.964]	[0.845]	[1.013]
i_{t-1}	0.944*	0.965*	1.002*	0.927*	0.951*	0.962*	0.932*	0.961*	0.979*
	[0.064]	[0.058]	[0.086]	[0.071]	[0.060]	[0.083]	[0.071]	[0.060]	[0.083]
$\tilde{\pi}_t$	0.082**	0.074**	0.078**						
	[0.037]	[0.031]	[0.032]						
$\tilde{y}_t$	0.029	0.050	0.089	0.007	0.023	0.040	0.064	0.059	0.064
	[0.083]	[0.073]	[0.096]	[0.088]	[0.073]	[0.088]	[0.091]	[0.076]	[0.088]
$\tilde{\pi}_{t+3}$	0.067	0.058	0.048	0.080	0.066	0.085	0.071	0.062	0.073
	[0.040]	[0.035]	[0.041]	[0.043]	[0.038]	[0.044]	[0.035]	[0.036]	[0.036]
π_{t-1}	0.018	0.031	0.040	0.018	0.044	0.067	0.029	0.038	0.042
	[0.050]	[0.051]	[0.070]	[0.058]	[0.051]	[0.066]	[0.056]	[0.049]	[0.063]
Panel D: Augmented Forward-Looking Taylor Rule									
c	-0.141	-0.153	-0.084	0.295	0.034	0.500	0.167	0.033	0.555
	[0.948]	[0.780]	[1.001]	[0.923]	[0.821]	[0.986]	[0.964]	[0.881]	[0.987]
i_{t-1}	0.952*	0.981*	1.013*	0.921*	0.970*	0.976*	0.933*	0.976*	0.981*
	[0.052]	[0.042]	[0.057]	[0.052]	[0.045]	[0.054]	[0.054]	[0.048]	[0.054]
$\tilde{\pi}_t$	0.068	0.069**	0.068***						
	[0.040]	[0.033]	[0.035]						
$\tilde{y}_t$	0.034	0.051	0.073	0.023	0.022	0.020	0.067	0.057	0.042
	[0.081]	[0.076]	[0.092]	[0.083]	[0.076]	[0.082]	[0.084]	[0.085]	[0.083]
Δe_{t-1}	0.013	0.014	0.020	0.030	0.026	0.037	0.027	0.022	0.030
	[0.019]	[0.016]	[0.022]	[0.017]	[0.017]	[0.021]	[0.017]	[0.017]	[0.021]
$\tilde{\pi}_{t+3}$	0.064	0.051	0.037	0.069	0.055	0.053			

	[0.039]	[0.033]	[0.036]	[0.040]	[0.034]	[0.034]			
$\tilde{\pi}_{t+1}$							0.055	0.049	0.049
							[0.034]	[0.033]	[0.034]

Note: PM denotes posterior mean; *,**&*** denote significant posterior mean at 1%, 5% & 10% significant level respectively; i_{t-1} denotes lagged changes in monetary policy rate; $\tilde{\pi}_t$ denotes positive deviation of inflation from target (i.e. inflationary periods). $\tilde{y}_t$ is overall output gap; Δe_{t-1} denotes previous nominal exchange rate depreciation; subscript "$t+1$" denotes one-quarter ahead inflation deviation from target. i_t^* represents US federal fund rate; $\tilde{m}_t$ is deviation of broad money growth from HP trend; π_{t-1} is first lagged of CPI inflation rate.

As clearly shown in Table 4.10, the broad money gap does not matter and the other parameters remain unchanged. Similarly, Panels C and D of Table 3 (see also Appendix 5Eii for monthly data) show that the estimated coefficients for expected future deviation of inflation from the target are positive as expected but statistically indifferent from zero. Besides, we also allow lagged inflation to enter the reaction function along with expected inflation and output gap. The lagged inflation does not significantly matter when it is added to the linear reaction function for Ghana. It also appears that the contemporaneous rule is better than the forward-looking rule for Ghana.

5.4.3.3 Multiscale Linear Taylor Rule Results

Table 5.11 presents the multiscale estimates for linear Taylor rule for Ghana. Close examination of the table reveals important findings from the multiscale estimates that are hardly discernible in the level (i.e. time-domain) estimates. Contrary to level estimates, the multiscale analysis reveals evident of medium-to-high interest rate persistent only at the medium-to-longer time-scale. We however find no evidence of policy inertia in the short run for the linear rule.

Table 5.11: Multiscale One-Stage Bayesian Quantile Estimates for Linear (Augmented) Taylor Rule

Panel A: Shorter Scale										
	30th	40th	50th	75th	90th	30th	40th	50th	75th	90th
c	-0.247	-0.118	-0.016	0.274	0.626**	-0.244	-0.109	0.008	0.295***	0.715*
	[0.136]	[0.127]	[0.120]	[0.149]	[0.267]	[0.146]	[0.134]	[0.131]	[0.150]	[0.291]
i_{t-1}	-0.29	-0.309	-0.31	-0.267	-0.224	-0.312	-0.31	-0.302	-0.263	-0.239
	[0.350]	[0.325]	[0.308]	[0.385]	[0.523]	[0.336]	[0.322]	[0.316]	[0.376]	[0.568]
$\tilde{\pi}_t$	0.03	0.038	0.043	0.056	0.051	0.028	0.034	0.038	0.049	0.046
	[0.058]	[0.056]	[0.057]	[0.062]	[0.077]	[0.061]	[0.058]	[0.056]	[0.059]	[0.078]
$\tilde{y}_t$	0.229	0.209	0.212	0.242	0.291	0.089	0.094	0.084	0.103	0.160
	[0.291]	[0.259]	[0.267]	[0.274]	[0.317]	[0.333]	[0.311]	[0.300]	[0.337]	[0.502]
Δe_{t-1}						0.051	0.050	0.051	0.055	0.050
						[0.079]	[0.071]	[0.067]	[0.075]	[0.120]
Panel B: Medium Scale										
c	-0.355	-0.179	-0.011	0.462**	0.956*	-0.371	-0.164	0.011	0.477	0.997
	[0.167]	[0.158]	[0.156]	[0.189]	[0.306]	[0.190]	[0.173]	[0.172]	[0.178]	[0.330]

i_{t-1}	0.597**	0.611**	0.611**	0.647**	0.713**	0.578**	0.598*	0.618*	0.667*	0.722**
	[0.223]	[0.210]	[0.210]	[0.230]	[0.341]	[0.225]	[0.206]	[0.192]	[0.221]	[0.321]
$\tilde{\pi}_t$	0.120**	0.123**	0.123**	0.133**	0.152**	0.106***	0.107**	0.108**	0.115**	0.128**
	[0.053]	[0.049]	[0.047]	[0.054]	[0.077]	[0.055]	[0.051]	[0.048]	[0.055]	[0.078]
$\tilde{y}_t$	-0.022	-0.007	0.005	0.02	0.101	-0.034	-0.026	-0.02	-0.014	0.004
	[0.143]	[0.146]	[0.136]	[0.163]	[0.215]	[0.142]	[0.136]	[0.135]	[0.153]	[0.224]
Δe_{t-1}						0.04	0.038	0.041	0.049	0.056
						[0.042]	[0.039]	[0.039]	[0.045]	[0.064]
Cumulative Reaction										
$\tilde{\pi}_t$	***0.30***	***0.32***	***0.32***	***0.38***	***0.53***	***0.25***	***0.27***	***0.28***	***0.35***	***0.30***
Panel C: Longer Scale										
c	-0.448	-0.233	-0.036	0.558*	1.202*	-0.431	-0.206	-0.001	0.557**	1.303*
	[0.181]	[0.166]	[0.177]	[0.197]	[0.357]	[0.193]	0.176	0.182	0.205	[0.381]
i_{t-1}	0.850*	0.850*	0.845*	0.816*	0.796*	0.804*	0.797**	0.791*	0.784*	0.805*
	[0.180]	[0.167]	[0.154]	[0.185]	[0.256]	[0.178]	[0.170]	[0.158]	[0.191]	[0.262]
$\tilde{\pi}_t$	0.109**	0.111**	0.108**	0.083	0.070	0.097**	0.099**	0.094**	0.076	0.061
	[0.043]	[0.041]	[0.039]	[0.044]	[0.046]	[0.043]	[0.044]	[0.042]	[0.041]	[0.049]
$\tilde{y}_t$	0.078	0.08	0.071	0.107	0.192	0.044	0.039	0.037	0.058	0.125
	[0.121]	[0.107]	[0.103]	[0.127]	[0.186]	[0.128]	[0.115]	[0.110]	[0.129]	[0.209]
Δe_{t-1}						0.025	0.024	0.025	0.023	0.027
						[0.026	[0.024]	[0.023]	[0.028]	[0.045]
Cumulative Reaction										
$\tilde{\pi}_t$	***0.73***	***0.74***	***0.70***	***0.45***	***0.34***	***0.49***	***0.49***	***0.45***	***0.35***	***0.31***

Note: i_{t-1} denotes lagged changes in monetary policy rate; $\tilde{\pi}_{t,}$ denotes deviation of (aggregated) inflation from target; $\tilde{y}_{t,}$ is output gap (overall); Δe_{t-1} denotes nominal exchange rate depreciation; Cumulative reaction is computed as $\frac{\zeta_\pi}{(1-\varpi_i)}$, where ζ_π is the coefficient of inflation gap; ϖ_i is the coefficient for i_{t-1}.

Another striking finding is that the positive coefficient for inflation gap is statistically significant only in the medium-to-long run. Compared to the level analysis, the magnitude of immediate policy reaction to inflation are relatively greater in the multiscale domain especially in the medium-to-longer time scale. However, the estimated instant and cumulative[78] coefficients for inflation gap are below unity across quantiles, contradicting the earlier linear estimates (see Table 5.9). By implication, an increase in nominal rate in response to a rise in inflation will not cause real interest rate to rise even in the long run. Consequently, the linear multiscale estimates point to an accommodative monetary policy rule in Ghana, contrary to the findings of Bleaney et al. (2020). In the short-to-medium run, policy reaction to inflation is relatively stronger when interest rate is high than when it is low. Conversely, policy responds to inflation is rather stronger when interest rate is low in the long run. Unfortunately, our

[78] In this paper the Cumulative reaction is computed as $\frac{\zeta_\pi}{(1-\varpi_i)}$, where ζ_π is the coefficient of inflation gap; ϖ_i is the coefficient for i_{t-1}.

multiscale findings are incomparable to that of Bleaney et al (2020) and Chevapatrakul and Paez-Farrell (2014) at the both latter studies rather focused on time domain analysis.

The estimated multiscale coefficients for output gap and exchange rate are positive but insignificant across quantiles and time horizons, consistent with the level analysis. However, the alternative method shows weakly significant (at 10% alpha level) and positive coefficients for output gap and exchange rate at the extreme higher quantiles in the long run and short run respectively. The estimated weak policy reaction to exchange rate and output gap is consistent with findings of Bleaney et al (2020). Above all, the estimated linear rule also seems to suggest that the Bank of Ghana places rather more weight on controlling inflation relatively to output stabilization. Intuitively, this finding could perhaps be attributed to an increased output uncertainty in Ghana or that the authority does not react to output gap independently of its concern about inflation. We validate the findings based on the linear Taylor rule in the next section using nonlinear (augmented) Taylor rule specification for Ghana.

5.4.3.4 Nonlinear Taylor Rule Results: Level vs. Multiscale Quantile Estimates

Here, we assess whether monetary policy behaviour differs when inflation (or output) is above or below its target (or potential) using spline quantile regression techniques. As specified in equation (4.9), we separate the latter variables into positive and negative gaps using zero (0) as a threshold value. Tables 5.11 and 5.12 report the estimates for nonlinear policy rule at levels (time-domain) and multiscale domain respectively based on the baseline (Bayesian) method. The figures at Appendix 5Ei and 5Eii-iv also display the corresponding estimated based on the alternative method. The parallel nonlinear two-stage bayesian quantile estimates are reported at Panel B of Appendix 5Fi and 5Fii. The estimates from both Bayesian methods yield parallel results, implying that the baseline method is good for economic inferences.

The basic finding is that both quantile methods show sufficient evidence of nonlinearity (asymmetry) in the monetary policy reaction function for Ghana, consistent with findings by Castro (2011) for Bank of England and European Central Bank. Similarly, the multiscale analysis remits important findings that are hardly discernible in the time-domain analysis. On a whole, both the linear and nonlinear Taylor rule estimates concur on the existence of policy

inertia in Ghana even though the nonlinear rule yields slightly lower magnitudes compared to the linear one.

There is clear evidence of nonlinear (asymmetric) policy reaction to inflation gap, contradicting the findings of the preceding linear policy rule and consistent with the GMM estimates. The estimated level coefficient for above-target inflation (i.e. positive deviation of inflation from target) is positive and significant across quantiles, while the counterpart level coefficient for below-target inflation (i.e. negative deviation of inflation from target) is insignificant across quantiles. Consistent with findings of Dolado et al (2005) and Chevapatrakul and Paez-Farrell (2014), the monetary authority in Ghana appear to place more weight on positive deviation of inflation from target than negative deviations. This surmises that the monetary authority in Ghana prefers below- to above-target inflation as it tries to build policy credibility (see, Goodhart, 1999). In contrast to the nonlinear time-domain (level) estimates, we find policy reaction to above-target inflation to be timescale dependent because the multiscale coefficient for the latter variable is significant only in the long run (while the alternative method shows significant response in the medium-to-long run). This implies that authority in Ghana appears to react rather strongly to above-target inflation (i.e. inflationary pressures) in the medium-to-long term. The delayed policy response to above-target inflation level could partly be an indication of an existence of a threshold positive inflation gap beyond (below) which the central bank intensifies (weakens) its response to price movements. This is further investigated in the next section.

The estimated instant policy response to above-target inflation (positive gap) is below unity across quantiles and analytical domains, consistent with the linear estimates. The estimated cumulative reaction to above-target inflation is however greater than unity for the level analysis (see Table 5.11) but below unity even at the longer timescale (see Table 5.12) in the multiscale analysis. Although our level estimated cumulative reaction corroborates with the findings by Bleaney et al (2020) that monetary authority follows the theoretically recommended response to inflation, the multiscale analysis reveals a strike contrast. The latter finding buttresses that

the monetary authority in Ghana appears not to adhere to the Taylor principle[79] even at the longer time horizon. This passive or accommodative policy reaction to positive inflation gap even in the long run could underpin the persistently high inflation episodes in Ghana. Their inability to react aggressively to inflationary pressure is attributable to inefficient monetary transmission mechanism due to shallow banking/financial system (Kovanen, 2011) as well as weak institutions (or lack of central bank legal independence) which reflect acute fiscal dominance (Cukierman et al 1992; Akpan et al. 2014; Bleaney et al. 2020) in Ghana. Given these constraints, the monetary authority often resort to its other available instruments like the international reserves to smooth exchange rate fluctuations so as to stable the macroeconomy.

The nonlinear multiscale estimates equally show a general weak policy reaction to both output gap and exchange rate. The nonlinear multiscale estimates thus reinforces that the central bank puts greater weight on price rather than output stabilization in line with its prime policy mandate of price stability. In other words, the bank does not react to the real economy independently of its concerns about inflation stabilization.

Table 5.11: Bayesian Quantile Estimates for Nonlinear Taylor Rules at Time-Domain

Panel A: Nonlinear (non-augmented) Taylor Rule							
	30th	40th	50th	60th	75th	80th	90th
Immediate Reaction							
c	0.644	0.601	0.644	0.734	0.930	0.946	1.128
	[0.954]	[0.843]	[0.760]	[0.750]	[0.854]	[0.913]	[1.356]
i_{t-1}	0.911**	0.927**	0.936**	0.942**	0.946**	0.950**	0.955**
	[0.056]	[0.050]	[0.044]	[0.043]	[0.049]	[0.052]	[0.076]
$\tilde{\pi}_t^+$	0.188**	0.181**	0.178**	0.176**	0.183**	0.189**	0.205**
	[0.050]	[0.047]	[0.046]	[0.046]	[0.051]	[0.056]	[0.081]
$\tilde{\pi}_t^-$	-0.034	-0.044	-0.049	-0.055	-0.061	-0.067	-0.093
	[0.065]	[0.057]	[0.052]	[0.051]	[0.059]	[0.069]	[0.112]
$\tilde{y}_t^+$	-0.090	-0.069	-0.068	-0.071	-0.058	-0.037	0.055
	[0.153]	[0.135]	[0.131]	[0.131]	[0.152]	[0.165]	[0.257]
$\tilde{y}_t^-$	0.170	0.145	0.136	0.126	0.087	0.070	0.014
	[0.200]	[0.172]	[0.163]	[0.162]	[0.182]	[0.198]	[0.290]
Cumulative Reaction							
$\tilde{\pi}_t^+$	***2.11***	***2.48***	***2.78***	***3.03***	***3.39***	***3.78***	***4.56***
Panel B: Nonlinear Augmented Taylor Rule							
Immediate Reaction							
c	0.778	0.641	0.699	0.791	0.945	0.990	1.118
	[0.993]	[0.844]	[0.780]	[0.768]	[0.864]	[0.956]	[1.408]
i_{t-1}	0.897**	0.918**	0.928**	0.935**	0.939**	0.942**	0.951**
	[0.061]	[0.053]	[0.048]	[0.046]	[0.050]	[0.055]	[0.080]
$\tilde{\pi}_t^+$	0.181**	0.178**	0.174**	0.170**	0.174**	0.176**	0.189**

[79] Several papers (e.g. Ball, 1999; Svensson, 1999, 2003; McCallum and Nelson, 1999; Carlson, 2007; and Martin and Milas, 2013) have argued that it is undesirable to follow the Taylor rule mechanically.

	[0.055]	[0.050]	[0.047]	[0.048]	[0.056]	[0.060]	[0.090]
$\tilde{\pi}_t^-$	-0.041	-0.045	-0.050	-0.054	-0.062	-0.063	-0.082
	[0.064]	[0.056]	[0.053]	[0.052]	[0.061]	[0.067]	[0.109]
$\tilde{y}_t^+$	-0.085	-0.065	-0.064	-0.065	-0.048	-0.031	0.056
	[0.155]	[0.136]	[0.129]	[0.131]	[0.161]	[0.180]	[0.278]
$\tilde{y}_t^-$	0.164	0.144	0.123	0.109	0.062	0.044	-0.015
	[0.198]	[0.179]	[0.167]	[0.167]	[0.194]	[0.215]	[0.320]
Δe_{t-1}	0.009	0.008	0.008	0.008	0.011	0.013	0.018
	[0.020]	[0.018]	[0.017]	[0.017]	[0.020]	[0.022]	[0.035]
Cumulative Reaction							
$\tilde{\pi}_t^+$	***1.76***	***2.17***	***2.42***	***2.62***	***2.85***	***3.03***	***3.86***

Note: MCMC applies 50000 replicates for the time scale analysis; i_{t-1} denotes lagged changes in monetary policy rate; $\tilde{\pi}_t^+$ denotes positive deviation of inflation from target (i.e. inflationary periods). Here, we use inflation target of 10% which is the upper band of the medium-term target; $\tilde{\pi}_t^-$, denotes negative deviation of inflation from target (i.e. disinflationary period); $\tilde{y}_t^+$ is positive output gap (period of economic boom); $\tilde{y}_t^-$ is negative output gap (period of economic downturn); Δe_{t-1} denotes nominal exchange rate depreciation; *, ** & *** represent 1%, 5% & 10% significance levels respectively. Cumulative reaction is computed as $\frac{\zeta_\pi}{(1-\varpi_i)}$, where ζ_π is the coefficient of inflation gap; ϖ_i is the coefficient for i_{t-1}.

Table 5.12: Bayesian Quantile Estimates for Nonlinear Taylor Rules at Multiscale Domain

Panel A: Shorter Scale										
	30th	**40th**	**50th**	**75th**	**90th**	**30th**	**40th**	**50th**	**75th**	**90th**
c	-0.267	-0.133	-0.019	0.297	0.743	-0.266	-0.123	0.001	0.330	0.850
	[0.140]	[0.129]	[0.127[	[0.152]	[0.288]	[0.159]	[0.138]	[0.129]	[0.159]	[0.346]
i_{t-1}	-0.319	-0.317	-0.299	-0.312	-0.261	-0.281	-0.297	-0.267	-0.226	-0.145
	[0.379]	[0.350]	[0.358]	[0.426]	[0.650]	[0.404]	[0.391]	[0.379]	[0.460]	[0.699]
$\tilde{\pi}_t^+$	0.002	0.013	0.022	0.032	0.051	0.002	0.009	0.016	0.034	0.045
	[0.095]	[0.090]	[0.087]	[0.099]	[0.128]	[0.096]	[0.089]	[0.084]	[0.099]	[0.138]
$\tilde{\pi}_t^-$	0.023	0.023	0.025	0.031	0.020	0.024	0.025	0.024	0.026	0.008
	[0.098]	[0.095]	[0.097]	[0.103]	[0.140]	[0.101]	[0.095]	[0.093]	[0.105]	[0.153]
$\tilde{y}_t^+$	0.280	0.279	0.284	0.301	0.355	0.159	0.166	0.180	0.188	0.272
	[0.304]	[0.283]	[0.271]	[0.290]	[0.386]	[0.340]	[0.338]	[0.328]	[0.362]	[0.554]
$\tilde{y}_t^-$	-0.220	-0.209	-0.141	-0.155	-0.157	-0.210	-0.211	-0.204	-0.185	-0.256
	[0.788]	[0.737]	[0.735]	[0.838]	[1.152]	[0.806]	[0.753]	[0.757]	[0.835]	[1.265]
Δe_{t-1}						0.039	0.041	0.039	0.042	0.034
						[0.076]	[0.073]	[0.070]	[0.084]	[0.133]
Panel B: Medium Scale										
c	-0.379	-0.178	-0.001	0.495	1.059	-0.397	-0.168	0.033	0.516	1.111
	[0.178]	[0.157]	[0.156]	[0.169]	[0.299]	[0.196]	[0.182]	[0.163]	[0.190]	[0.373]
i_{t-1}	0.527*	0.543*	0.544*	0.546*	0.557*	0.550*	0.568*	0.582*	0.597*	0.606*
	[0.244]	[0.225]	[0.219]	[0.239]	[0.342]	[0.248]	[0.229]	[0.217]	[0.251]	[0.376]
$\tilde{\pi}_t^+$	0.098	0.106	0.105	0.105	0.114	0.102	0.106	0.103	0.099	0.105
	[0.088]	[0.080]	[0.076]	[0.081]	[0.114]	[0.087]	[0.077]	[0.076]	[0.084]	[0.116]
$\tilde{\pi}_t^-$	0.078	0.074	0.062	0.042	0.025	0.061	0.048	0.034	-0.001	-0.016
	[0.102]	[0.094]	[0.092]	[0.098]	[0.131]	[0.103]	[0.098]	[0.099]	[0.109]	[0.156]
$\tilde{y}_t^+$	0.092	0.113	0.133	0.187	0.284	0.051	0.082	0.106	0.152	0.211
	[0.206]	[0.187]	[0.169]	[0.191]	[0.238]	[0.188]	[0.169]	[0.161]	[0.168]	[0.246]
$\tilde{y}_t^-$	-0.196	-0.192	-0.219	-0.278	-0.302	-0.135	-0.168	-0.183	-0.284	-0.359
	[0.328]	[0.312]	[0.301]	[0.314]	[0.459]	[0.333]	[0.307]	[0.297]	[0.330]	[0.529]
Δe_{t-1}						0.041	0.038	0.041	0.055	0.054
						[0.045]	[0.042]	[0.038]	[0.043]	[0.073]
Panel C: Longer Scale										
c	-0.383	-0.191	0.012	0.553	1.152	-0.378	-0.167	0.048	0.567	1.224
	[0.180]	[0.169]	[0.166]	[0.174]	[0.324]	[0.199]	[0.194]	[0.185]	[0.203]	[0.384]
i_{t-1}	0.767*	0.752*	0.737*	0.692*	0.635*	0.743*	0.734*	0.712*	0.675*	0.638*
	[0.179]	[0.166]	[0.165]	[0.184]	[0.279]	[0.175]	[0.172]	[0.166]	[0.193]	[0.284]
$\tilde{\pi}_t^+$	0.232**	0.227**	0.224**	0.207**	0.215**	0.213**	0.206**	0.203**	0.197**	0.206**

	[0.078]	[0.070]	[0.070]	[0.082]	[0.123]	[0.081]	[0.074]	[0.071]	[0.084]	[0.120]
$\tilde{\pi}_t^-$	-0.076	-0.076	-0.078	-0.083	-0.098	-0.077	-0.069	-0.074	-0.091	-0.111
	[0.074]	[0.074]	[0.072]	[0.069]	[0.088]	[0.074]	[0.070]	[0.068]	[0.070]	[0.098]
$\tilde{y}_t^+$	0.207	0.219	0.213	0.253	0.336	0.181	0.181	0.180	0.202	0.276
	[0.167]	[0.158]	[0.162]	[0.160]	[0.206]	[0.161]	[0.150]	[0.147]	[0.155]	[0.229]
$\tilde{y}_t^-$	-0.140	-0.173	-0.207	-0.312	-0.380	-0.178	-0.214	-0.270	-0.380	-0.498
	[0.259]	[0.251]	[0.263]	[0.313]	[0.515]	[0.260]	[0.267]	[0.272]	[0.325]	[0.514]
Δe_{t-1}						0.016	0.019	0.021	0.027	0.032
						[0.029]	[0.026]	[0.024]	[0.027]	[0.043]
Cumulative Reaction										
$\tilde{\pi}_t^+$	***1.00***	***0.91***	***0.85***	***0.67***	***0.59***	***0.83***	***0.77***	***0.70***	***0.61***	***0.57***

Note: MCMC applies 50000 replicates for the time scale analysis; i_{t-1} denotes lagged changes in monetary policy rate; $\tilde{\pi}_t^+$ denotes positive deviation of inflation from target (i.e. inflationary periods). Here, we use inflation target of 10% which is the upper band of the medium-term target; $\tilde{\pi}_t^-$, denotes negative deviation of inflation from target (i.e. disinflationary period); $\tilde{y}_t^+$ is positive output gap (period of economic boom); $\tilde{y}_t^-$ is negative output gap (period of economic downturn); Δe_{t-1} denotes nominal exchange rate depreciation; *, ** & *** represent 1%, 5% & 10% significance levels respectively. Cumulative reaction is computed as $\frac{\zeta_\pi}{(1-\varpi_i)}$, where ζ_π is the coefficient of inflation gap; ϖ_i is the coefficient for i_{t-1}.

The table at Appendix 5Fiii also reports the generated MPIP values for the predictor variables based on the baseline method. The table clearly reinforces of monetary policy inertia in Ghana as the lagged interest rate (i_{t-1}) obtain MPIP values greater than the threshold (i.e. 1/2) across all quantiles and datasets. Aside that, only positive inflation gap ($i.e.\tilde{\pi}_t > 0$) attains MPIP values greater than the 0.5 across all quantiles in the nonlinear estimates. Both the output gap and exchange rate record MPIP values below 0.5 across quantiles, backing earlier conjecture that the monetary authority in Ghana does not react to the real economy independently of its concern about inflation.

5.4.4 Threshold Regression Estimates

Given the delayed policy reaction to above-target inflation in the multiscale analysis, we proceed to use a more standard threshold regression method developed by Hansen (1999) to investigate the possibility of threshold interest rate reaction to inflation, output gap and exchange in Ghana. Here, we fit threshold models based on (i) a simple rule (see, Taylor, 1993), (ii) a forward-looking rule (following Clarida et al. 1998, 2000), (iii) augmented contemporaneous rule including the lagged and current exchange rate (see, Ball, 1999; Svensson, 2000; Taylor, 1999, 2001; Caporale et al, 2018) and (iv) augmented forward-looking rule that includes the expected and current inflation gap as well as lagged and current exchange rate. We allow for a trimming percentage of 25 and a maximum threshold of one based on the Bai-Perron (1998) tests of global L thresholds vs. none.

The Bai-Perron (1998) test rejects the null of linearity in favour of an alternative nonlinear rule for Ghana and the corresponding estimated results for nonlinear threshold Taylor rule are reported in Table 5.13. In terms of model selection, the augmented forward-looking Taylor rule including both the current and expected inflation gap as well as current and lagged exchange rate emerges as the best suited nonlinear (threshold) policy rule for Ghana (see, model VI). This however contradicts the preceding non-threshold estimates. The interest rate smoothing coefficient is still close to unity in both inflation regimes across all specifications. This confirms the earlier evidence that the monetary authority smooth interest rate adjustment in Ghana, and consistent with findings of Caporale et al (2018) for Indonesia, Israel, South Korea, Thailand and Turkey.

The estimated inflation gap coefficient is positive and significant in both regimes. However, the monetary authority in Ghana appears to react to both the current and expected inflation gap in the high inflation regime but respond only to current inflation gap in the low inflation regime. In line with Bleaney et al. (2020), we find that policy rate seems to react more strongly to an expected than to actual inflation gap in the high inflation regime. In contrast, the reaction of policy rate to actual inflation is rather stronger than to expected inflation in the low inflation regime. Collectively, these findings suggest that the interest rate transmission of monetary policy works well in both low- and high-inflation environment in Ghana. Yet, the cumulative response to inflation gap is below unity in the low inflation but above unity in the high inflation regime (see the preferred model VI). This rather surmises that the monetary authority in Ghana does not mechanically follow the Taylor principle especially in low inflation regime, confirming the earlier finding. But the authority seems to adhere to the rule especially during high inflation regime as it becomes more forward-looking in the latter regime.

The estimated coefficient for current exchange rate is positive and statistically significant across models in the low inflation regime. But the estimated coefficient for lagged exchange rate is negative but insignificant across models in the low inflation regime. In line with the literature (see Ball 1999; Taylor, 1999, 2001; Svensson, 2000; Obstfeld and Rogoff, 1995), we finds that (i) the size of the current exchange rate coefficient is larger than the lagged exchange rate coefficient in absolute terms and (ii) both the current exchange rate coefficient and the sum

of two coefficients are greater than zero. This is intuitively interpreted that a depreciation (appreciation) in nominal exchange rate would initially call for a tightening (an easing) of monetary policy stance followed by a partial offsetting policy easing (tightening) stance (see, Obstfeld and Rogoff, 1995; Taylor, 2001). These findings, in contrast with Bayesian estimates, suggest that the central bank reacts to exchange rate fluctuations only in the low inflation (and interest rate) regime in Ghana. This finding is consistent with that of Caporale et al., (2018) for Indonesia, South Korea and Thailand. The greater weight on the exchange rate in the low inflation regime is conceivably justified by the proclivity for policy makers to chase other objectives when the inflation rate undershoots the target and rely also on the exchange rate channel for stabilizing the economy (Akdogan, 2015). It appears therefore that the nominal exchange rate has an important role in the determining the behaviour of Bank of Ghana in the low inflation regime. This finding is coherent with extant literature (see, Ghosh et al. 2016; Mahanty, 2013; among others) that developing and emerging economies have inherent comfort zone for smoothing exchange rate fluctuations even if they do not specify an exchange rate target.

The estimated output gap coefficients are positive and negative in the low and high inflation regimes respective but are broadly insignificant across regimes in Ghana, consistent with the Bayesian estimates. Yet, the coefficient for the output gap is positive and significant in the low inflation regime for the simple model without expected inflation and exchange rate (see, model III). Also, the output gap coefficient is however negative and significant in the high inflation regime for forward-looking rule with or without exchange rate (see, models IV and VIII). The monetary authority in Ghana appears to be more concerned with aggregate demand pressures when inflation is low and therefore adopts a contractionary monetary policy stance to dampen such pressures. This is broadly in line with literature that contractionary monetary policy has negative impact on output (e.g. Mallick and Sousa, 2012; Jawadi et al. 2014; Caporale et al., 2018). The negative output gap coefficient in the high inflation regime can also be inferred that the Bank of Ghana is highly concerned with economic growth as its secondary mandate is to promote or ensure a sustained economic growth without prejudice to its prime objective of price stability.

Table 5.13: Nonlinear Taylor Rule based on Standard Threshold Regression

Model	I	II	III	IV	V	VI	VII	VIII
q_t	π_{t-1}	π_{t-1}	π_{t-1}	π_{t-1}	π_{t-1}	π_{t-1}	π_{t-1}	π_{t-1}
γ	13.79	16.44	11.39	11.67	16.13	16.44	11.67	11.67
				Panel A				
Regime 1:				**Low Inflation Regime**				
C	2.605*	2.253*	0.428	0.749	2.191*	2.255*		
	[0.246]	[0.283]	[1.374]	[1.131]	[0.353]	[0.391]		
i_{t-1}	0.777*	0.806*	0.964*	0.943*	0.819*	0.808*	0.978*	0.975*
	[0.013]	[0.019]	[0.101]	[0.082]	[0.022]	[0.025]	[0.011]	[0.013]
$\tilde{y}_t$	-0.008	0.020	0.099***	0.087	0.025	0.011	0.069	0.067
	[0.025]	[0.033]	[0.059]	[0.057]	[0.042]	[0.044]	[0.048]	[0.049]
$\tilde{\pi}_t$	0.102*	0.108*	0.056***	0.053	0.104*	0.100*	0.067***	0.064**
	[0.019]	[0.018]	[0.031]	[0.035]	[0.028]	[0.033]	[0.034]	[0.031]
$\tilde{\pi}_{t+1}$		0.016		-0.016		0.021		0.028
		[0.019]		[0.030]		[0.026]		[0.042]
Δe_t	0.061*	0.039*			0.074*	0.068**	0.083	0.095***
	[0.008]	[0.006]			[0.020]	[0.025]	[0.034]	[0.049
Δe_{t-1}					-0.053**	-0.035	-0.053	-0.065
					[0.022]	[0.026]	[0.033]	[0.049]
Cumulative Reaction								
$\tilde{\pi}_t$	***0.46***	***0.56***	***1.56***	***0.93***	***0.57***	***0.52***	***3.05***	***2.56***
				Panel B				
Regime 2:				**High Inflation Regime**				
C	0.493	1.072	1.114	0.598	1.095	1.164		
	[0.958]	[1.432]	[0.719]	[0.037]	[1.565]	[1.475]		
i_{t-1}	0.936*	0.890*	0.888*	0.902*	0.918*	0.886*	0.939*	0.932*
	[0.049]	[0.073]	[0.039]	[0.037]	[0.074]	[0.076]	[0.012]	[0.012]
$\tilde{y}_t$	0.075	-0.147	-0.068	-0.145**	0.109	-0.192	-0.053	-0.142**
	[0.058]	[0.152]	[0.053]	[0.058]	[0.094]	[0.155]	[0.066]	[0.062]
$\tilde{\pi}_t$	0.017*	0.102*	0.193*	0.124*	0.170*	0.103*	0.179*	0.119*
	[0.018]	[0.027]	[0.022]	[0.029]	[0.022]	[0.028]	[0.019]	[0.026]
$\tilde{\pi}_{t+1}$		0.193***		0.117**		0.192***		0.129***
		[0.100]		[0.058]		[0.010]		[0.065]
Δe_t	0.003	-0.036***			-0.021	-0.049	0.021	0.003
	[0.008]	[0.018]			[0.028]	[0.034]	[0.017]	[0.019]
Δe_{t-1}					0.019	0.014	-0.011	-0.007
					[0.021]	[0.023]	[0.019]	[0.016]
Cumulative Reaction								
$\tilde{\pi}_t$	***0.46***	***0.56***	***1.56***	***0.93***	***0.57***	***0.52***	***3.05***	***2.56***
$\tilde{\pi}_{t+1}$		***1.75***		***1.19***		***1.68***		***1.90***
R-squared	0.972	0.977	0.968	0.973	0.972	0.978	0.969	0.975
SSR	32.61	26.85	36.28	30.71	31.75	25.47	35.46	29.39
AIC	2.56	2.43	2.60	2.52	2.60	2.47	2.65	2.55
SBC	2.91	2.85	2.88	2.87	3.02	2.97	2.99	2.97
Log likelihood	-66.85	-61.02	-70.04	-64.46	-66.05	-58.94	-69.36	-63.16
D-W Stat	2.063	1.941	1.863	1.771	2.132	1.967	1.874	1.820
H-Test	{0.210}	{0.903}	{0.244}	{0.787}	{0.149}	{0.906}	{0.369}	{0.579}
SC-Test	{0.827}	{0.210}	{0.489}	{0.644}	{0.821}	{0.312}	{0.544}	{0.710}
Trimming %	25	25	25	25	25	25	25	25
Sig. level	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01

Note: *, **&*** denotes 1%, 5% & 10% significance levels respectively. H-T and SC-Test denote heteroskedasticity test and serial correlation test respectively. $\tilde{\pi}_t$ and $\tilde{y}_t$ denote inflation gap and output gap respectively; π_{t-1}, y_{t-1} and i_{t-1} are first lag of inflation rate, output growth and policy interest rate respectively;

$Xdep_t$ is change in exchange rate. The estimation covers the period 2003Q1-2017Q4 in order to focus only the preparatory and full IFT regime in Ghana. We applied HAC to estimate the standard errors and covariance.

5.5 Conclusion

This chapter has examined the interest rate setting behaviour of monetary authority in Ghana covering predominantly the commencement period of inflation targeting (IT) lite and the full adoption of inflation-forecast-targeting (IFT) regime. To fully comprehend the historical policy behaviour of Bank of Ghana following the adoption of inflation targeting regime, we estimate monetary policy reaction function in Ghana within the context of Taylor-type rules. The rationale is to ascertain whether the monetary authority in Ghana strictly follows the Taylor's (1993) principles as inflation remain persistently above its target. Besides specifying the standard linear Taylor rule, we also considered an augmented rule including the exchange rate, broad money, and/or foreign interest rate in line with the open economy literature (Daude et al 2016; Ghosh et al. 2016; Caporale et el. 2018; among others). Also following the recent empirical studies (e.g. Taylor and Davradakis, 2006; Surico, 2007; Cukierman and Muscatelli, 2008; Castro, 2011; Martin and Milas, 2004, 2013; Ahmad, 2016; Caporale et al. 2018; among others), we further estimate a nonlinear policy rule for Ghana using the spline Bayesian quantile regression as well as the more standard threshold regression method developed by Hansen (1999). In addition to the time-domain analysis which is mainly adopted by the previous studies, this chapter also provides perspective on monetary policy behaviour in Ghana at time-frequency (multiscale) domain using wavelet multi-resolution framework. Using quarterly data spanning the period 2001Q1-2017Q4, we also derive a segregated dataset from the latter by separating inflation and output gaps into positive and negative gaps. Each dataset is decomposed into three different wavelet time scales using Maximal Overlap Discrete Wavelet Transforms (MODWT) with Debauchies least asymmetric filter of length 8 (LA8). In terms of estimation techniques, we determine BOG monetary policy rule at conditional mean using GMM technique and at the tails via Frequentist and Bayesian quantile regressions.

Our empirical results show important findings regarding the historical behaviour of the monetary authority in Ghana (the BOG). The basic finding is that an asymmetric (nonlinear) Taylor rule captures the behaviour of interest rate settings in Ghana better than a symmetric (linear) rule. This is consistent with the findings of Caporale et al. (2018) and Miles and

Schreyer (2012). There is strong evidence of monetary policy inertia in Ghana as the coefficient of lagged interest rate is close to unity. The estimated instant coefficient for inflation gap is positive and statistically significant, but the authority is rather more inclined to react strongly to above-target inflation (i.e. inflationary pressures) in the medium-to-long term than in the short-term. The Bank of Ghana however appears not to have followed a fixed rule as interest reaction to output, inflation and exchange rate differs depending on the prevailing conditions. The exchange rate exerts an important influence on interest rate settings especially in the low inflation regime, supporting an augmented nonlinear (threshold) Taylor rule for Ghana in the latter regime. The greater policy reaction to the exchange rate in the low inflation regime is underscored by the inclination for policy makers to chase other objectives when the inflation rate undershoots the target and rely also on the exchange rate channel for stabilizing the economy (Akdogan, 2015). In the normal policy environment (i.e. non-threshold rule), the central bank rather reacts strongly to the current (positive) inflation gap across historical time interval and time-frequency domain. Under such environment, a nonlinear non-augmented rule is appropriate as the inclusion of exchange rate increases the variances of both inflation and output gap, a contradiction to the findings of Ball (1999) and Debelle (1999). In the high inflation regime, however, the reaction to expected inflation gap is relatively stronger than to current inflation gap. This indicates that the monetary authority becomes more forward-looking in the high inflation regime as its cumulative reaction to expected inflation exceeds unity. On a whole, the Bank of Ghana is more aggressive toward inflation than output growth. There is thus an apparent policy pursuit of a precautionary demand for price stability in a quest to building policy credibility, consistent with the findings of Bleaney et al (2020), Dolado et al (2005), Chevapatrakul and Paez-Farrell (2014). The weak policy response to output gap could either mean an increased output uncertainty as the authority is unable to accurately gauge the true state of the Ghanaian business cycle at the time of decision making or the authority does not react to the real economy independently from its concerns about inflation.

Despite the overriding bias towards positive inflation gap, the multiscale estimated coefficient for the latter variable is below unity even at the longer timescale. This suggests that monetary authority in Ghana has not responded to inflation shock in a manner recommended by the Taylor principle, given its external and domestic constraints. This further surmises that the

authority in Ghana has broadly been very accommodative to inflationary pressures as other policy interventions have not yielded the intended purpose of successfully taming inflation. The passive response to inflationary pressures is primarily underpinned by weak institutions (see, Bleaney et al. 2020; Akpan et al 2014; Cukierman et al. 1992) as well as inefficient transmission of monetary policy to the money market and the real sector (see, Kovanen 2011).

Another vital observation is that the quantile process estimates at the tails do not deviate significantly from the mean (50th decile) estimates. This surmises that the conditional mean estimate of the policy reaction function that focuses on the mean of interest rate distribution provides an adequate reflection of policy dynamics of interest rate distribution in Ghana.

Consistent with the findings of Dolado et al (2005), we find BOG to react positively and significantly to spill-overs from contemporaneous output gap to future expected inflation (four quarters ahead), especially at the shorter run. The time-scale dependence was evident as policy response to this output spill-overs is statistically insignificant at the medium and long run. This suggests that although the BOG may face a convex (non-linear) Philips curve, this is not apparent across all time scales.

Although there is unambiguous policy aversion to positive inflation gap across political regimes in line with the price stability objective of BOG, the conditional mean estimates show relatively higher aggression during political regime two (i.e. PR2). This is conceivable as the era is credibly linked to the frequent adverse demand and supply-side shocks during the era. Particular instances include negative spillovers from global financial and European debt crises (2007-2010 which reflected slowdown in domestic economic activity in 2009), energy supply challenges (in 2009 and 2014-15), large fiscal and external imbalances (2012), rising crude oil prices and acute exchange rate pressures (2014-15).

The empirical results remit strong policy implications in the face of high and persistent deviation of inflation from the medium term target of 8±2 percent. The high and persistent policy inertia suggests the BOG adherence to backward-looking Taylor rule which does not bode well for IT regime as the latter mostly hinges on forward-looking policy dynamics. Yet, the delays and lags in changing the monetary policy stance by the MPC are, in part, due to loss aversion. The latter is compelled primarily by policy uncertainty about the true state of the

economy at the time of decision making. Additionally, the MPC is unable to accurately determine if the previous policy action has already fully impacted the economy due partly to ineffective interest rate transmission mechanism in Ghana (see, Kovanen, 2011; Akosah, 2015). Consequently, a more forward-looking policy dynamics with deliberate and systematic reduction on policy inertia would warrant capacity building of the forecasting team at the central bank to help improve information flow and particularly proffer accurate assessment of the state of the economy at the time of making policy decision. Besides human capacity building, policy should also gear toward enhancing availability of data (both low and high frequencies) relevant for quick policy decisions by creating central database for the economy which would be easily accessible by especially relevant agencies and departments. While the central bank follows the requisite procedure in an IT regime, monetary policy transmission remains inefficient due to fiscal dominance, shallow and segmented financial market and interest rate rigidities. To improve the effectiveness of monetary policy, the central bank should be granted legal independence in order to eliminate the fiscal requirement of monetary policy.

Besides, BOG should identify other salient instruments or strategies aside the policy interest rate to address peculiar supply side shocks for which the latter may be ineffective. International evidence strongly suggests that the direct foreign exchange interventions are very costly (e.g. due to much lower reserves) and ineffective. Therefore, BOG needs to intensify other sterilization intervention measures (such as the Open Market Operation or daily liquidity management) in the domestic overnight interbank market so as to curtail excessive currency outside bank which often finds its way into the foreign exchange market. Since passive monetary policy rule has been linked to sufficiently high unbanked consumers, the BOG should strongly embrace the on-going mobile money platform to execute policies envisioned to boost financial inclusion. This is expected to increase the direct policy effect as the share of included consumers rises. To enhance financial inclusion also requires confidence in the financial system. Therefore, the BOG should beef up its supervisory role to ensure strict adherence of financial regulations and guidelines by the commercial banks and microfinance institutions. Cogent and proactive supervisory measures are thus warranted to ensure early detection and resolution of the most fragile financial institutions so as to prevent systemic risks and public dissatisfaction with the financial system.

Moreover, the continuous economic exposures to acute supply and demand-side shocks necessitate deliberate and consistent efforts to restructure the economy from over-dependence on imported goods to long-term domestic substitutes. This is expected to minimize the perennial external pressures that reflect in acute exchange rate volatilities. In the same token, the domestic structural weaknesses also warrant continuous harmonization of domestic monetary and fiscal policies in order to curtail unwarranted fiscal policy surprises which adversely affect business and consumer sentiments and trigger sudden stops in capital inflows.

Furthermore, the bank should address the bottlenecks that inhibit competition in the banking system and hasting the development of the secondary market by coming up credible and proactive policies. Notable extension to this chapter could be an investigation of the impact of inflation and output uncertainties in the monetary policy reaction function for Ghana and beyond.

CHAPTER SIX

Monetary Policy and Macroeconomic Uncertainties in a Small-Open Economy:

Application of New Keynesian Model with Representative Agents for Ghana

6.0 Introduction

The methodological advances in applied open macroeconomic analysis have been astronomical since the 1960s. The main tools available for applied macroeconomic analysis in the 1960s and 1970s were the large-scale macro-econometric models. These models have several equations that link variables of interest to explanatory factors and all the interested variables in each equation are chosen based on economic theory. Similarly, the coefficients of the variables were purely determined on empirical grounds using historical data. The model however came under sharp empirical and theoretical criticisms in the late 1970s, following the emergence of stagflation which made the traditional Philip curve empirically impractical to be included in these models. Lucas (1972, 1973, 1976) opined that the conundrum of stagflation was an empirical manifestation of a typical theoretical problem, corresponding to the "Lucas critique". He avers that agents are rational and behave in an optimizing dynamic way. Their current and future decisions are contingent on the anticipated changes in the economic environment. Therefore, the reliant of past linkages by traditional models simply necessitates that previous economic linkages would still be valid to explain current economic developments irrespective of a change in context (see, Palas, 2010). These models however fail to recognize that the agent's anticipation of these changes could vary the way they reacted, hence nullifying the earlier established interactions between the macroeconomic variables.

The inadequacies of the large-scale macro-econometric models gave rise to the RBC models in the 1980s, following the influential work of Kydland and Prescott (1982). Using general equilibrium framework based on rational economic agents, Kydland and Prescott (1982) improved the neoclassical Ramsey-Cass-Koopmans growth model by adding stochastic productivity shock. They model clearly highlights the microeconomic decision making problems of economic agents (market decision and forming expectations) that result in the macroeconomic dynamics in a DSGE framework. The RBC models became the main reference framework for the analysis of economic fluctuations and to a large extent the core of macroeconomics in the 1980s. Essentially, the impact of the RBC revolution had both a methodological and a conceptual dimension. From the methodological standpoint, the RBC theory firmly established the use of DSGE models as a central tool for macroeconomic analysis. Also, rational expectation replaced the hitherto adhoc assumption on the formation of expectation.

Additionally, the RBC model accorded greater emphasis to the quantitative aspects of modeling by given a central role to calibration, simulation and evaluation of their models.

Perhaps, the most outstanding feature in the RBC revolution relates to three conceptual claims. Of no particular order, the first feature the RBC model by construction is the efficiency of the business cycle which conjectures a frictionless model economy where prices and quantities adjust instantly to their ideal levels after a shock. Therefore, economic oscillations could be interpreted as an equilibrium outcome resulting from the agent's response to exogenous variations in real forces in an environment characterized by frictionless market. The second claim pertains to the importance of technological shock as a source of economic fluctuations. This claim largely hinges on the ability of the basic RBC model to produce "accurate" variations in output and other macroeconomic variables, even when changes in total factor productivity (calibrated to match the properties of Solow residual) are assumed to be the only source of exogenous driving force. The third claim stems from the resulting RBC framework, which is referred to as the classical monetary model. The classical monetary model generally predicts neutrality (near neutrality) of monetary policy with respect to real macroeconomic variables.

Although RBC models gained astronomical popularity in the 1980s, these three conceptual assumptions nevertheless ignited sharp criticisms for the RBC models among economists and practitioners (e.g. at central banks). In particular, the limited role or absent of monetary factors in the RBC models discouraged its application for policy evaluation by central banks. In fact, the monetary neutrality creed by the RBC theory was perceived to be at odds with both the empirical evidences (see, Christiano et al., 1999; Friedman and Schwartz, 1963) and the widely held beliefs (particularly, among central bankers) in the power of monetary policy to influence output and employment development at least in the short run (see Gali, 2015). Indeed, empirical evidences strongly debunked the ideology of monetary neutrality and the importance of technological shock in the RBC theory (see, Gali, 1999; Basu et al., 2006; Christiano et al., 2010; Gali and Rabanal, 2004). Besides the empirical challenges, the normative implication of the classical monetary models pertaining to the optimality of the Friedman rule – a policy that requires the central banks to keep short-term real interest rate constant at a zero level – led many economists to question their relevance as a framework for policy evaluation. This is because such policy prescription seems to bear no connection whatsoever with the monetary policy pursued (or viewed as desirable) by vast majority of central banks. In contrast with the Friedman rule, monetary policy setting is broadly epitomized by frequent large adjustments of interest rates in

response to deviations of inflation and output from their target levels. Or if targeting monetary aggregate or exchange rate.

These shortcomings of the classical monetary model – regarding the conflicts between theoretical predictions and empirical evidence and between normative implication and actual policy practice – are the main motivation that underpinned the introduction of some Keynesian assumptions while upholding the underlying structure of RBC models. The challenges of RBC models thus led to the so-called New-Keynesian Macroeconomics (NKM) in the 1980s, which basically extend RBC with rigidities otherwise they are broadly the same. Both the NKM and RBC schools of thought agree that macroeconomics needed rigorous micro-foundation and therefore the use DSGE models are the ideal workhorse model. However, NKM rather views the real-world economy not to be perfectly flexible (nor perfectly competitive) but subject to imperfections and nominal rigidities. Based on this view and to surmount the shortfalls of RBC models, the NKM modeling approach combines the DSGE structure (which is the hallmark of RBC theory) with assumption on the business cycle that differ considerably from those found in the classical monetary model. Especially, the NK economists introduced monopolistic competition and nominal rigidities which allow for short-run non-neutrality of monetary policy[80].

Some notable advances in the NK-DSGE models are: normal price rigidities by Calvo (1983) and Rotemberg (1982) which endorsed price inertia and broke the money neutrality assumption of the RBC; consumption habits formation by Abel (1990), which helped to capture the persistence in consumption; the introduction of demand shocks by Rotemberg and Woodford (1995); nominal sticky wages based on the influential works of Erceg et al., (2000), which is acknowledged to offer crucial explanation for inflation and output dynamics; the introduction of price and wage indexation, and investment adjustment costs by Christiano et al., (2005), which have enriched the ability of the DSGE models to demonstrate the present of inflation persistence in macro-data and investment dynamics.

Significant achievements in open economy macroeconomics are accredited to the rapid development of the NK-DSGE models. In particular, it is acknowledged that the methodological advances by NK economists have persuasively offered answers to relevant policy questions in open economy macroeconomics (see Uribe and Schmitt-Grohe, 2017), spreading NK-DSGE models from the

[80]The recent confluence of elements from the New-Keynesianism (which contributed nominal rigidities) and new classical economics (which contributed the methodology behind RBC theory) led some authors (see, Goodfriend and King, 1997) to label the new paradigm as the "New Neoclassical Synthesis". This new synthesis is similar to the "neoclassical synthesis" that combined neoclassical economics with Keynesian macroeconomics (Mankiw, 2000).

academia to policy-making institutions. Notably, these models have been widely embraced by most central banks and the other large institutions such as the International Monetary Fund (IMF) since the late 1980s for the conduct of policy analysis as well as systematic and consistent forecasts.

Econometric apparatus linked to DSGE models did not lag behind the pace of the theoretical advancements. The parallel developments in econometric methods reflected in the emergence of numerous procedures to parameterize and estimate DSGE models. These methodological advancements are categorized into limited and full-information methods. Under the limited information methods, a DSGE model imitates the world via a specific set of dimensions. A typical example of a limited information method is calibration, which was originally proposed by Kydland and Prescott (1982). In the calibration approach, values are simply assigned to the parameters under consideration based on common knowledge and previous studies so as to ensure that the model replicates the key moments of the data. The Generalized Methods of Moments (GMM) used in Christiano and Eichenbaum (1990) is another example that fit the limited information method. Christiano et al. (2005) also proposed another limited information method where parameters of interest are computed by minimizing the disparities between impulse response functions from a DSGE model and those derived from an identified VAR.

On the other hand, the full-information methods attempt to attain estimates that offer a complete description of the observable macro-data by taking into account the whole set of implications of the model. Essentially, both the Classical and Bayesian Maximum Likelihood Estimation (MLE) fall into this group. MLEs depend on the description of probability structure for the model to form the likelihood function given the dataset and model's parameters. After several iterations, the likelihood generates the combination of parameters that produces the maximum value for the function. The Classical MLEs directly generate parameter estimates via this process, while Bayesian MLE requires additional function and the prior. The prior represents the probability assigns to the parameters by the researcher, based on previous studies or on his beliefs, before observing the data. The prior can be perceived as weights on the likelihood function so as to give more importance to certain areas of the parameter subspace. Theoretically, these two building blocks – priors and likelihood function- are tied together by Bayes' rule. Both Kim (2000) and Ireland (2001) have applied the Classical MLE method, while the application of Bayesian MLE techniques for the estimation of a DSGE model was first done by DeJong, et al., (2000). Since then, this has been adopted by several researchers including Adolfson et al., (2007a), and An and Schorfheide (2007), Christoffel et al., (2008), Almeida, (2009); Rudolf and Zurlinden, (2014), etc. Between the two approaches, the full-information technique is deemed as the

superior one (see, Almeida, 2009), while Bayesian MLE stands out as the one that has gathered more popularity within full-information methods.

These significant advances in econometric frameworks have substantially expanded the latitude of DSGE application. The increasing attraction of DSGE models is not only underpinned by their theoretical coherency but also linked to development of recent statistical and software application platforms, such as the Bayesian techniques and Dynare application platform[81]. Combining good explanatory power (based on empirical evidence) along with solid theoretical structure, the NK DSGE models are now the object of attention not only in the academia but also in a number of policy-making institutions, such as central banks and the IMF. In the case of Ghana, very few studies have applied DSGE models, namely: Dagher et al (2010, 2012) used calibrated NK model to investigate the short-run impact of the oil windfall in Ghana and the role of various fiscal and monetary policy responses; Bondzie et al., (2014) also used a calibrated NK model to analyse oil price fluctuation and its impact on economic growth in Ghana; The FPAS model of the Bank of Ghana also relies on calibration. An exceptional study is by Houssa, Otrok and Puslenghea (2010) which developed a small-open economy DSGE model to examine monetary policy analysis for sub-Saharan Africa using Bayesian inference and Ghanaian dataset for the period 1981-2007. The limited studies that have applied NK Bayesian DSGE model for monetary policy analysis using most recent Ghanaian data motives this chapter.

This chapter develops a small-open economy's NK-DSGE model for monetary policy investigation and analysis in developing African economy, using Ghana as a representative country[82]. Specifically, the model is used to address a number of policy issues: Are monetary policy responses to and influence on macroeconomic shocks consistent with economic theory? What are the main driven forces of output and inflation in the Ghanaian economy? Given the large size of the public sector and its crucial role in employment and consumption in most developing African economies, what is the impact of an increase in government spending in Ghana? Does exchange rate depreciation (or appreciation) stimulate (or dampen) economic growth and private consumption in Ghana? Are there significant spillovers effects from the foreign economy to the Ghanaian economy? What is the best empirical monetary policy instrument rule for Ghana? The latter question is particularly motivated by the fact that most empirical

[81] Dynare is a pre-processor and a collection of publicly available Matlab routines for the solution, simulation and estimation of DSGE models (see, Almeida, 2009; Griffoli 2010). For more on Dynare please go to:
http://www.cepremap.cnrs.fr/dynare/

[82]Ghana is a small-open economy and is also a second longest practicing inflation targeting African economy (after South Africa). With recent discovery of oil in commercial quantities (since 2011), Ghana's trade dynamics broadly share similar traits to those of either the oil- or non-oil exporting economies in African and hence, seemingly a good representation for a small-open Africa economy.

studies for developing and emerging economies just either assume the standard Taylor rule or augmented with exchange rate. There is however no clear consensus on the empirical validity of such specifications for small-open developing and emerging economies[83]. In this midst of empirical indefiniteness, the current FPAS model of central bank of Ghana (BOG) also utilizes a forward-looking policy rule where authority reacts to 3rd-quarter-ahead inflation deviation from target alongside current output gap.

The model parameters are estimated using Bayesian techniques based on nine (9) key macroeconomic variables, comprising six domestic and three foreign variables. The domestic variables include real GDP, private consumption, government consumption spending, investment, consumer prices and nominal interest rate, while the foreign macro-variables are consumer prices, real GDP and nominal interest rate of the Euro Area. Our choice of the Euro Area as a representative foreign economy is mainly due to the latter's sizeable share (about 34.61%) of Ghana's external trade. The design of the small-open economy model builds on previous works done in this area, notably by Adolfson et al (2005, 2007a,b, 2008), Almeida (2009), Christiano et al. (2005), Clarida et al. (2000), Erceg et al., (2000), Gali and Monacelli (2005), and Smets and Wouters (2002, 2003, 2007), etc.

The chapter provides substantial contribution to existing literature for Ghana and beyond. First, the Bayesian DSGE modeling is a contribution worth-mentioning as it has received very little attention in Ghana and other developing African economies. Indeed, there is virtually no study that has explored Bayesian DSGE techniques for monetary policy analysis in the context of Ghana[84]. Second, the consideration of suits of monetary policy rules to determine the most appropriate rule for the Ghanaian macro-policy environment is a contribution worth-noting. Third, the paper extends the Ghanaian

[83]Carlstrom et al., (2006) argued that contemporaneous IT – authority reacts to current inflation deviation from target– guarantees determinacy in the closed economy and conjured that the result would generalize to the open economy. This assertion was confirmed by Airaudo et al (2016) for the open economy. Airaudo et al (2016) further argue that exchange rate policy and the choice of price index do not matter if the central bank targets current inflation. However, other scholars have questioned its practically feasibility since the contemporaneous interest rate rule requires that policy makers have access to precise information on the current values of inflation and other variables. For example, Bullard and Mitra (2002) contended that such requisite information for contemporaneous policy rule is unavailable in many developed economies let alone developing and emerging economies. McCallum (1999) also asserts strongly that contemporaneous policy rules are "non-operational". More so, most empirical studies for developing and emerging economies either use the standard Taylor rule or augmented policy rule with exchange rate and/or foreign interest rate (see, Mohanty and Klau, 2005; Davis and Presno, 2017).

[84] Only few studies have employed DSGE models in the case of Ghana but with different focus and estimation techniques. For instance, Dagher et al (2010, 2012) used a fully-calibrated NK-DSGE model to analyse the short-run impact of the oil windfall in Ghana and the role of various fiscal and monetary policy responses. Bondzie et al., (2014) also employed a fully-calibrated NK-DSGE model to analyse oil price fluctuation and its impact on economic growth in Ghana. Moreover, the current FPAS model of the Bank of Ghana relies on full calibration.

literature on Bayesian NK-DSGE models which could be operationalized in a policy institution such as the central bank.

6.1 The Model with Representative Agents

The model has two economies (Home and Foreign) that interact in both goods and financial markets. The home economy is assumed to be insignificantly small in size relative to the foreign economy. Consequently, the foreign economy is assumed to be exogenous to developments in the domestic economy. Essentially, the model also consists of forward-looking agents who are made up of households, firms and government. Households maximize their expected lifetime utility by consuming goods (produced domestically and foreign imports) and supplying labour and capital to firms. Households are able to smooth consumption via habit formation in consumption. The firm, in turn, produces goods and set prices so as to maximize expected profit. Government ensures a balanced budget at all times, spends on only consumption goods (no public investment) and sets the short-term interest rate based on a Taylor-type rule. The subsequent subsections lay out the model in stages, starting with the specification of households.

6.1.1 Domestic Households

There is a continuum of infinitely lived intertemporal optimizing households in the domestic economy that seeks to maximize a lifetime utility function given by (as in Coenen and Straub, 2005; Smets and Wouters, 2002; Costa Jr., 2016; Palas, 2017):

$$\max_{C_t,N_t,K_{t+1},B_{t+1}} E_t \sum_{i=0}^{\infty} \beta^i \zeta_t^c \left[\left(\frac{C_t - hC_{t-1}}{1-\sigma_c} \right)^{1-\sigma_c} - \hat{\zeta}_t^n \frac{(N_t)^{1+\vartheta_l}}{1+\vartheta_l} \right], \tag{6.1}$$

where E_t is expectation operator which is conditional on known information set at time t; $\beta^t \in [0,1]$ is the household's time discount factor which typically captures the notion that household cherishes present utility more than future utility; C_t is the quantity of goods consumed in an economy; N_t is hours work (labour supply) by each group of households. ϑ_l with $\vartheta_l > 1$ is the marginal disutility with regards to supply of labour. $\sigma_c \in (0,1)$ is the inverse elasticity of intertemporal substitution for household consumption; $h \in [0,1]$ is external habit persistence in consumption which reflects that current consumption is affected by aggregate consumption level in the previous period ($hC_{R,t-1}$); ζ_t^c is a general shock to preferences that affect the intertemporal substitution of households (preference shock) and ζ_t^n represents shock to the labour supply. The utility function in equation (5.1) is assumed to be continuous and twice differentiable. The households' consumption of foreign and domestic goods, C_t, is a Dixit-Stiglitz index, defined as:

$$C_t = \left[(1-\Omega)^{\frac{1}{\eta}} C_{\mathrm{H},t}^{\frac{\eta-1}{\eta}} + \Omega^{\frac{1}{\eta}} C_{\mathrm{F},t}^{\frac{\eta-1}{\eta}}\right]^{\frac{\eta}{\eta-1}} \tag{6.2}$$

where $C_{\mathrm{H},t}$ and $C_{\mathrm{F},t}$ are indices of consumption of goods produced domestically and imported from the foreign economy respectively; Ω with $\Omega \in [0,1]$ measures the degree of openness of the home economy.[85] If Ω is closer to one, the domestic economy is said to be more open, while if $\Omega = 0$, we get the closed economy case. η, with $\eta > 1$, measures the elasticity of substitution between a bundle of final domestic and foreign (imported) goods. The indices of consumption of domestic goods ($C_{\mathrm{H},t}$) and imported goods from the foreign economy ($C_{\mathrm{F},t}$) are given by the CES aggregates;

$$C_{\mathrm{H},t} = \left[\int_0^1 C_{\mathrm{H},t}(j)^{\frac{\gamma_h-1}{\gamma_h}}\right]^{\frac{\gamma_h}{1-\gamma_h}} ;\; C_{\mathrm{F},t} = \left[\int_0^1 C_{\mathrm{F},t}(j)^{\frac{\gamma_h-1}{\gamma_h}}\right]^{\frac{\gamma_h}{1-\gamma_h}} \tag{6.3}$$

with $\gamma_h > 1$ denoting the elasticity of substitution between differentiated intermediate goods $j \in [0,1]$ produced within a given economy. Given equation (5.3), the optimal allocation for good j is given by the following demand functions:

$$C_{\mathrm{H},t}(j) = \left[\int_0^1 \frac{P_{H,t}(j)}{P_t}\right]^{-\gamma_h} C_{\mathrm{H},t} ; \quad C_{\mathrm{F},t}(j) = \left[\int_0^1 \frac{P_{F,t}(j)}{P_t}\right]^{-\gamma_h} C_{\mathrm{F},t} \tag{6.4}$$

where $P_{H,t}$ is the price index of home produced goods and $P_{F,t}$ is the import price index. By assuming symmetry across good j, the corresponding optimal allocation of expenditure on domestic goods ($C_{\mathrm{H},t}$) and foreign/imported goods ($C_{\mathrm{F},t}$) based on the demand function are given by;

$$C_{\mathrm{H},t} = (1-\Omega)\left(\frac{P_{H,t}(j)}{P_t}\right)^{-\eta} C_t; \qquad C_{\mathrm{F},t} = \Omega\left(\frac{P_{F,t}(j)}{P_t}\right)^{-\eta} C_t \tag{6.5}$$

where P_t representing the aggregate price index (CPI) for the home economy is defined:

$$P_t = \left[(1-\Omega){P_{H,t}}^{1-\eta} + \Omega {P_{F,t}}^{1-\eta}\right]^{\frac{1}{1-\eta}} \tag{6.6}$$

Accordingly, total consumption expenditure for the domestic household is given by $P_t C_t = P_{H,t} C_{\mathrm{H},t} + P_{F,t} C_{\mathrm{F},t}$. The representative households also receive labour income (wages) from their labour services offered to firms and capital stocks and rents them to domestic firms at the rental rate of R_t^k.

The optimizing households have the following budget constraint:

$$P_t C_t + P_t I_t + E_t\left(Q_{t,t+1} B_{t+1}\right) = W_t N_t + B_t + R_{t+1}^K K_{t+1} - P_H T_{R,t} + \Pi_t \tag{6.7}$$

[85] As $\eta \to 1$, the consumption index is given by $C_t = k^{-1} {C_{\mathrm{H},t}}^{1-\Omega} {C_{\mathrm{F},t}}^{\Omega}$, where $k = (1-\Omega)^{(1-\Omega)}\Omega^{\Omega}$

where $P_t C_{R,t} = \int_0^1 P_{H,t}(j) C_{H,t}(j)\, dj + \int_0^1 P_{F,t}(j) C_{F,t}(j)\, dj$; for $t = 1,2,3,\ldots,\infty$; $P_{H,t}(j)$ and $P_{F,t}(j)$ denote the prices of domestic and foreign good j respectively, $E_t(Q_{t,t+1})$ is the stochastic discount rate on nominal payoff; $B_{\mathrm{R},t+1}$ is the nominal payoff on the portfolio held at $t+1$ and W_t is the nominal wage for Ricardian households; Π_t is nominal dividend received by households for owning firms; $T_{R,t}$ is lump-sum taxes paid by Ricardian households. They have the following capital accumulation function:

$$K_{t+1} = (1-\varrho)K_t + I_t \tag{6.8}$$

Equation (6.8) clearly illustrates that the capital accumulation equation defines next period's capital stock (K_{t+1}) determined by the current period's capital stock (K_t) net of depreciation ($\varrho K_t, \varrho \in [0,1]$) plus the amount of current capital accumulation which is conditional on the current investment (I_t). For simplicity, we assume that there is no capital adjustment cost. Solving the optimization problem for optimizing households yields the following FOCs:

$$\frac{\partial L}{\partial C_t}: \quad \zeta_t^c (C_t - hC_{t-1})^{-\sigma_c} - \wedge_t P_t = 0 \tag{6.9}$$

$$\frac{\partial L}{\partial N_t,}: \quad -\beta \zeta_t^n N_t^{\vartheta_l} + \beta \wedge_t w_t = 0; \tag{6.10}$$

$$\frac{\partial L}{\partial B_{t+1},}: \quad -E_t Q_{t,t+1} \wedge_t + \beta \wedge_{t+1} = 0; \tag{6.11}$$

$$\frac{\partial L}{\partial K_{t+1}}: -\wedge_t P_t + \beta \wedge_{t+1} (1-\varrho) E_t P_{t+1} + \beta \wedge_{t+1} E_t R_{t+1}^{\kappa} = 0 \tag{6.12}$$

$$\frac{\partial L}{\partial \wedge_t}: P_t C_t + P_t(K_{t+1} - (1-\varrho)K_t) + \frac{B_{t+1}}{R_t} = W_t N_t + R_{t+1}^{\kappa} K_t + B_t - P_t T_t + \Pi_t \tag{6.13}$$

From equation (6.9), we have the Ricardian Lagrange multiplier as

$$P_t \wedge_{R,t} = \zeta_t^c \left(C_{R,t} - hC_{R,t-1}\right)^{-\sigma_c} \tag{6.14}$$

From equation (6.10) also we have an expression that equates real wage to marginal rate of substation between consumption and leisure as;

$$\frac{W_t}{P_t} = \frac{N_t^{\vartheta_l}}{\left[\left(C_{R,t} - hC_{t-1}\right)^{-\sigma_c}\right]} \left(\frac{\zeta_t^n}{\zeta_t^c}\right) \tag{6.15}$$

We then derive the consumption Euler equation from equations (6.9) and (6.11) as

$$\Leftrightarrow \beta \left(\frac{C_{t+1}}{C_t}\right)^{-\sigma_c} \left(\frac{P_t}{P_{t+1}}\right) \left(\frac{\zeta_{t+1}^c}{\zeta_t^c}\right) = R_t \tag{6.16}$$

where ${C_{t+1}}^{-\sigma_c} = (C_{t+1} - hC_t)^{-\sigma_c}$; ${C_t}^{-\sigma_c} = (C_t - hC_{t-1})^{-\sigma_c}$ and $R_t = \frac{1}{E_t(Q_{t,t+1})}$ is gross interest payoff for asset for period t.

6.1.1.1 Wage Determination

Each household supplies a differentiated type of labour, indexed $j \in [0,1]$, in a monopolistic competitive market and therefore acts as price-setters in the labour market. This labour service is sold to a representative firm that aggregates these different types of labour (N_j) into a single labour input (N). To satisfy this assumption, the labour-aggregating firm uses the technology

$$N_t = \int_0^1 \left(N_{j,t}^{\frac{\gamma_{w,t-1}}{\gamma_{w,t}}} \, \mathrm{dj} \right)^{\frac{\gamma_{w,t}}{\gamma_{w,t}-1}}, \tag{6.17}$$

where γ_w denotes the elasticity of substitution between differentiated labour while $N_{j,t}$ represents the amount of differentiated labour supplied by household, j; N_t is per capita employment. Each type of labour is paid with a wage, $W_{j,t}$. Therefore, the problem of labour aggregated firm is to maximize its profit;

$$\max_{N_{j,t}} \; W_t \left[\int_0^1 \left(N_{j,t}^{\frac{\gamma_{w,t}-1}{\gamma_{w,t}}} \, dj \right)^{\frac{\gamma_{w,t}}{\gamma_{w,t}-1}} \right] - W_{j,t} \int_0^1 N_{j,t} dj \tag{5.18}$$

The FOC of (5.18) for N_t yields the demand equation for differentiated labour as

$$N_{j,t} = \left(\frac{W_t}{W_{j,t}} \right)^{\gamma_{w,t}} N_t \tag{6.19}$$

where W_t denotes aggregate wage index and is defined by

$$W_t = \left[\int_0^1 \left(W_{j,t}^{1-\gamma_{w,t}} dj \right)^{\frac{1}{1-\gamma_{w,t}}} \right] \tag{6.20}$$

In line with Erceg et al. (2000), all households face the same wage rigidity in the labour market. Unlike Houssa et al (2010), we impose staggered wage mechanism a la Calvo (1983) whereby only a fraction of households with $(1-\theta_w)$[86] probability is randomly chosen to reset their price each period. Households choose the optimal wage, $\widetilde{W}_t^{\tau}$, in each period because they have identical optimization problem. The remaining households that are not able to reset wages, θ_w, maintain the wage level as in the previous period, (i.e. $W_t = W_{t-1}$). Consequently, in chosen wage $\widetilde{W}_{j,t}^{\tau}$, households seek to solve the following utility problem[87];

[86] Since $(1-\vartheta_w)$ is also the probability of households that get to re-optimize price in each period, its inverse $(\frac{1}{1-\vartheta_w})$ connotes the duration of wage contracts.

[87] The wage determination problem only utilizes the parts of the households' utility function and budget constraints that relate to the choice of labour.

$$\max_{\widetilde{W}_t^{\tau}} E_t \sum_{i=0}^{\infty} (\beta \vartheta_w)^i \left\{ \zeta_{t+i}^n \left[-\frac{N_{t+i}^{1+\vartheta_l}}{1+\vartheta_l} \right] - \wedge_{j,t} \left[-\widetilde{W}_t^{\tau} N_{t+i} \right] \right\} \tag{6.21}$$

Given (6.19), we can re-specify (6.21) as follows (by substituting for $N_{j,t}$)

$$\max_{\widetilde{W}_{H,t}^{\tau}} E_t \sum_{i=0}^{\infty} (\beta \vartheta_w)^i \left\{ -\frac{\zeta_{t+i}^n}{1+\vartheta_l} \left[N_{t+i} \left(\frac{W_t}{\widetilde{W}_{H,t}^{\tau}} \right)^{\gamma_{w,t}} \right]^{1+\vartheta_l} + \wedge_{H,t+i} \left[\widetilde{W}_{H,t}^{\tau} N_{H,t+i} \left(\frac{W_t}{\widetilde{W}_{H,t}^{\tau}} \right)^{\gamma_{w,t}} \right] \right\} \tag{6.22}$$

Solving the optimization problem with respect to $\widetilde{W}_t^{\tau}$ yields;

$$E_t \sum_{i=0}^{\infty} (\beta \vartheta_w)^i \left\{ \gamma_{w,t} \zeta_{t+i}^n N_{t+i}^{\vartheta_l} \left(\frac{1}{\widetilde{W}_t^{\tau}} \right) + (1-\gamma_{w,t}) \wedge_{t+i} \right\} = 0 \tag{6.23}$$

The optimal wage, $\widetilde{W}_{H,t}^{\tau}$, level is obtained as;

$$\widetilde{W}_t^{\tau} = \left(\frac{\gamma_{w,t}}{\gamma_{w,t}-1} \right) E_t \sum_{i=0}^{\infty} (\beta \vartheta_w)^i \left\{ \frac{\zeta_{t+i}^n N_{t+i}^{\vartheta_l}}{\wedge_{t+i}} \right\} \tag{6.24}$$

This can also be written as:

$$\widetilde{W}_t^{\tau} = (1-\gamma_{w,t}) E_t \sum_{i=0}^{\infty} (\beta \vartheta_w)^i \left\{ \frac{\zeta_{t+i}^n N_{t+i}^{\vartheta_l}}{\wedge_{t+i}} \right\} \tag{6.25}$$

When wages are perfectly flexible ($\vartheta_w = 0$), the nominal wage will be a mark-up (equal to $\frac{\gamma_{w,t}}{\gamma_{w,t}-1}$) over the current ratio of the marginal disutility of labour and the marginal utility of an additional unit of consumption. We assume that shock to the wage mark-up, $\gamma_{w,t} = \gamma_w + \zeta_t^w$, are IID-normal around a constant. In addition, $MRS_{t+i} = -\frac{\zeta_{t+i}^n N_{t+i}^{\vartheta_l}}{\wedge_{t+i}}$; and there is an common labour supply shock, ζ_t^n. The nominal wage level for category of households is thus given by:

$$W_t = \left[\vartheta_w W_{t-1}^{1-\gamma_{w,t}} + (1-\vartheta_w) \widetilde{W}_t^{\tau\,1-\gamma_{w,t}} \right]^{\frac{1}{1-\gamma_{w,t}}} \tag{6.26}$$

6.1.2 The Firm

As in Smets and Wouters (2003), they are final good and intermediate good producers.

6.1.2.1 Final Goods Firm

Final good firm aggregates a continuum of intermediate goods as inputs to produce a final good and sell it in a perfectly competitive market. The functional form for aggregation technology of the final good firm is the Dixit-Stiglitz aggregator;

$$Y_t = \left[\int_0^1 Y_{j,t}^{\frac{\gamma_h - 1}{\gamma_h}} dj \right]^{\frac{\gamma_h}{\gamma_h - 1}} \tag{6.27}$$

where Y_t is a final good in period t, $Y_{j,t}$ for $j \in [0,1]$ is the intermediate inputs j. γ_h is the elasticity of substitution between the differentiated intermediate goods. The representative final good firm chooses the optimal amount of each intermediate goods to maximize its profit function which is given as the difference between revenues and costs;

$$\max_{Y_{j,t}} P_t Y_t - P_{j,t} \int_0^1 Y_{j,t} dj \tag{6.28}$$

where $P_{j,t}$ represents nominal price of $j-th$ intermediate good. The FOC of equation (6.28) with respect to $Y_{j,t}$ results in a demand function for intermediate good j as;

$$Y_{j,t} = Y_t \left(\frac{P_t}{P_{j,t}}\right)^{\gamma_h} \tag{6.29}$$

Equation (6.29) illustrates that the demand for intermediate good j is directly proportional to aggregate demand Y_t and inversely related to its relative price level, $\frac{P_t}{P_{j,t}}$. Substituting (6.29) into (6.27) based on zero-profit condition results in the pricing rule for the final good firm as follows;

$$P_t = \left[\int_0^1 P_{j,t}^{1-\gamma_h} dj\right]^{\frac{1}{1-\gamma_h}} \tag{6.30}$$

6.1.2.2 Intermediate Firm

We assume a continuum of intermediate firms that operate the same technology and hence face the same marginal cost (identical per unit cost of production). The production function for intermediate good producing firm, i, is given by

$$Y_{i,t} = \mho_t K_{i,t}^{\lambda} N_{i,t}^{1-\lambda} \tag{6.31}$$

where $\mho_t$ is the total factor productivity (or technological progress) which follows an AR(1) process as:

$$\log(\mho_t) = (1-p_{\mho})\log(\mho_{ss}) + p_{\mho}\log(\mho_{t-1}) + \varepsilon_t^u \tag{6.32}$$

$p_{\mho}$ is the autoregressive parameter of productivity with $|p_{\mho}| < 1$ while $\varepsilon_t^u \sim (0, \sigma_{\mho})$ signifies innovation. K_t denotes rented physical capital; N_t represents amount of differentiated labour hired by the $i-th$ firm. The overall labour input of $i-th$ producer is defined as

$$N_{i,t} = \left[\int_0^1 N_{i,j,t}^{\frac{\gamma_h - 1}{\gamma_h}} di\right]^{\frac{\gamma_h}{\gamma_h - 1}} \tag{6.33}$$

where $N_{i,j,t}$ is the quantity of labour of type j demanded by firm i and is given by;

$$N_{i,j,t} = \left(\frac{W_t}{W_{j,t}}\right)^{\gamma_h} N_{i,t} \tag{6.34}$$

The aggregate wage index, W_t, is expressed as

$$W_t = \left[\int_0^1 {W_{i,j,t}}^{1-\gamma_h}\, di\right]^{\frac{1}{1-\gamma_h}} \tag{6.35}$$

Taking the prices of factors of production (W_t, R_t^{κ}) as given, intermediate firm seeks to minimize the total cost of production subject to the production technology constraint in (6.31). The total cost minimization (see Appendix 6Ai for full derivation) yields the following demand for labour and capital inputs respectively

$$N_{i,t} = \frac{Y_{i,t}}{\mho_t}\left[\frac{ɮ}{(1-ɮ)}\frac{W_t}{R_t^{\kappa}}\right]^{-ɮ} \tag{6.36}$$

$$K_{i,t} = \frac{Y_{i,t}}{\mho_t}\left[\frac{ɮ}{(1-ɮ)}\frac{W_t}{R_t^{\kappa}}\right]^{1-ɮ} \tag{6.37}$$

Combining equations (6.36) and (6.37) results in an expression that links economic rate of substitution (ERS) to marginal rate of technical substitution (MRTS) as

$$\frac{W_t}{R_t^{\kappa}} = \frac{(1-ɮ)}{ɮ}\frac{K_{i,t}}{N_{i,t}} \tag{6.38}$$

The LHS of (6.38) is the ERS, gauging the extent to which labour can be replaced by capital while maintaining the same cost. The RHS is the MRTS, measuring the rate at which labour can be replaced with capital while maintaining a constant level of technology. The nominal marginal cost which is identical for all intermediate firm $(MC_t = MC_{i,t} = \frac{\partial TC_{i,t}}{\partial Y_{i,t}})$ is derived as

$$MC_t = \frac{1}{\mho_t}\left[\frac{W_t}{1-ɮ}\right]^{1-ɮ}\left(\frac{R_t^{\kappa}}{ɮ}\right)^{ɮ} \tag{6.39}$$

Firm's profits are expressed as

$$\Pi_t(j) = \big(P_{h,t}(j) - MC_t\big)Y_t(j) \tag{6.40}$$

The aggregate profit in the economy are given by

$$\Pi_t = \int_0^1 \Pi_t(j)dj \tag{6.41}$$

6.1.2.3 Price Setting

Following much of the literature, a model of staggered price setting due to Calvo (1983) and typified by random price durations is applied. Accordingly, only a fraction of domestic intermediate firms with

probability $(1-\vartheta_h)$ are permitted to re-optimize their price for each period. Each firm that can re-optimize its price in a given period will choose a common new price, $\tilde{P}_{i,t}^{\tau}$ according to the optimization problem:

$$\max_{\tilde{P}_{i,t}^{\tau}} \sum_{k=0}^{\infty} (\vartheta_h)^k \; E_t\{Q_{t,t+1} Y_{t+k}[\tilde{P}_{h,t}^{\tau} \; - \; \zeta_{t+k}^{p} TC_{i,t+k}]\} \tag{6.42}$$

where ζ_t^p is domestic price mark-up shock common to all producers and $(\vartheta_h)^k E_t Q_{t,t+1}$ is the effective stochastic discount rate to allow for the fact that firms have a $(1-\vartheta_h)$ probability of being able to adjust price in each period. We know that the consumption Euler equation in (6.16) can be written as:

$$Q_{t,t+1} = \beta^t \left(\frac{\zeta_t^c}{\zeta_{t+1}^c}\right)\left(\frac{C_t^{-\sigma}}{C_{t+1}^{-\sigma}}\right)\frac{P_{h,t+1}}{P_{h,t}} \tag{6.43}$$

Substituting equation (5.43) and (5.29) into (5.42) yields,

$$\max_{\tilde{P}_{i,t}^{\tau}} \sum_{k=0}^{\infty} (\beta\vartheta_h)^k \; \zeta_t^z C_t^{-\sigma} P_t^{-1} E_t \left\{ \zeta_{t+k}^{z-1} C_{t+k}^{-\sigma} P_{t+k}^{-1} Y_{i,t+k} \left(\frac{P_{h,t+k}}{\tilde{P}_{h,t}^{\tau}}\right)^{\gamma_h} \; [\tilde{P}_{h,t}^{\tau} - \; \zeta_{t+k}^{p} MC_{t+k}^{n}] \right\} \tag{6.44}$$

Where MC_{t+k}^{n} is nominal marginal cost. The corresponding FOC for $\tilde{P}_{h,t}^{\tau}$ yields;

$$\sum_{k=0}^{\infty} (\beta\vartheta_h)^k \; \zeta_t^c C_t^{-\sigma} P_t^{-1} E_t\{\zeta_{t+k}^{c-1} C_{t+k}^{-\sigma} P_{t+k}^{-1} Y_{i,t+k}[(1-\gamma_h)\tilde{P}_{h,t}^{\tau} + \gamma_h \zeta_{t+k}^{p} MC_{t+k} P_{h,t+k}]\} = 0 \tag{6.45}$$

Where $MC_{t+k} = \frac{MC_{t+k}^{n}}{P_{t+k}}$ is real marginal cost. Since $\zeta_t^z C_t^{-\sigma} P_{h,t}^{-1}$ is known at date t, it can be taken out of the expectation summation. Then, equation (6.45) be can written as

$$\sum_{k=0}^{\infty} (\beta\vartheta_h)^k \; E_t \left\{ \zeta_{t+k}^{c-1} C_{t+k}^{-\sigma} Y_{i,t+k} \frac{P_{h,t-1}}{P_{t+k}} \left[(1-\gamma_h) \frac{\tilde{P}_{i,t}^{\tau}}{P_{h,t-1}} + \gamma_h \zeta_{t+k}^{p} MC_{t+k} \frac{P_{h,t+k}}{P_{h,t-1}} \right] \right\} = 0 \tag{6.46}$$

The optimal price $\tilde{P}_{h,j,t}^{\tau}$ equation for chosen firms is derived as;

$$\tilde{P}_{i,t}^{\tau} = \left(\frac{\gamma_h}{\gamma_h - 1}\right) P_{h,t-1} \frac{\sum_{k=0}^{\infty} (\beta\vartheta_h)^k \; E_t \left\{ \zeta_{t+k}^{c-1} C_{t+k}^{-\sigma} Y_{i,t+k} \frac{P_{h,t-1}}{P_{t+k}} \zeta_{t+k}^{p} MC_{t+k} \frac{P_{h,t+k}}{P_{h,t-1}} \right\}}{\sum_{k=0}^{\infty} (\beta\vartheta_h)^k \; E_t \left\{ \zeta_{t+k}^{c-1} C_{t+k}^{-\sigma} Y_{i,t+k} \frac{P_{h,t-1}}{P_{t+k}} \right\}} \tag{6.47}$$

This is further simplified to yield;

$$\tilde{P}_{h,t}^{\tau} = \left(\frac{\gamma_h}{\gamma_h - 1}\right) E_t \sum_{k=0}^{\infty} (\beta\vartheta_h)^k \left\{ \zeta_{t+k}^{p} MC_{t+k} \; \pi_{h,t+k} \right\} P_{h,t-1} \tag{6.48}$$

A firm that cannot re-optimize is assumed to index its price to last period's inflation as follows:

$$P_{h,t}^{n}(j) = \; P_{h,t-1}(j) \tag{6.49}$$

The degree of past inflation indexation is assumed to be same as the probability of resetting its price. The aggregate domestic price level will evolve according to:

$$P_{h,t} = \left[(1-\vartheta_h)\tilde{P}_{i,t}^{\tau\ 1-\vartheta_h} + \vartheta_h P_{h,t-1}^{\ 1-\vartheta_h}\right]^{\frac{1}{1-\vartheta_h}} \tag{6.50}$$

6.1.3 Government

As often in the New Keynesian literature, we assume a cashless economy (see Woodford, 2003). The government comprises the fiscal authority and the monetary authority. For simplicity, the fiscal authority endeavours to keep a sustainable debt-to-GDP ratio by imposing lump-sum taxes. Thus, the fiscal authority collects lump-sum taxes and also issues a one-period domestic bond (B_t) to finances government's spending and debt. The government budget constraint is presumed to follow the evolution that debt issuance is equaled to expenditure-revenue gap (see, Baltini et al, 2009):

$$\frac{B_{t+1}}{R_t} - B_t = P_{H,t}G_t - P_{H,t}T_t \tag{6.51}$$

where B_t denotes nominal value of one-period government bond; T_t denotes lump-sum taxes; G_t represents the real government expenditure on final good. For simplicity, we assume that government only consumes goods and there is no public investment as in Smets and Wouters (2003) and Palas (2017). Since fiscal debt clears government budget constraint, the lump-sum taxes require a separate equation which includes fiscal debt and public spending similar to Gali, Lopez-Salido and Valles (2007):

$$\hat{t}_t = \zeta_b \hat{b}_{t-1} + \zeta_g \hat{g}_{t-1} \tag{6.52}$$

where $\hat{t}_t = \frac{T_t - T_{ss}}{Y_{ss}}$, $\hat{g}_t = \frac{G_t - G_{ss}}{Y_{ss}}$ and $\hat{b}_t = \frac{B_t/P_{H,t-1} - B_{ss}/P_{H,ss}}{Y_{ss}}$. μ_t^T denotes a tax shock and $\hat{g}_t$ evolves exogenously according to the AR(1) process. Equation (6.52) supposes that fiscal authority upholds a simple fiscal rule which ensures that lump-sum taxes increase when there is an increase in public expenditure or debt. Note also that there is no shock to lump-sum taxes in equation (6.52) assuming that fiscal debt is not generated by tax cut in the place; only public spending can suddenly increase.

The monetary authority changes nominal interest rate in response to variations in both the inflation and output using a Taylor-type rule. It increases the nominal interest rate in the case of positive output gap or a positive inflation gap. Additionally, the authority tries to keep the nominal interest rate relatively stable and therefore the rule also contains a smoothing term. The rule is given by (see also, Costa Jr., 2016; Palas, 2017):

$$\hat{r}_t = \alpha_R \hat{r}_{t-1} + (1-\alpha_R)\left[\alpha_\pi \hat{\pi}_{t+1} + \alpha_y \hat{y}_t\right] + \mu_t^{fl} \tag{6.53}$$

With $\alpha_R, \alpha_y, \alpha_\pi \in [0,1]$ and where α_R is the smoothing parameter or interest rate persistent; α_π, and α_y measure the sensitivity of short-term nominal interest rate to deviations of inflation, and output

from their respective steady state values; and $\mu_t^{fl} \sim NID(0,1)$ is monetary policy shock which is normally distributed with zero mean and constant variance σ^2. The choice of overall CPI inflation instead of domestic inflation (or core inflation) is based on the literature that model with monetary policy rule that targets core inflation (or domestic inflation) is fraught with risks. For instance, Airaudo et al (2016) advocated that such a policy may lead to indeterminacy. Nonetheless, this chapter also considers several alternative specifications of policy rules and the details are provided in Section 6.6.2.1.

6.1.4 Foreign Economy

As aforementioned, the home economy is insignificantly small in size relative to the foreign economy. Therefore, even significant changes in the domestic inflation, the interest rate or demand cannot influence the foreign macroeconomy. Consequently, the shares of home economy goods and investments (capital and bonds) in the consumption bundle and portfolio of the foreign economy households are set to zero[88]. Thus, foreign output gap ($\hat{y}_t^*$), inflation ($\hat{\pi}_t^*$) and short-term nominal interest rate ($\hat{r}_t^*$) are assumed to have AR(1) processes. Foreign demand for export of consumption and investment goods from the domestic economy is given by:

$$\mathrm{T}_t^x = \Omega \left(\frac{P_{H,t}}{e_t P_t^*} \right)^{-\eta} \mathrm{Y}_t^* \tag{6.56}$$

Ω denotes the degree of opening for the foreign economy; $\eta \in [0,1]$ is the elasticity of substitution between goods produced in home and foreign economy (from the foreign economy's perspective); Y_t^* is the aggregate output in the foreign economy.

6.1.5 International Linkage and Risk Sharing

Our approach for international linkage follows the work of Gali (2015). The terms of trade *(X)* is assumed to be exogenous to the small open economy. It is defined as the price of foreign goods ($P_{F,t}$) in terms of domestic goods ($P_{H,t}$):

$$X = \frac{P_{F,t}}{P_{H,t}} \tag{6.57}$$

Changes in the terms of trade represent changes in the competitiveness of the domestic economy. Assuming that the law of one price (LOOP) holds at all times, the domestic price of imported goods ($P_{F,t}$) is given by:

[88] We assume that foreign output comprises of foreign private consumption (C_t^*), foreign government consumption (G_t^*) and foreign investment (I_t^*): $Y_t^* = C_t^* + I_t^* + G_t^*$. Therefore, we can write, $P_t^* = P_{F,t}$, $C_t^* = C_{F,t}$ and $Y_t^* = Y_{F,t}$.

$$P_{H,t} = P_{F,t} = \varepsilon_t P_t^* \tag{6.58}$$

where ε_t is the nominal bilateral exchange rate between the home and foreign economy, in terms of the home currency. Given equation (6.60), the terms of trade can be expressed as:

$$X_t = \frac{e_t P_t^*}{P_{H,t}} \tag{6.59}$$

The real exchange rate (CPI terms) between the home and foreign economy, which is defined as the ratio of both countries' CPI expressed in terms of the domestic currency, is specified as;

$$RER_t = \frac{p_{F,t}}{P_t} \tag{6.60}$$

Combining (6.58) (6.59) and (6.60), we obtain an expression that links real exchange rate to terms of trade, domestic price and CPI as:

$$RER_t = \frac{e_t P_t^*}{P_t} = \frac{X_t P_{H,t}}{P_t} \tag{6.61}$$

Given complete international financial market, the price in terms of domestic currency of a risk-free bond denominated in the foreign currency is given by

$$\frac{\epsilon_t}{R_t^*} = E_t\left[Q_{t,t+1}\epsilon_{t+1}\right] \tag{6.62}$$

Combining (6.67) with its domestic counterpart, $R_t = \frac{1}{E_t Q_{t,t+1}}$, we get the following uncovered interest rate parity (UIP) expression:

$$\frac{R_t}{R_t^*} = E_t\left(\frac{\epsilon_{t+1}}{\epsilon_t}\right) \tag{6.63}$$

Assuming that UIP holds means that investors are indifferent between investing in domestic or foreign assets. However, we introduce a UIP shock (μ_e) which capture speculative activities that trigger currency depreciation (or appreciation) with change divergence in the foreign and domestic interest rates

$$\frac{R_t}{R_t^*} + \mu_e = E_t\left(\frac{\epsilon_{t+1}}{\epsilon_t}\right) \tag{6.69}$$

where μ_e is a transitory shock.

6.1.6 Equilibrium Condition/Market Clearing

All goods produced by home and foreign firms are consumed by home and foreign households. Final home goods are partly exported (T_t^x) and partly consumed by domestic households. As a result, the goods market clearing condition for the home economy requires that domestic output must be equal to

aggregate (private) consumption (C_t), private investment ($I_{\mathrm{h},t}$), government expenditure (G_t) and net export ($\mathrm{T}_t^x - \mathrm{T}_t^{IM}$):

$$Y_t = C_t + I_{\mathrm{h},t} + G_t + \mathrm{T}_t^x - \mathrm{T}_t^{IM} \tag{6.70}$$

6.1.7 Log Linearization of the Model

We proceed to log-linearize the relevant equations using Uhlig's Method[89]. Euler equation for public bond is derived as

$$(\hat{c}_t - h\hat{c}_{t-1}) = (\hat{c}_{t+1} - h\hat{c}_t) - \alpha^C\{E_t\hat{r}_{t+1} - E_t\hat{\pi}_{t+1}\} + \alpha^C\left(1 - \rho_{\hat{\zeta}_t^c}\right)\hat{\zeta}_t^c \tag{6.71}$$

where $\alpha^C = \frac{(1-h)}{\sigma_c}$

Demand for home and foreign consumption goods are given by

$$\hat{c}_{H,t} = \hat{c}_t + \eta\hat{x}_t \tag{6.72}$$

$$\hat{c}_{F,t} = \hat{c}_t - \eta(1-\Omega)\hat{x}_t \tag{6.73}$$

The law of motion of capital is given by

$$\hat{k}_{t+1} = (1-\varrho)\hat{k}_t + \varrho\hat{\imath}_t \tag{6.74}$$

The equations for households' wage are given respectively as follows:

$$\hat{\pi}_t^w = \beta E_t\hat{\pi}_{t+1}^w + \frac{(1-\vartheta_w)(1-\beta\vartheta_w)}{\vartheta_w}\left\{\vartheta_l\hat{n}_t + \frac{\sigma_c}{(1-h)}\left[\hat{c}_t - h\hat{c}_{t-1}\right] - (\hat{w}_t - \hat{p}_t) - \hat{\zeta}_t^c + \zeta_t^n\right\} \tag{6.75}$$

The NKPC for domestic inflation rate of the home economy is obtained as

$$\hat{\pi}_{h,t} = \beta E_t\hat{\pi}_{h,t+1} + \frac{(1-\vartheta_h)(1-\beta\vartheta_h)}{\vartheta_h}(\widehat{mc}_{h,t} + \hat{\zeta}_t^p) \tag{6.76}$$

Where $\hat{\pi}_{h,t} = \hat{p}_{h,t} - \hat{p}_{h,t-1}$

The production function, labour and capital demand are given respectively by

$$\hat{y}_t = \hat{u}_t + \lambda\hat{k}_t + (1-\lambda)\hat{n}_t \tag{6.77}$$

$$\hat{n}_t = \hat{y}_t + (1-\mathfrak{Z})\hat{r}_t^K - \hat{u}_t - \hat{w}_t \tag{6.78}$$

$$\hat{k}_t = \hat{y}_t + \mathfrak{Z}\hat{w}_t - \hat{r}_t^K - \hat{u}_t \tag{6.79}$$

Marginal cost is given by

$$\widehat{mc}_t = (1-\mathfrak{Z})\hat{w}_t + \mathfrak{Z}\hat{r}_t^K - \hat{u}_t \tag{6.80}$$

Market clearing condition is log-linearized as

$$\hat{y}_t = (\phi_C - \Omega\phi_{IM})\hat{c}_t + \phi_i\hat{\imath}_t + \phi_{IM}\eta\widehat{rer}_t + \phi_x(\eta\hat{x}_t + \hat{y}_t^*) + \phi_g\hat{g}_t \tag{6.81}$$

where $\phi_C = \frac{C_{ss}}{Y_{ss}}$; $\phi_i = \frac{I_{ss}}{Y_{ss}}$; $\phi_x = \frac{T_{ss}^x}{Y_{ss}}$; $\phi_{IM} = \frac{IM_{ss}}{Y_{ss}}$ and $\phi_g = \frac{G_{ss}}{Y_{ss}}$

[89] For instance, a variable Z_t is log-linearized as $Z_t = Z_{ss}e^{\hat{z}_t} = Z_{ss}(1+\hat{z}_t)$, while that of two variable with a multiplicative form (Z_tY_t) is derived as $Z_tY_t = Z_{ss}Y_{ss}e^{(\hat{z}_t+\hat{y}_t)} = Z_{ss}Y_{ss}(1+\hat{z}_t+\hat{y}_t)$.

Monetary policy rule(s) for flexible regime is a forward-looking Taylor rule derived as:

$$\hat{r}_t = \alpha_R \hat{r}_{t-1} + (1-\alpha_R)\left[\alpha_\pi \hat{\pi}_{t+1} + \alpha_y \hat{y}_t\right] + \mu_t^{fl} \tag{6.82}$$

Log-linearized foreign output, inflation and policy interest rate equations are given respectively by:

$$\hat{y}_t^* = p_{*y}\, \hat{y}_{t-1}^* + \varepsilon_t^{*y} \tag{6.83}$$

$$\hat{\pi}_t^* = p_{*\pi}\, \hat{\pi}_{t-1}^* + \varepsilon_t^{*\pi} \tag{6.84}$$

$$\hat{r}_t^* = p_{*r}\, \hat{r}_{t-1}^* + \varepsilon_t^{*r} \tag{6.85}$$

Log-linearizing equations (6.6) and (6.59) and simplifying, we obtained aggregate consumer price index that links consumer inflation to domestic inflation and terms of trade as

$$\hat{\pi}_t = \hat{\pi}_{h,t} + \Omega_c \Delta \hat{x}_t \tag{6.86}$$

Terms of trade is defined as

$$\Delta \hat{x}_{t+1} = \Delta \hat{e}_{t+1} + \hat{\pi}_{t+1}^* - \hat{\pi}_{h,t+1} \tag{6.87}$$

Given equation (6.62) and (6.61), the log-linearized real exchange rate is defined as

$$\widehat{rer}_t = (1-\Omega)\hat{x}_t \tag{6.88}$$

UIP is expressed as

$$E_t \hat{e}_{t+1} - \hat{e}_t = \hat{r}_t - \hat{r}_t^* + \mu_t^{uip} \tag{6.89}$$

Technological shock is expressed as

$$\hat{u}_t = p_u \hat{u}_{t-1} + v_t^u \tag{6.90}$$

Government expenditure shock is expressed as

$$\hat{g}_t = p_g \hat{g}_{t-1} + v_t^g \tag{6.91}$$

The domestic price mark-up shock is given by

$$\hat{\zeta}_t^p = p_{\hat{\zeta}_t^p} \hat{\zeta}_{t-1}^p + v_t^{\hat{\zeta}_t^p} \tag{6.92}$$

The domestic wage mark-up shock is given by

$$\hat{\zeta}_t^w = v_t^{\hat{\zeta}_t^w} \tag{6.93}$$

Preference shifter is expressed as

$$\hat{\zeta}_t^c = p_{\hat{\zeta}_t^c} \hat{\zeta}_{t-1}^c + v_t^{\hat{\zeta}_t^c} \tag{6.94}$$

Labour supply shock is expressed as

$$\hat{\zeta}_t^n = p_{\hat{\zeta}_t^c} \hat{\zeta}_{t-1}^n + v_t^{\hat{\zeta}_t^n} \tag{6.95}$$

Domestic monetary policy shock is expressed as:

$$\mu_t^{fl} = v_t^{fl} \tag{6.96}$$

UIP shock is given by

$$\hat{u}_t^{uip} = v_t^{uip} \tag{6.97}$$

Foreign output shock is defined

$$\varepsilon_t^{*y} = v_t^{*y} \tag{6.98}$$

Foreign inflation shock is defined

$$\varepsilon_t^{*\pi} = v_t^{*\pi} \tag{6.99}$$

Foreign monetary policy shock is expressed as

$$\varepsilon_t^{*r} = v_t^{*r} \tag{6.100}$$

6.2 Estimation Methodology

The rational expectation solution of the log-linearized model is estimated using Bayesian estimation techniques[90] following the extant literature (for instance, An and Schorfheide, 2007; Almeida, 2009; Schorfheide et al., 2010; Rudolf and Zurlinden, 2014; etc.). At its rudimentary level, Bayesian estimation is a bridge between calibration and maximum likelihood. On one hand, the calibration is conventionally attained through the specification of priors, while the maximum likelihood approach emerges via the estimation process based on confronting the model with data. Theoretically, these two building blocks – priors and likelihood function- are tied together by Bayes' rule. On the whole, the Bayesian approach requires the choice of prior densities[91] of the parameters being estimated and the construction of the posterior distribution from the prior densities and the likelihood function.

6.2.1 Prior Distribution

Priors are described by a density function of a form

$$P(\theta_A|A) \tag{6.101}$$

where A stands for a specific model, θ_A denotes the parameter of model A, $P(.)$ connotes a probability density function (pdf), conditional on past studies or/and occurrences or simply, reflecting subjective views of the researcher without any reference to the data. For the prior functional form, the general practice in the literature is that the inverse gamma distribution is utilized for parameters that are restricted to be positive, while beta distribution is employed for parameters that are confined to fall within zero and one. On the other hand, normal distribution is deployed for parameters without bounds.

[90] The Bayesian approach provides a middle ground between classical econometric estimation and calibration of macroeconomic models. The Bayesian approach is widely acclaimed to overcome the deficiencies of the classical estimation and calibration methods (see, Anand et al 2011; Schorfheide, 2000, 2004; and Geweke, 1999).

[91] Priors can be weak or strong. A weak prior is thus a type of an uninformative prior in which the posterior distribution is completely reliant on the data. In contrast, a strong prior conveys a very precise belief as to where a parameter values may lie. A strong prior is a type of informative prior in which the information contained in the prior distribution dominates the information contained in the data being analyzed.

Amid inadequate empirical evidence, we prefer relatively diffused priors that cover a wide range of parameter values. Particularly, beta distribution is adopted for the structural parameters (such as autoregressive shock process) that are theoretically constricted to lie between zero and one. In line with the literature, inverted gamma distribution is used for the standard errors of the shock processes, as it ensures a positive variance but with a large domain.

6.2.2 **The Likelihood**

Blanchard and Khan (1980) demonstrated that linear rational expectation models can be written as a linear combination of backward-looking and forward-looking solutions. Subsequently, different approaches for solving linear rational expectations models have emerged[92]. However, the extant literature clearly articulates that the assumptions about the beliefs and expectations formation result in a sequence of reduced-form matrices. Following the extant literature, our solution method for the version of the linear rational expectation NK model described above in Equations (6.71) - (6.100) can therefore be written as

$$A_o m_t = C_o + A_1 m_{t-1} + B_o E_t m_{t+1} + D_o \varepsilon_t \tag{6.102}$$

where m_t is a $nx1$ vector of jump and state variables (where n denotes number of equations) and ε_t is a $lx1$ vector of exogenous variables. ε_t is generally assumed to be white noise and to have I_l as their covariance matrix. As in Binder and Pesaran (1997) and Kulish and Pagan (2014), equation (6.102) can be generalized to allow additional lags of m_t as well as conditional expectations at different horizons and from earlier dates. If it exists and is unique, the solution to equation (6.102) will be a VAR of the form

$$m_t = C + Q m_{t-1} + G \varepsilon_t \tag{6.103}$$

where m_t contains the endogenous state vectors; Q and G are functions of the models deep parameters; H expresses the link between the observed and state variables. Given the sample data, $\{z_t\}_{t=1}^{T}$, where z_t is an $nx1$ vector of observable variables that relate to the model's variables by

$$z_t = \mathrm{H} m_t + v_t \tag{6.104}$$

where v_t is an iid measurement error with $E(v_t) = 0$, and $E(v_t v_t') = 0$. Equation (6.104) and (6.103) are the observation (or measurement) equation and state (or transition) equation respectively which constitute a state space model. As outlined in Harvey (1989) and Kulish and Pagan (2014), Kalman

[92] Notably studies include Binder and Pesaran (1997), Clarida et al., (2000), Farmer (1999), Farmer and Khramov (2013), Kerr and King (1996), King and Watson (1998), Klein (2000), Kulish and Pagan (2014), Lubik and Schorfheide (2004), Sims (2001) and Uhlig (1999).

filter can therefore be used to construct the likelihood function for the sample, $\{z_t\}_{t=1}^{T}$. Based on recursive Kalman filter, log-likelihood is given by[93]:

$$\mathcal{L}(\theta|z_t) = \frac{Tn}{2} ln(2\pi) - \frac{1}{2}\sum_{t=1}^{T} \ln det\left(\mathrm{H}\Sigma_{t|t-1}\mathrm{H}' + \mathrm{V}\right) - \frac{1}{2}\sum_{t=1}^{T} u_t'\left(\mathrm{H}\Sigma_{t|t-1}\mathrm{H}' + \mathrm{V}\right)u_t \quad (6.105)$$

where $\Sigma_{t|t-1} = E(m_t - E_{t-1}m_t)(z_t - E_{t-1}z_t)'$ is the variance-covariance matrix of the state variable m_t conditional on information up to $t-1$; $u_t = (z_t - E_{t-1}z_t) = \mathrm{H}(m_t - E_{t-1}m_t) + v_t$ is the prediction/forecast error; $cov_{t-1}(z_t) = E(u_t u_t') = \left(\mathrm{H}\Sigma_{t|t-1}\mathrm{H}' + \mathrm{V}\right)$ and $\mathrm{V} = E(v_t v_t')$ is the covariance matrix of the measurement error.

Our linear rational expectations NK model in Equations (6.71) - (6.100) is solved using Dynare, a Matlab-based software platform for handling a wide class of economic model in particular DSGE. If the model is determinate (i.e. has a unique solution), Dynare finds the unique series of non-fundamental errors that keeps the state variables bounded and produces a message "Blanchard and Khan conditions are satisfied". In the case of indeterminacy, Dynare produces an error with a message "Blanchard and Khan conditions are not satisfied: indeterminacy". According to Blanchard and Khan (1980), indeterminacy arises when the number of explosive roots is smaller than the number of non-predetermined variables.

6.2.3 Posterior Distribution

After specifying the priors and deriving the likelihood, the posterior distribution, $p(\theta_A|z_t)$, is then estimated using Bayes theorem. According to Bayes Law, the posterior density is proportional to the product of the prior density of the parameters $p(\theta_A)$ and the distribution of the data given the parameter set $p(z_t|\theta_A)$:

$$p(\theta_A|z_T, A) = \frac{p(\theta_A|A)p(z_T|\theta_A, A)}{p(z_T|A)} \quad (6.106)$$

where $p(z_t|A)$ is the marginal density (distribution) of the data conditional on the model:

$$p(z_T|A) = \int_{\theta_A} p(\theta_A; z_T|A)d\theta_A \quad (6.107)$$

The numerator of equation (5.106) corresponds to the posterior kernel:

$$p(\theta_A|z_T, A) \propto p(z_T|\theta_A, A)p(\theta_A|A) \equiv \mathrm{K}(\theta_A|z_T, A) \quad (6.108)$$

The posterior kernel is the un-normalized posterior densities, given that the marginal density is constant or equal for any parameter. The log-posterior kernel is expressed as

[93] Detailed derivation of the likelihood function is provided by Kulish and Pagan (2014).

$$\ln K(\theta_A|Z_T^*) = ln\mathcal{L}(\theta_A|Z_T^*) + lnp(\theta_A) \quad (6.109)$$

where the term on the RHS is known after carrying out the KF recursion while the second term are the priors which are also known. Thus, the mode of the posterior distribution is identified by simply maximizing the log-posterior kernel with respect to θ_A using Laplace approximation. Since the distribution of the deep parameters is given by a nonlinear posterior kernel in (6.109), the direct sampling is difficult. As a result, we utilize Metropolis-Hastings (MH) algorithm, which is a Markov Chain Monte Carlo (MCMC) method to simulate the posterior distribution. The MH method is well-acclaimed in the literature to be efficient sampling method for obtaining a sequence of random samples from probability distribution from which direct sampling is problematic.

6.2.4 Data and Preliminary Analysis

We estimate the parameters of the model and the stochastic processes governing the structural shock using six key macroeconomic variables, comprising real GDP (Y), private consumption (C), government consumption spending (G), private investment (I), consumer inflation (π) and nominal interest rate (R). In terms of sources, the domestic datasets were obtained from Bank of Ghana, Ghana Statistical Services, Ministry of Finance and Economic Planning, World Bank's African Development Indicators and UNCTAD database. The inclusion of both output and consumption in this chapter is consistent with Smet and Wouters (2002).

The Bayesian estimates of the NKDSGE model parameters are conditional on the information set:

$$\hat{z}_t = [\hat{y}_t, \hat{c}_t, \hat{g}_t, \hat{\imath}_t, \hat{\pi}_t, \hat{r}_t] \quad (6.110)$$

where $Z = f(Y, C, G, I, \pi, R)$, a hat (^) denotes deviation of a variable in question from its steady state level: $\hat{z}_t = 400(\Delta logZ_t - \Delta logZ_{ss})$ and subscript ss denotes steady state value and Δ is the first difference operator.

We also allow for a total of eleven exogenous shocks driving the stochastic behaviour of the model: two supply shocks (i.e. productivity shock and labour supply shock), four mark-up shocks (i.e. domestic price mark-up shock, wage mark-up shock, exchange rate risk premium (UIP) shock and foreign inflation shocks), demand shocks (i.e., preference shock and foreign output shock) and three policy shocks (i.e. domestic monetary policy shock, foreign monetary policy shock and government spending shock). The inclusion of an expansive set of shocks is vital so as to replicate the time-series properties of the data adequately.

Since the likelihood function has to be combined with a prior density for the model parameters in order to obtain the posterior distribution of the parameters, we first discuss the choice of the prior distribution. We divide the parameters vector Γ_v into three parts. The parameters of economic interest in the log-linearized model, as described in Section 5.3, can be written in a $39\ x\ 1$ column vector as

$$\Gamma_v = \begin{bmatrix} \varphi_c\ \varphi_g\ \varphi_i\ \varphi_x\ \varphi_m\ \varphi_k\ \varphi_b\ \ \beta\ \sigma_c\ \sigma_l\ \Omega\ \alpha_r\ \alpha_\pi\ \alpha_y\ \varrho \\ \theta_h\ \theta_w\ \eta\ \rho_{\pi h}\ \rho_u\ \rho_g\ \rho_{\zeta c}\ \rho_{\zeta n}\ \tau_{y^*}\tau_{\pi^*}\ \tau_{r^*}\ \nu_{\pi h}\ \upsilon_u\ \upsilon_g\ \nu_{\zeta c} \\ \nu_{\zeta n}\ \eta_{\zeta w}\ \eta_{uip}\ \eta_r\ \eta_{y^*}\ \eta_{\pi^*}\ \eta_{r^*}\ h\ \lambda \end{bmatrix}' \tag{6.111}$$

Under the Del Negro and Schorfheide (2008) prior rubic, the elements in Γ_v are grouped into steady-state parameter vector

$$\Gamma_{v,ss} = \left[\varphi_c\ \varphi_g\ \varphi_i\ \varphi_x\ \varphi_m\ \varphi_k\ \varphi_b\ \gamma_h\ \gamma_w\right]' \tag{6.112}$$

the parameters tied to endogenous propagation in the model

$$\Gamma_{v,prop} = \left[h\ \beta\ \sigma_c\ \sigma_l\ \Omega\ \alpha_r\ \alpha_\pi\ \alpha_y\ \varrho\ \theta_h\ \theta_w\ \eta\ \ \tau_{y^*}\ \tau_{\pi^*}\ \tau_{r^*}\ \lambda\right]' \tag{6.113}$$

and

$$\Gamma_{v,exog} = \left[\rho_{\pi h}\ \rho_u\ \rho_g\ \rho_{\zeta c}\ \rho_{\zeta n}\ \nu_{\pi h}\ \upsilon_u\ \upsilon_g\ \nu_{\zeta c}\ \nu_{\zeta n}\ \eta_{\zeta w}\ \eta_{uip}\ \eta_r\ \eta_{y^*}\ \eta_{\pi^*}\ \eta_{r^*}\right]' \tag{6.114}$$

The choice of priors for our estimation is guided by several considerations. At a basic level, the priors reflect our beliefs and confidence we have about the likely location of the structural parameters. We also considered information on the structural characteristics of the Ghanaian economy such as the degree of openness, exchange rate pass-through and its institutional settings. Micro-level studies on Ghana are relatively scarce. Therefore, priors from similar studies using Ghanaian datasets, for instance Dagher et al (2010, 2012) and Bondzie et al., (2014), were also considered. In addition, the Bank of Ghana's main macro-model (FPAS) is taken as a good approximation of the Bank's view of the Ghanaian economy. The key parameter contained in the FPAS model and their implicit dynamic properties were thus utilized to inform our choice of priors.

As a usual routine in the empirical literature, we first impose a very strict prior on a number of parameters by keeping them fixed in the model. Primarily, most of these parameters are precisely linked to the steady-state values of the state variables. Therefore, they could simply be derived from the means of the observed variables (or linear combination of them). But they cannot be easily identified in the estimation procedure due to the fact that our observed variables are already demeaned. Thus, most of the parameters in vector in $\Gamma_{v,ss}$ have strict priors. Some of the key technological parameters with fixed priors are reported in Panel D of Table 3.6 (in Chapter 3) based on their steady-state values. Notably, the steady-state private consumption output ratio (φ_c) is 0.78 while government

consumption-output ratio (φ_g) is estimated at 0.188. The share of steady-state investment (φ_i), exports (φ_x) and imports (φ_m) in total output are derived as 0.166, 0.294 and 0.438 respectively while capital-output ratio (φ_k) is 2.92. We calibrate the depreciation rate of capital, ϱ, based on the steady-state formula (as in equation 6.115)

$$I_{ss} = \varrho K_{ss} \Leftrightarrow \varrho = I_{ss}/K_{ss} \Leftrightarrow \varrho = \varphi_i Y_{ss}/\varphi_k Y_{ss} \Leftrightarrow \varrho = \varphi_i/\varphi_k \qquad (6.115)$$

with $\varphi_i = I_{ss}/Y_{ss}$ and $\varphi_k = K_{ss}/Y_{ss}$. This yields a depreciation rate of capital as 0.056 per quarter, which implies an equivalent annual depreciation on capital of 22%. This value appears to be very high compared to extant empirical literature on Ghana (e.g. Dagher et al, 2012; Bondzie et al., 2014). In contrast to the previous studies which tend to arbitrarily calibrate ϱ, we prefer to derive the latter based on the preceding expression using observed dataset. The degree of openness, defined as total external trade to GDP, is also estimated to be 0.72.

Table 6.1 reports our assumptions for the prior distribution of the other 29 estimated parameters. Following the extant empirical literature and to guarantee a positive variance, all the variances of the shocks are assumed to have an inverted Gamma distribution with a degree of freedom equal to 2. However, the exact mean for the prior is determined by previous estimation outcomes and trials with a very weak prior, in line with Smet and Wouters (2002). In particular, all the autoregressive parameters for the shocks have beta distribution with prior mean 0.8 and standard error of 0.15. Although the beta distribution covers the range between 0 and 1, a rather restricted standard error is assumed so as to ensure an unambiguous disparity between persistent and non-persistent shocks.

The remaining sets of parameters regarding technology, utility (or preference) and pricing settings were assumed to have either Normal or Beta distribution. The means of these parameters, which are restricted within a range of 0 and 1, were set according to the extant literature. We set the corresponding standard errors to ensure that their domain envelop a reasonable range of parameter values. With respect to the utility (preference) parameter, the prior mean for intertemporal elasticity of substitution was set to 2. Similarly, the prior mean for marginal disutility of labour supply is set to 2, falling within the range of values used in the standard empirical literature. For instance, Bondzie et al., (2014) assumed a value of 1 while Dagher et al., (2010, 2012) used a value of 3 for Ghana. We however assumed much wider variance of 0.75 (as in Smet and Wouters, 2002) to ensure broader range of values. Also, the prior mean for the elasticity of substitution between home and foreign goods was set to 2. Following the empirical literature (notably, Smet and Wouters, 2002; Gali et al., 2001; and Costa Jr., 2016), the means of the Calvo parameters in the price and wage setting equations were set to 0.75.

These prior values were mainly to ensure that the wage contract is about one year. The standard errors for the Calvo parameters were set at 0.05, mainly to allow for divergence between 3 quarters and 2 years. Besides, the discount factor, β, is calibrated to be 0.983, which implies an annual steady-state real interest rate of 7.8% (a mean long run value for 2015-2018).

Regarding other technological parameters, we set the share of capital in production, λ, to 0.3 in line with standard literature (notably, Dagher et al., 2012). This roughly implies a steady state share of labour income in total output of 70%. We assume a prior mean of 0.7 for consumption habit parameter, h, and the standard error of 0.2. The values were derived as mean and the corresponding standard deviation from the five detrending approaches in Table 2.5 of Section 2. The prior mean for h is within the empirical estimates by Guerron-Quintana & Nason (2012), and Kirchner & Tranamil (2016).

Finally, the prior on the coefficients in the monetary policy rule are standard. For instance, the prior mean for interest rate sensitivity to inflation deviation from its steady-state, α_π, is set at 1.4 with standard error of 0.25. The imposition of a relatively higher α_π is to obey the Taylor Principle that interest rate rises more than the increase in inflation deviation from the target level (or steady state value). Thus, the prior on α_π is to guarantee unique solution path when solving the model. Likewise, the prior mean for the autoregressive parameter was set to 0.8 with a standard error of 0.15. On the other hand, the parameter for policy interest rate sensitivity to output deviation from its steady-state has a prior mean of 0.125 and standard error of 0.35. This is based on the empirical estimates of interest rate rules that generally place α_y between 0.1 and 0.5 for less developed countries (see, Airaudo et al., 2016). This implies smaller response of policy interest rate to the output gap but this response is non-zero.

Table 6.1: Calibrated Parameters of the Baseline RANK-DSGE model

Parameter	Description	Prior Distribution		
		type	mean	std. error
σ_c	Inverse elasticity of inter-temporal subst.	normal	2.00	0.38
σ_l	Marginal disutility of labour supply	normal	2.00	0.75
η	Elast. of subs. btn home and foreign goods	normal	2.00	0.75
h	External consumption habit formation	beta	0.60	0.20
λ_y	Elasticity of Capital in production	normal	0.30	0.08
θ_w	Calvo wage parameter	beta	0.75	0.15
θ_h	Calvo price parameter	beta	0.75	0.15
α_π	Interest rate sensitivity to Inflation gap	normal	1.40	0.25
α_y	Interest rate sensitivity to output gap	normal	0.13	0.35
α_r	AR coefficient for Domestic Monetary Policy	beta	0.80	0.15
Ω	Degree of openness	beta	0.72	0.025

γ_w	Elast. of subst. btn differentiated labour	beta	0.75	0.05
γ_h	Elast. of subst. btn differentiated goods	beta	0.75	0.05
β	Discount Factor	beta	0.98	0.01
ϱ	Depreciation rate of capital	normal	0.05	0.03
v_u	Productivity Shock	inverted gamma	0.13	2.00
v_g	Government Spending Shock	inverted gamma	0.14	2.00
$v_{\pi h}$	Domestic Price Mark-up Shock	inverted gamma	0.02	2.00
v_r	Domestic Interest Rate Shock	inverted gamma	0.13	2.00
v_{tot}	Nominal Exchange Rate (UIP) Shock	inverted gamma	0.24	2.00
$v_{\zeta w}$	Domestic Wage Mark-up Shock	inverted gamma	0.24	2.00
$v_{\zeta c}$	Preference Shock	inverted gamma	0.26	2.00
$v_{\zeta n}$	Labour Supply Shock	inverted gamma	1.00	2.00
η_{r^*}	Foreign Interest rate Shock	inverted gamma	0.10	2.00
η_{y^*}	Foreign output Shock	inverted gamma	0.20	2.00
η_{π^*}	Foreign inflation Shock	inverted gamma	0.30	2.00
ρ_u	AR coefficient for Productivity Shock	beta	0.80	0.15
ρ_g	AR coefficient for Gov't Spending Shock	beta	0.80	0.15
$\rho_{\pi h}$	AR coefficient for Domestic Mark-up Shock	beta	0.80	0.15
$\rho_{\zeta c}$	AR coefficient for Preference Shock	beta	0.80	0.15
$\rho_{\zeta n}$	AR coefficient for Labour Supply Shock	beta	0.80	0.15

6.3 Estimation Results and Analysis

More shocks were included in the model in order to avoid the problem of stochastic singularity in the case where there are more observed variables than the number of shocks. Also, following Brooks and Gelman (1998)[94], various convergence statistics were computed and the figures in Appendix 6Bi-ii broadly reveal no significant convergence problems for most parameters in the baseline model. We carried out Markov Chain Monte Carlo simulations with MH-algorithm using five parallel block chains for (a) 100000 draws and (b) 300000 draws. For brevity, we report the posterior distribution generated from the five parallel Markov Chains with 300,000 draws. In the ensuing sections, we discuss the posterior estimates of the model parameters and proceeds with analysis of the model diagnostics regarding dynamics of shocks and impulse response functions to ascertain the suitability of the model for policy analysis in Ghana.

6.3.1 Posterior Parameter Estimates

Based on five independent Markov Chains with 300000 draws, Table 6.2 reports two sets of posterior parameter estimates for the baseline model. The first category is the estimated posterior mode of the

[94] For brevity, interested reader should kindly refer to Brooks and Gelman (1998) and Gelman and Rubic (1992) for detailed expositions on the convergence diagnostics.

parameters. The posterior modes are attained by maximizing the log of the posterior distribution with respect to the parameters and an approximate standard error based on the corresponding Hessian. The second category reports the estimated posterior mean with the corresponding 5% and 95% credible intervals of the posterior distribution of the parameters.[95]

Table 6.2: Posterior estimates from the Baseline RANK-DSGE model

	Est. Max. Posterior		**Posterior Distr. MH**		
	mode	**std. error**	**mean**	**5%**	**95%**
Panel A: Distribution of Shock Processes					
v_u	0.163	0.103	0.400	0.291	0.541
v_g	4.000	0.286	3.941	3.830	4.000
$v_{\pi h}$	0.975	0.138	1.015	0.786	1.273
v_r	0.287	0.128	0.320	0.242	0.407
v_{tot}	3.523	0.407	3.551	3.055	4.000
$v_{\zeta w}$	0.642	0.171	0.188	0.100	0.352
$v_{\zeta c}$	0.090	0.113	0.290	0.044	0.958
$v_{\zeta n}$	2.359	1.065	2.406	1.616	3.252
η_{r^*}	0.197	0.018	0.202	0.163	0.244
η_{y^*}	0.231	0.021	0.235	0.194	0.283
η_{π^*}	0.440	0.050	0.442	0.347	0.539
ρ_u	0.944	0.029	0.571	0.419	0.689
ρ_g	0.987	0.024	0.985	0.977	0.990
$\rho_{\pi h}$	0.578	0.079	0.603	0.493	0.707
$\rho_{\zeta c}$	0.561	0.123	0.936	0.762	0.990
$\rho_{\zeta n}$	0.990	0.097	0.945	0.906	0.990
Panel B: Distribution of Structural Parameters					
σ_c	0.910	0.438	0.739	0.331	1.139
σ_l	4.000	1.255	3.835	3.473	4.000
η	1.064	0.401	0.846	0.559	1.133
h	0.300	0.013	0.326	0.300	0.367
λ_y	0.301	0.001	0.301	0.299	0.302
θ_w	0.702	0.044	0.702	0.604	0.786
θ_h	0.773	0.025	0.730	0.646	0.797
α_π	1.856	0.299	1.704	1.218	2.000
α_y	0.827	0.080	0.605	0.197	0.972
α_r	0.830	0.051	0.831	0.777	0.881
Ω	0.689	0.030	0.687	0.639	0.732
β	0.990	0.003	0.979	0.955	0.990
ϱ	0.060	0.013	0.064	0.051	0.078
Marginal likelihood (Laplace)				-633.0	
Marginal likelihood (Harmonic mean)				**-617.9**	
CARPC	0.20	0.21	0.27	0.25	0.26

Note: CARPC denotes current acceptance ratio per chain

[95] This information is also visually presented in Appendix 6Bii. The figure plots the prior distribution, the posterior distribution and the probability curve for a normal distribution with mean as the posterior mode and the corresponding Hessian-based estimate as standard error. The plots indicate that there is a considerable amount of information contained in the datasets that can be utilized to update our prior beliefs about the model parameters. With the exception of Calvo wage and price rigidity parameters (θ_w and θ_h), the posterior marginal densities are pictorially much more concentrated than the prior densities.

Panel A of Table 6.2 gives the estimated posterior distribution of the shock processes. A number of observations are worth making regarding the estimated processes for the exogenous shock variables. We find quite distinct posterior estimates for all the shock parameters when compared to the assumed priors. This observation connotes that the estimates extract vital information from the actual data. On a whole, it appears that data is quite informative on the stochastic processes for the exogenous disturbances as indicated by the lower variance of the posterior distribution relative to the prior distribution. The government consumption, labour supply and preference shock processes are estimated to be the most persistent, with an AR(1) coefficients of 0.985, 0.945 and 0.936 respectively. In contrast, productivity is the least persistent parameter, with an AR(1) coefficients of 0.571. The mean of the standard error of government consumption is 3.394

Turning to the estimates of the main behavioural parameters, as exhibited in Panel B of Table 6.2, it turns out that the mean of the posterior distribution is generally relatively close to the mean of the prior assumptions. Overall, it appears that the data are quite informative on the behavioural parameters, as reflected by the lower variance of the posterior distribution relative to the prior distribution. There are however few notable exceptions. The estimated posterior variances of the intertemporal elasticity of substitution, degree of openness, marginal disutility of labour, depreciation rate on capital are higher than their corresponding prior values, while the posterior and prior variances for capital share in production is identical. This suggests that these parameters appear to have very informative priors as information contained in the prior distribution dominates the information contained in the data being analyzed.

The posterior mean estimate of the intertemporal elasticity of substitution is less than one (σ_c =0.739) and below the assumed prior distribution. Nevertheless, our estimate falls within the assumption made in much of the RBC literature which assumes an elasticity of substitution between 0.5 and 1. It should however be noted that our model assumes an external habit formation, h, which turns out be significant and hence, such comparison ought to be done with caution. The external consumption habit stock, h, is estimated at 0.32 which is smaller than our prior mean and also below the estimates reported in Smet and Wouters (2002), CEE (2005) and Liu (2006). Nevertheless, the relatively moderate values for σ_c and h imply that households are less willing to accept deviations from a uniform pattern of consumption over time. Ignoring the preference shocks, our consumption function in equation (6.71) can be written as

$$\hat{c}_t = \left(\frac{h}{1-h}\right)\hat{c}_{t-1} + \left(\frac{1}{1-h}\right)\hat{c}_{t+1} - \frac{(1-h)}{(1+h)\sigma_c}\{\hat{r}_t - E_t\hat{\pi}_{t+1}\} \qquad (6.116)$$

Given equation (6.116) and our estimates for σ and h, an expected one percent rise in the short-term real interest rate for four quarters has an impact on consumption of about 0.697. In contrast, the estimated inverse elasticity of substitution for labour, σ_l, turn out be much greater than unity (σ_l =3.835), in line with the estimate for New Zealand as reported in Liu (2006). This implies that a one percent increase in real wage will result in only a small change in labour supply. This is plausible given the large size of the informal sector in Ghana. For instance, Hohberg and Lay (2015) find no significant spillover effect of minimum (real) wage on informal workers due to (among others) a noncompliance of informal sector employers to labour market regulations. Besides, Broecke, Forti and Vandeweyer (2015) argued that increases in the real wage may have no significant effect on overall employment in an economy characterized by large informal sector because a fall in formal sector employment due to wage increase may simply be compensated by a rise in informal sector employment as displaced workers migrate from one sector to the other.

The estimated posterior mean for elasticity of substitution between home and foreign goods, η, is 0.846, below the prior mean and the value used in Dagher et al (2012) for Ghana. The relatively low value for η is broadly coherent with the fact that Ghana is commodity-producer and foreign produced goods form a sizeable proportion of its consumption basket. Consistently, the posterior mean for the parameter characterizing the degree of openness, Ω, is estimated at 0.687. Although it is slightly smaller than the assumed prior distribution, the estimates surmises that the Ghanaian economy is very open, exposing the economy to the vagaries of external developments.

There is a considerable degree of Calvo price and wage rigidities. The average duration of price contracts is estimated to be about seven quarters, whereas the average duration of wage contracts is much shorter at two quarters. The greater stickiness in prices relative to wages is somewhat counterintuitive but it emerges to be a very robust outcome of the estimated model. Even though we impose a relatively tight prior on the Calvo price (wage) parameter, the data prefer a much higher (lower) degree of stickiness. One important explanation is the underlying specification of the process driving marginal cost which tends to bias upward the estimate of Calvo price stickiness (see, Smets and Wouters, 2002).

The posterior mean for the discount factor, β, is estimate at 0.979 (with a range of 0.955-0.990), which is slightly smaller than the prior mean. This implies annual steady state real interest rate of 7.6%. The depreciation rate, ϱ, is estimated at 0.06, implying an annual depreciation on capital of about 24%. Although this value appears to be very high, our prior is more informative than much of the other

empirical studies. The posterior mean parameter for capital share in production, λ_y, is found to be 0.301, nearly consistent with the prior mean. This suggests that about 70% of production process entails labour inputs with the residual 30% contributed by capital inputs. This observation is perhaps very intuitive as the production/economic activities or set-ups in Ghana (like other developing economies) are generally labour intensive.

Turning to the monetary policy reaction function parameters, the posterior mean parameter for interest elasticity to inflation, α_π, is estimated to be relatively high (1.704) with 95% credible range of (1.00 – 1.88). This illustrates that the value for α_π satisfies the so-called Taylor Principles as it is greater than one and close to values suggested by Taylor (1993), contradicting the findings in Chapter four. However consistent with our GMM estimates (in Chapter 4), there is a considerable degree of interest rate smoothing, as the mean of the coefficient of the lagged interest rate, α_r, is estimated to be 0.83 with 95% credible range of (0.77-0.88). Finally, the response to output gap, α_y, is estimated to be 0.605, higher than the prior distribution and exceeding the empirical range for less developed countries between 0.1 and 0.5.

6.3.2 Determining the Appropriate Monetary Policy Rules

The empirical literature is remains inconclusiveness on the appropriate specification of monetary policy rule for developing and emerging economies. For instance, Carlstrom et al., (2006) argued that contemporaneous IT – authority reacts to current inflation – the policy rule guarantees determinacy in the closed economy. This assertion was confirmed by Airaudo et al (2016) that it upholds for the open economy. They further argue that exchange rate policy and the choice of price index do not matter if the central bank targets current inflation: even in a flexible exchange rate system, Core- and CPI-IT are compatible with a unique equilibrium under active policy where $\alpha_\pi > 1$. Contemporaneous interest rate rules presume that policy makers have access to precise information on the current values of inflation and other variables. In contrast, Bullard and Mitra (2002) argued that the requisite information for contemporaneous policy rule is unavailable in many developed economies let alone less developed economies. McCallum (1999) also asserts strongly that contemporaneous policy rules are "non-operational". In line with this argument, Smet and Wouters (2003) applied an augmented Taylor rule where policy reacts to deviation of previous (rather than current) inflation from target and in addition to other variables.

In view of this controversy, our baseline model adopts a forward-looking of the kind proposed by Taylor (1993) in which the monetary authority uses the nominal interest rate to secure the objectives

of minimizing volatility in output and expected inflation. For robustness, however, we ascertain the suitability of such policy specification for Ghana by first comparing the baseline policy rule against both (1) the contemporaneous rule following Carlstrom et al., (2006) and Airaudo et al (2016) and (2) "backward-looking" rule as in Smets and Wouters (2003). Explicitly, the contemporaneous and "backward-looking" policy rules in this chapter are specified respectively as:

$$\hat{r}_t = \alpha_R \hat{r}_{t-1} + (1-\alpha_R)\left[\alpha_\pi \hat{\pi}_t + \alpha_y \hat{y}_t\right] + \mu_t^{fl} \tag{6.117}$$

and

$$\hat{r}_t = \alpha_R \hat{r}_{t-1} + (1-\alpha_R)\left[\alpha_\pi \hat{\pi}_{t-1} + \alpha_y \hat{y}_t\right] + \mu_t^{fl} \tag{6.118}$$

It is also generally acknowledged that monetary authorities in a small open economy (such as Ghana) are regularly beset with other macroeconomic instabilities such as exchange rate volatility and foreign interest rate volatility. For that reason, studies (including Svensson, 2003; Gali, Jordi & Monacelli, 2005) have urged authorities to also consider other variables that can reflect the uncertainty in the expected inflation and deviation of the actual output from the potential level. One of the important variables in the context of open economies literature is exchange rate. When the pass-through of the exchange rate into prices is high, the latter variable is likely to assume special importance for monetary policy. Consistently, Mohanty and Klau, (2005) found exchange rate smoothing as an important consideration in the policy reaction function of most developing and emerging economies (see also Davis and Presno, 2017). As a result, the first consider an alternative policy rule (henceforth, Alt.Mod1) with a Taylor rule that incorporate nominal depreciation as an additional policy variable in line with a "dirty float system" (Benes et al, 2008, 2013) as follows:

$$\hat{r}_t = \alpha_R \hat{r}_{t-1} + (1-\alpha_R)\left[\alpha_\pi \hat{\pi}_{t+1} + \alpha_y \hat{y}_t + \alpha_{\phi\epsilon} \Delta \hat{e}_t\right] + \mu_t^{fl} \tag{6.119}$$

This monetary policy rule suggests that, in addition of inflation and output gap, the monetary authority directly reacts to nominal exchange rate developments in line with managed floating exchange rate system especially for developing and emerging economies that exhibit fear of floating. Examples of empirical studies that have adopted this type of Taylor rule are Anand et al (2011) for Sri Lanka, Dizioli and Schmittmann (2015) for Vietnam, and Andrle et al., (2013) for Kenya. Nevertheless, the extent of policy response to exchange rate fluctuations is primarily contingent on the availability of other instruments that can be utilized by the central bank to stabilize exchange rate expectations. Mohanty and Klau (2005) assert that these instruments do not only involve the traditional types (for example, foreign exchange intervention) but also encompass the less standard ones (for instance, debt swaps, temporary capital controls and exchange rate-linked instruments).

It would also be expedient to explore the influence of key international interest rates on domestic monetary policy in the face of growing pace of dollarization and financial integration in Ghana. Following the arguments by Mohanty and Klau (2005) and Davis and Presno (2017), we further explore another alternative policy specification (henceforth, Alt.mod2) as:

$$\hat{r}_t = \alpha_R \hat{r}_{t-1} + (1-\alpha_R)\left[\alpha_\pi \hat{\pi}_{t+1} + \alpha_y \hat{y}_t + \alpha_{\phi\epsilon}\Delta\hat{e}_{t+1} + \alpha_{r^*}\hat{r}_t^*\right] + \mu_t^{fl} \qquad (6.120)$$

where α_{r^*} represents sensitivity domestic policy interest rate to changes in foreign interest rate. Alt.mod2 relaxes such assumption to permit a range of possible interest rate sensitivity to changes in these variables between zero and one. Besides, equation (6.120) helps to account for the effect of dollarization on interesting rate setting in Ghana.

Furthermore, it is asserted that exchange rate policy and the choice of price index do not matter if the central bank targets current inflation (see Airaudo et al., 2016). We further validate this assertion by specifying an augmented contemporaneous rule that incorporates nominal exchange rate depreciation as follows (Alt.mod4):

$$\hat{r}_t = \alpha_R \hat{r}_{t-1} + (1-\alpha_R)\left[\alpha_\pi \hat{\pi}_t + \alpha_y \hat{y}_t + \alpha_{\phi\epsilon}\Delta\hat{e}_{t+1}\right] + \mu_t^{fl} \qquad (6.121)$$

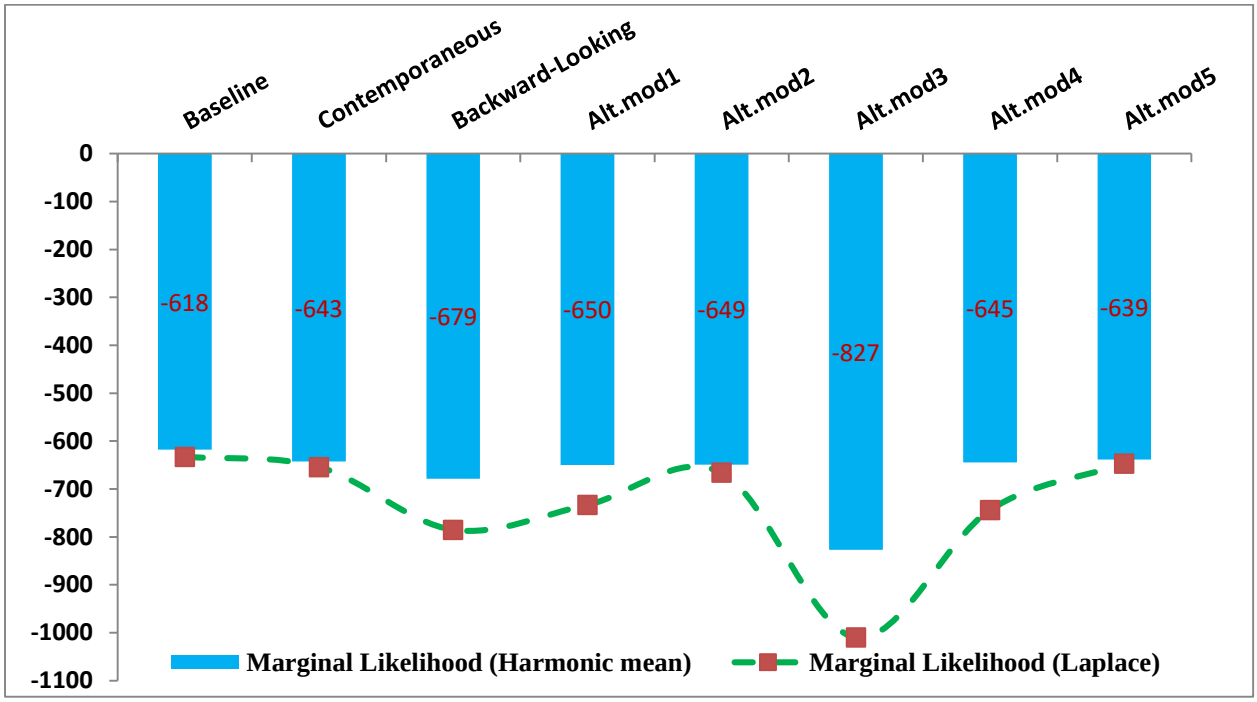
In this framework, the assertion by Airaudo et al., (2016) holds if the marginal likelihood is lower than that computed for the equation (5.117) above. On the other hand, the assertion does not hold in the case of Ghana if the computed marginal probability for equation (6.121) exceeds that for equation (6.117).

In this case, the only different between the baseline and the other alternative models is the divergent specification of the policy rule in each model as all the remaining equations, datasets and the prior distribution are the same across models. This makes the various models with different policy rules highly comparable, such that noticeable differences in the posterior distribution can therefore be attributable to the monetary policy rule under consideration.

One advantage of the Bayesian estimation approach is that it provides a framework for comparing and choosing between fundamentally mis-specified models. Such comparison can be carried out on the basis of the marginal likelihood of the model (see, Smet and Wouters, 2002; Landon-Lane, 1998; Geweke, 1999, 2006). Given the same dataset, we therefore determine the overall fit of the various models using the respective marginal densities following Smet and Wouters (2002). In this regard, we evaluate these models using both the Schorfheide (2002) Laplace transformation and Geweke's (1999, 2006) modified harmonic mean (MHm) estimators of maximum likelihood, even though the MHm is our preferred estimator.

Figure 6.1 reports the marginal likelihood estimates for the comparative models based on the two estimators. It is apparent that both the Laplace and modified harmonic mean estimators unanimously yield higher marginal likelihoods for the baseline model than the alternative models. This observation implies that the baseline DSGE model has a stronger out-of-sample prediction performance than the other competing models.

Figure 6.1: Prediction Performance of Baseline vs. Alternative Policy Rules



Note: the chart above is based on the model with the following monetary policy rules

Baseline rule: $\hat{r} = f(\hat{r}_{t-1}, \hat{\pi}_{t+1}, \hat{y}_t)$

Contemporaneous rule: $\hat{r} = f(\hat{r}_{t-1}, \hat{\pi}_t, \hat{y}_t)$

Backward-looking rule: $\hat{r} = f(\hat{r}_{t-1}, \hat{\pi}_{t-1}, \hat{y}_t)$

Alt.mod1: $\hat{r} = f(\hat{r}_{t-1}, \hat{\pi}_{t+1}, \hat{y}_t, \Delta\hat{e}_{t+1})$

Alt.mod2: $\hat{r} = f(\hat{r}_{t-1}, \hat{\pi}_t, \hat{y}_t, \Delta\hat{e}_{t+1})$

Alt.mod3: $\hat{r} = f(\hat{r}_{t-1}, \hat{\pi}_t, \hat{y}_t, \Delta\hat{e}_{t+1}, r_t^*)$

Alt.mod4: $\hat{r} = f(\hat{r}_{t-1}, \hat{\pi}_{t+2}, \hat{y}_t)$

Alt.mod5: $\hat{r} = f(\hat{r}_{t-1}, \hat{\pi}_{t+3}, \hat{y}_t)$

where $\hat{r}$ denotes domestic policy short-term nominal interest rate; $\hat{\pi}_t$ is inflation deviation from steady state; $\hat{y}_t$ is output gap; $\hat{e}$ is nominal exchange rate (GHS per unit of Euro); r_t^* is foreign short-term nominal interest rate; Δ denote change;

The estimated baseline DSGE model has the most appropriate monetary policy rule for Ghana, given the observable dataset and prior distribution. By implication, it is highly adequate to conclude that the most appropriate policy rule for observable Ghanaian dataset is the forward-looking Taylor rule in which the monetary authority responds to deviation of one-period-ahead inflation deviation from target along with current output gap. Consistently, the inclusion of exchange rate and foreign interest rate in the policy rule considerably worsened the marginal probability of the model when compare to corresponding estimates for the baseline and contemporaneous models. Particularly, our empirical

analysis strongly accentuates that the standard forward-looking Taylor rule also hold for small-open developing economies irrespective of the exchange rate system. Our finding also reinforces the assertion by Carlstrom et al (2006) and Airaudo et al., (2016) as inclusion of exchange rate in both contemporaneous and forward-looking rules deteriorated the marginal likelihood. In addition, our result also contradicts the findings of Davis and Presno (2017) which explain the potentially important element of the foreign interest rate in the monetary policy reaction of emerging market economies. By implication, adhoc inclusion of exchange rate or foreign interest rate in monetary policy rules for Ghana (or developing economies) is likely to yield less plausible estimates for accurate policy inference.

6.3.3 Sensitivity Analysis

The sensitivity analysis is in twofold. First, we ascertain the robustness of prior distribution in the baseline model and also evaluate the relative importance of the nominal and real frictions imposed in the baseline DSGE model.

6.3.3.1 Robustness of prior distribution in the baseline model

We assess the sensitivity of baseline model to the prior distributions by changing the latter in several ways and the model re-estimated for each of the cases. Similarly, the posterior distribution of the corresponding DSGE model based on the new prior distribution was obtained via five parallel block chains with 300,000 replications of the Metropolis-Hastings Algorithm. In this section, we first examine the variations in the posterior means relative to the baseline model. Secondly, we appraise the out-of-sample prediction performance of each of the scenarios to the baseline DSGE model using the respective marginal likelihoods. For illustrative purposes, Table 6.3 reports the results of the posterior means (PMs) from the five alternative scenarios (cases) based on baseline model.

For Case I, all prior means are increased by 20% while the standard errors are decreased by 10%. The Table reveals that estimated posterior means for the majority of the parameters changed. However, these changes are generally insubstantial in absolute terms except for five parameters namely household's inverse elasticity of intertemporal substitution, marginal disutility of labour supply, persistent parameter for productivity shock, and interest rate sensitivity to inflation gap which varied by more than 0.5. In the Case II, both the prior means and standard errors are increased by 10% as in Almeida (2009). Comparing the obtained results with those of the baseline model, we can see from the table that the estimated posterior means for the majority of the parameters also increased marginally. The variations are broadly below what is observed in Case I, except for the parameter of household's

inverse elasticity of intertemporal substitution which changed by more than unity. In the Case III, we maintain the prior means but increased the standard errors substantially by 50% as in Almeida (2009). The overall conclusions remained broadly the same as the autoregressive and the behavioural parameters recorded insubstantial changes except for household's inverse elasticity of intertemporal substitution with posterior modes deviating by about 0.45.

For Case IV, we assume a uniform distribution for the Calvo price and wage parameters and this assumption amounts to considering an uninformative prior. In line with Cases I-III, the autoregressive and behavioural parameters recorded marginal changes for Case IV. A notable exception however is the parameter of household's inverse elasticity of intertemporal substitution with a posterior mean below that of the baseline by more than unity, as in Case II. For Case V, we assume beta distribution for the elasticity of substitution between intermediate goods and between labour inputs. This amounts to considering an informative prior rather than the uniform distribution assumption made for the two parameters in the baseline model. This scenario also yielded similar insubstantial changes when compared to the baseline model except for the parameters of household's inverse elasticity of intertemporal substitution and marginal disutility of labour supply which recorded much higher positive and negative variations respectively than in the other cases.

Notably, the bottom part of Table 6.3 presents the corresponding marginal likelihood for each alternative case as an indicator of out-of-sample prediction performance of the model. It is conspicuous from the table that in each of the alternative cases the marginal likelihood deteriorates relative to the baseline model. This observation is robust from both the Laplace and modified harmonic mean estimators of marginal likelihood. Consequently, the results from this sensitivity analysis illustrate that the estimated parameters in the baseline model appear to be relatively robust to changes in the prior distribution.

Table 6.3: Sensitivity Analysis – Robustness of prior distribution in the baseline model

	Baseline Model	**Case I**		**Case II**		**Case III**		**Case IV**		**Case V**	
	PM	PM	**Diff.**	**PM**	**Diff.**	**PM**	**Diff.**	**PM**	**Diff.**	**PM**	**Diff.**
Exogenous Shocks Processes											
v_u	0.400	0.445	0.05	0.231	-0.17	0.393	-0.01	0.597	0.20	0.810	0.41
v_g	3.941	3.944	0.00	3.931	-0.01	3.940	0.00	3.945	0.00	3.947	0.01
$v_{\pi h}$	1.015	0.803	-0.21	0.961	-0.05	0.082	-0.93	0.242	-0.77	0.193	-0.82
v_r	0.320	0.260	-0.06	0.352	0.03	0.456	0.14	0.297	-0.02	0.604	0.28
v_{uip}	3.551	2.781	-0.77	3.092	-0.46	3.089	-0.46	2.943	-0.61	1.664	-1.89
$v_{\zeta w}$	0.188	0.265	0.08	0.650	0.46	0.932	0.74	0.291	0.10	1.627	1.44
$v_{\zeta c}$	0.290	0.198	-0.09	0.183	-0.11	0.740	0.45	3.841	3.55	0.637	0.35
$v_{\zeta n}$	2.406	1.031	-1.37	2.082	-0.32	0.421	-1.98	1.357	-1.05	1.155	-1.25

η_{r^*}	0.202	0.198	0.00	0.220	0.02	0.203	0.00	0.203	0.00	0.196	-0.01
η_{y^*}	0.235	0.235	0.00	0.234	0.00	0.234	0.00	0.229	-0.01	0.236	0.00
η_{π^*}	0.442	0.452	0.01	0.443	0.00	0.450	0.01	0.453	0.01	0.449	0.01
Autoregressive parameters of Exogenous Shocks processes											
ρ_u	0.571	0.994	0.42	0.994	0.42	0.995	0.42	0.976	0.41	0.957	0.39
ρ_g	0.985	0.988	0.00	0.982	0.00	0.970	-0.01	0.975	-0.01	0.987	0.00
$\rho_{\pi h}$	0.603	0.681	0.08	0.482	-0.12	0.370	-0.23	0.513	-0.09	0.858	0.26
$\rho_{\zeta c}$	0.936	0.746	-0.19	0.719	-0.22	0.980	0.04	0.630	-0.31	0.763	-0.17
$\rho_{\zeta n}$	0.945	0.946	0.00	0.975	0.03	0.797	-0.15	0.929	-0.02	0.931	-0.01
Structural Parameters											
σ_c	0.739	1.542	0.80	0.748	0.01	1.188	0.45	1.647	0.91	1.694	0.95
σ_l	3.835	3.239	-0.60	2.248	-1.59	3.819	-0.02	2.682	-1.15	2.136	-1.70
η	0.846	0.663	-0.18	1.023	0.18	0.530	-0.32	0.561	-0.29	0.534	-0.31
h	0.326	0.309	-0.02	0.317	-0.01	0.304	-0.02	0.304	-0.02	0.316	-0.01
λ_y	0.301	0.353	0.05	0.311	0.01	0.297	0.00	0.300	0.00	0.301	0.00
θ_w	0.702	0.677	-0.02	0.689	-0.01	0.574	-0.13	0.583	-0.12	0.627	-0.07
θ_h	0.730	0.570	-0.16	0.832	0.10	0.835	0.10	0.892	0.16	0.887	0.16
α_π	1.704	1.167	-0.54	1.483	-0.22	1.865	0.16	1.888	0.18	1.257	-0.45
α_y	0.605	0.934	0.33	0.902	0.30	0.817	0.21	0.940	0.34	0.641	0.04
α_r	0.831	0.698	-0.13	0.752	-0.08	0.595	-0.24	0.582	-0.25	0.734	-0.10
Ω	0.687	0.865	0.18	0.678	-0.01	0.686	0.00	0.717	0.03	0.727	0.04
γ_w	0.545	0.698	0.15	0.934	0.39	0.692	0.15	0.791	0.25	0.779	0.23
γ_h	0.593	0.544	-0.05	0.733	0.14	0.847	0.25	0.531	-0.06	0.657	0.06
β	0.979	0.978	0.00	0.894	-0.09	0.982	0.00	0.982	0.00	0.984	0.00
ϱ	0.064	0.054	-0.01	0.055	-0.01	0.011	-0.05	0.068	0.00	0.056	-0.01
Marginal Likelihood											
Laplace	***-633***		***-743.3***		***-838.4***		***-700.3***		***-663.6***		***-701.1***
Harmonic Mean	***-618***		***-629.1***		***-691.0***		***-661.1***		***-631.3***		***-657.3***

PM denotes posterior mean, while Diff. denotes absolute difference between the posterior means computed as the PM for alternative Cases minus PM for baseline model.

6.3.3.2 Policy relevance of some key shocks and frictions

The introduction of a large number of frictions and shocks raises the question of which of those inclusions is really necessary to capture the dynamics of the data (see Smets and Wouters, 2007). In this section, we examine the contribution of a number of frictions and shocks to the marginal likelihood of the DSGE model. Table 6.4 presents the estimates of the posterior means alongside marginal likelihoods for relative importance of some frictions and shocks introduced in the baseline model, similarly based on 5 parallel block chains of Metropolis-Hastings algorithm with 300000 repetitions.

We first focus on the shock parameters. We investigate the relevance of exchange rate and consumption preference shocks in the baseline DSGE model by sequentially setting v_{uip}=0 and $v_{\zeta c}$=0. As displayed in Columns 2 and 3 of Table 6.4, the elimination of either of the shocks from the baseline is very costly in term of a deterioration of the marginal likelihood. According to the harmonic mean and Laplace estimators, marginal likelihood falls considerably by about 116 and 220 respectively when exchange shock is removed from the baseline model. The exclusion of nominal exchange rate depreciation causes notable variations in all the parameters. For instance, it leads to a strong increase in the parameters of price mark-up, wage mark-up, domestic policy and consumption preference

shocks, elasticity of substitution between foreign and domestic goods and productivity persistence. In addition, the degree of openness, productivity shock, discount factor, and the elasticity of substitution between supply and between intermediate goods also increase as a result. On the contrary, the remaining parameters decline following the exclusion of nominal exchange rate shock with a considerable drop however recorded for labour supply shock. Similarly, shutting off consumption preference shocks also results in significant variations in a number of parameters. Particularly, this exercise leads to substantial increases in nine parameters (including price mark-up, wage mark-up, domestic policy, labour supply and foreign inflation shocks, elasticity of substitution between foreign and domestic goods, productivity persistence interest rate sensitivity to output gap and intertemporal elasticity of substitution). However, government spending shock drops considerably while the remaining variable recorded somewhat minimal changes as a result of excluding consumption preference shock from the baseline model. The noticeably variations in the parameters following the elimination of each of the shocks from the baseline model surmise that these shocks are essential for macroeconomic dynamics in Ghana.

Now, we turn to real frictions. Considering a much lower degree of trade openness (0.3) than in the baseline model, as displayed in column 4 of Table 6.4, is much more costly as it results in more than 100% (793) deterioration in marginal likelihood. This scenario particularly leads to significant decline in exchange rate shock, all the persistent parameters (except productivity persistence), policy parameter for inflation gap, and marginal disutility of labour supply. However, significant increases were recorded for five shock processes (such as price mark-up, wage mark-up, government spending consumption preference and foreign inflation shocks) in addition to intertemporal elasticity of substitution, elasticity of substitution between foreign and domestic goods. In contrast, very high degree of openness, as displayed in column 5 of Table 6.4, results in much higher values for domestic policy parameters (particularly, for output gap) relative to lower degree of openness, largely driven by higher magnitudes of productivity and exchange rate shocks. On the other hand, higher degree of openness results in considerable decline in domestic price mark-up shock compared to baseline model and the case of lower degree of openness. The divergent magnitude to policy sensitivity to changes in inflation and output gaps depending on the degree of openness implies that the latter significant affect the monetary policy effectiveness in Ghana, consistent with the extent literature. In addition, we observed much lesser deterioration in marginal likelihood in the case of higher degree of openness compared to that of lower degree of openness. By implication, the Ghanaian economy appears to be very open to international financial and commodity market, consistent with the result from the business cycle analysis.

Also, reducing the habit formation in consumption is fairly costly, although much less so than plummeting the degree of openness. As exhibited in column 6 of Table 6.4, this action reflects in considerable increases in the magnitudes of consumption preference shock, domestic policy shocks and monetary policy parameter for output gap. Also, noticeable increases are recorded for productivity shock and its autoregressive parameter, domestic price and wage mark-up shocks, exchange rate shock and the discount factor in the case of a relatively lower habit formation in consumption.

Considering a slightly higher share of capital inputs in production from 0.3 to 0.7 rather yields a minimal deterioration in the marginal likelihood, as demonstrated in Column 7 of Table 6.4. This implies that apportioning 70% of the inputs of production to capital do not significantly cost the overall out-of-sample prediction performance of the model even though some noticeable variations are observed for the other parameters (see Column 9 of Table 6.4).

Turning to the nominal frictions, we examine the importance of the Calvo wage and price parameters. Column 8 presents the effect of considering higher degree of stickiness in both nominal price and wage with each having a Calvo probability of 0.85. The table clearly reveals imposing a much higher degree of stickiness in both price and wages comes with a huge cost in terms of the marginal likelihood as the latter worsens by about 159. This surmises that although both wage and price stickiness are very important, the degree of stickiness beyond what is presumed in the baseline model considerably deteriorates the out-of-sample prediction performance in the context of Ghana. Higher stickiness leads to significant increases in wage mark-up, labour supply shock, monetary policy shock, policy reaction to changes in output gap and intertemporal elasticity of substitution, while both government spending shock and marginal disutility of labour supply, price mark-up shock (and its persistence) drop considerably as a result. We also analyse the separate effects by considering a relatively lower degree of price and wage stickiness with respective Calvo probabilities of 0.25. As shown in Columns 9 and 10 of Table 6.4, the marginal likelihoods deteriorate in both cases. However, the deterioration in marginal likelihood is much more acute for the case of lower price rigidity than that of lower wage rigidity, implying that prices appear to be rather more rigid than wages in Ghana. Primarily, an important justification for the rather higher degree of nominal rigidities in prices than in wages is the underlying specification of the process driving marginal cost. On one hand, the individual marginal disutility of labour implies that individual household's marginal costs of supplying labour are upward-sloping. On the other hand, each firm in the intermediate goods sector is assumed to have a flat marginal cost curve and also operates at constant returns to scale (implying same marginal cost across

firms). Therefore, for a given elasticity of prices to real marginal cost, this will incline to bias upward the estimate of Calvo price stickiness (see, Smets and Wouters, 2002). The worsening of the marginal likelihood due to variations in the Calvo parameters has two main implications: First it reinforces that the Calvo parameters are very important in the baseline model. Second, it highlights that the prior distribution in the baseline is relative adequate to generate better out-of-sample prediction performance.

Overall, the sensitivity analysis illustrates that the estimated parameter appear reasonably robust to sequentially changes in the frictions and shocks. Specifically, the analysis strongly articulates that the Calvo price and wage rigidities, habit formation in consumption are very important in the baseline model. In addition, both nominal exchange rate and preference shocks are equally critical as the overall fit of the baseline model deteriorates when either shock is shut off.

Table 6.4: Sensitivity Analysis - some key shocks and frictions in the baseline model

	Baseline	v_{uip}**=0**	$v_{\zeta c}$**=0**	**Ω = 0.3**	**Ω = 0.9**	λ_y**=0.7**	**h=0.1**	θ_h**=0.85** θ_w**=0.85**	θ_h**=0.25**	θ_w**=0.25**
Exogenous Shocks Processes										
v_u	0.400	0.697	0.576	0.668	1.199	0.246	0.690	0.292	0.656	0.573
v_g	3.941	3.934	3.046	3.038	3.943	3.943	3.221	3.301	2.230	4.000
$v_{\pi h}$	1.015	2.159	2.451	2.228	0.419	0.519	1.434	0.755	0.192	2.323
v_r	0.320	0.910	0.799	0.317	0.427	0.633	0.650	0.696	0.396	0.401
v_{uip}	3.551	na	3.077	1.110	2.426	2.667	3.780	3.414	2.583	2.788
$v_{\zeta w}$	0.188	1.418	0.601	1.277	2.873	1.473	0.307	1.027	1.297	0.119
$v_{\zeta c}$	0.290	1.753	na	1.316	0.161	0.236	3.884	0.101	0.497	4.000
$v_{\zeta n}$	2.406	0.528	5.827	3.941	0.794	3.611	0.608	4.828	2.089	1.558
η_{r^*}	0.202	0.195	0.363	0.197	0.201	0.198	0.194	0.180	0.220	0.193
η_{y^*}	0.235	0.232	0.228	0.196	0.236	0.236	0.245	0.240	0.308	0.240
η_{π^*}	0.442	0.444	0.714	0.834	0.443	0.442	0.532	0.456	0.500	0.426
Autoregressive parameters of Exogenous Shocks processes										
ρ_u	0.571	0.997	0.998	1.000	0.996	0.981	0.989	0.989	1.000	0.995
ρ_g	0.985	0.971	0.835	0.840	0.986	0.986	0.850	0.916	0.889	0.987
$\rho_{\pi h}$	0.603	0.584	0.512	0.635	0.556	0.762	0.650	0.349	0.758	0.795
$\rho_{\zeta c}$	0.936	0.988	na	0.422	0.742	0.680	0.635	0.981	0.693	0.600
$\rho_{\zeta n}$	0.945	0.673	0.484	0.679	0.519	0.893	0.927	0.973	0.667	0.435
Structural Parameters										
σ_c	0.739	0.597	1.172	1.883	1.224	2.251	1.089	2.848	1.675	1.727
σ_l	3.835	3.818	3.947	2.262	1.508	1.064	1.670	1.198	1.698	0.500
η	0.846	1.239	1.646	2.583	0.572	0.590	1.484	0.981	1.625	1.074
h	0.326	0.314	0.454	0.658	0.313	0.937	0.096	0.335	0.685	0.346
λ_y	0.301	0.300	0.301	0.299	0.300	0.700	0.301	0.300	0.301	0.304
θ_w	0.702	0.549	0.763	0.790	0.486	0.806	0.736	0.870	0.752	0.418
θ_h	0.730	0.516	0.485	0.447	0.865	0.709	0.636	0.861	0.250	0.398
α_π	1.704	1.668	1.431	1.004	1.386	1.575	1.320	1.773	1.333	2.000
α_y	0.605	0.396	0.914	0.481	0.892	0.844	0.981	0.968	0.388	0.160
α_r	0.831	0.802	0.796	0.732	0.766	0.804	0.777	0.488	0.688	0.610

Ω	0.687	0.726	0.683	0.300	0.901	0.731	0.717	0.594	0.527	0.658
γ_w	0.545	0.852	0.572	0.678	0.677	0.585	0.751	0.348	0.990	0.665
γ_h	0.593	0.793	0.774	0.858	0.564	0.349	0.719	0.149	0.923	0.100
β	0.979	0.988	0.988	0.982	0.980	0.977	0.989	0.955	0.977	0.977
ϱ	0.064	0.036	0.046	0.038	0.056	0.027	0.038	0.056	0.047	0.031
Marginal Likelihood										
Laplace	***-633***	***-852.6***	***-1022.9***	***-1673.1***	***-679.9***	***-641.6***	***-926.4***	***-954.1***	***-5559.2***	***-714.1***
MHm	***-618***	***-734.3***	***-931.4***	***-1411***	***-662.5***	***-630.4***	***-803.2***	***-776.8***	***-5274.1***	***-671.5***

Note: the parameter values are the estimated posterior means based on 300000 MCMC iterations with 5 parallel block chains. The term "NA" means the shock is shut off. MHm denotes modified harmonic mean.

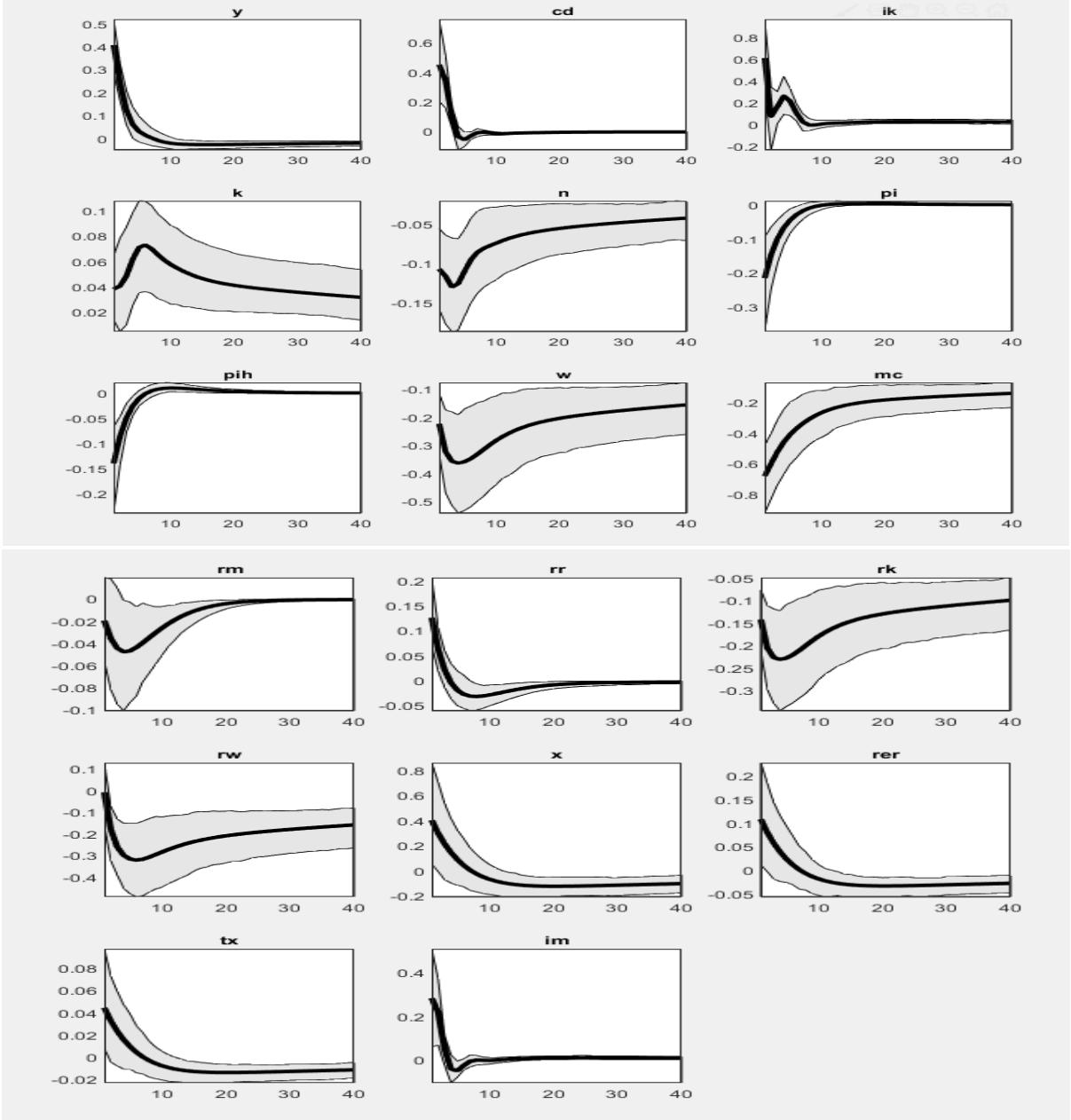
6.3.4 Macroeconomic impact of Domestic shock

We provide the baseline impulse response functions for each of structural shocks in order to comprehend the behavior of the economy in the case of unexpected temporary innovation to a particular endogenous macroeconomic variable. In addition, the examination of the impulse response function enables us to determine whether the model with purely optimizing consumers is suitable for policy investigation in Ghana. We first illustrate impulse responses of the main variables for 40 successive quarters after the shock that emanated predominantly from domestic sources.

6.3.4.1 Productivity Shock

Figure 6.2 shows impulse responses from a temporary positive total factor productivity shock. The posterior estimate for the size of the productivity shock is 0.40 and is set to be moderately persistent with ρ_u=0.571. Output increases in response to improvement in production technology. Consistent with standard new-Keynesian models (See, Gali, 1999; Smets and Wouters, 2002), labour supply declines on the back of the interaction between sticky price and technological change. Even though technological change causes marginal costs to plummet (across all firms), prices are not fully adjusted by firms due to the assumption of price rigidities (as not all firms receive the price reset signals). For that reason, although aggregate price falls, consumption (or aggregate demand) increases less than proportionately to the increase in productivity and thus, firm reacts by cutting employment. Consistently, monetary authority raises interest rate (albeit moderately) in response to the increase in aggregate demand. The contractionary policy stance induces real exchange rate appreciation and a concomitant deterioration in terms-of-trade, and hence drive output towards its steady state level.

Figure 6.2: Impulse Responses to Positive Productivity Shock



Note: y is output; cd is overall consumption; ik is investment, k is capital input; n is labour supply (or employment); pi is overall inflation; pih is domestic inflation; w is nominal wage; mc is marginal cost; rm is nominal interest rate; rr is real interest rate; rk is rental rate of capital; x is terms of trade; rer is real exchange rate (where + means depreciation; - means appreciation); tx is export; im is imports (i.e. consumption of imported goods);

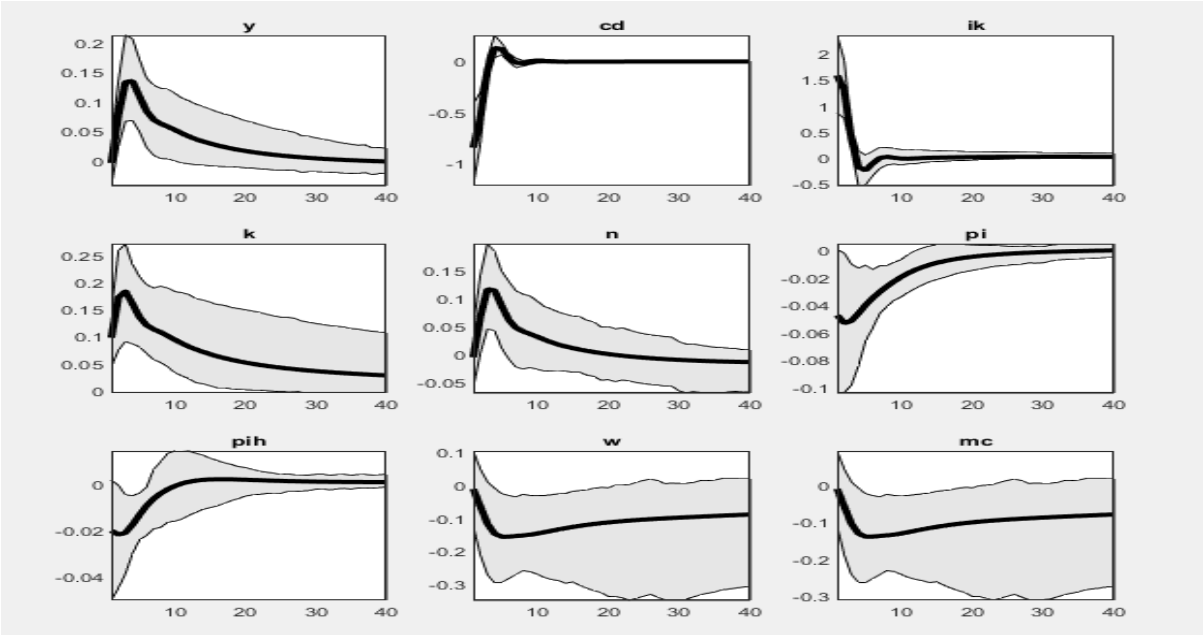
6.3.4.2 Labour Supply Shock

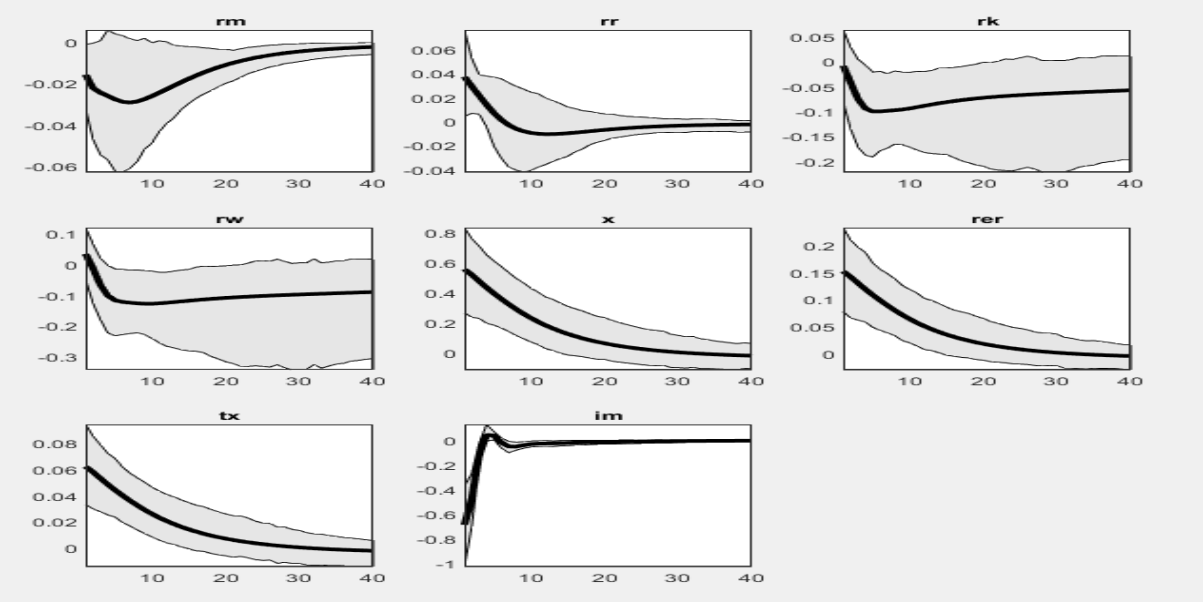
Figure 6.3 displays the impulse responses of a positive labour supply preference shock. The posterior estimate for the size of the labour supply shock is 2.406 and is set to be highly persistent with

$\rho_{\zeta n}$=0.945. The qualitative effect of this supply shock is broadly identical to that of positive productivity shock. Marginal cost, nominal wage and inflation fall immediately on impact of positive labour supply shock. In contrast, capital stock and investment increase on impact amid a decline in rental rate of capital following a positive labour supply shock. The easing monetary policy stance despite the decline in marginal cost supports a disinflationary process. The main difference however is that consumption, output and employment (or labour supply) fall on impact due to relatively larger drop in nominal wage. However, the larger decline in domestic inflation relative to nominal wage and interest rate led to causes real wage and real interest rate to rise respectively.

The contemporaneous increase in real wage in turn increases the marginal utility of working, leading to subsequent increase in labour supply. The immediate rise in real interest rate motivates households to consume less and save more in order to achieve higher future consumption and higher overall utility through the intertemporal substitution. Thus, consumption falls while investment rises on the back of rising real interest rate in line with the Euler consumption equation. The relatively larger increase in real interest rate leads to immediate real exchange rate appreciation accompanied by a worsening terms-of-trade (i.e. import increases and export falls), leading to output decline on impact. The subsequent decline in real interest rate however stimulates both household consumption and output.

Figure 6.3: Impulse Responses to Positive Labour Supply Shock



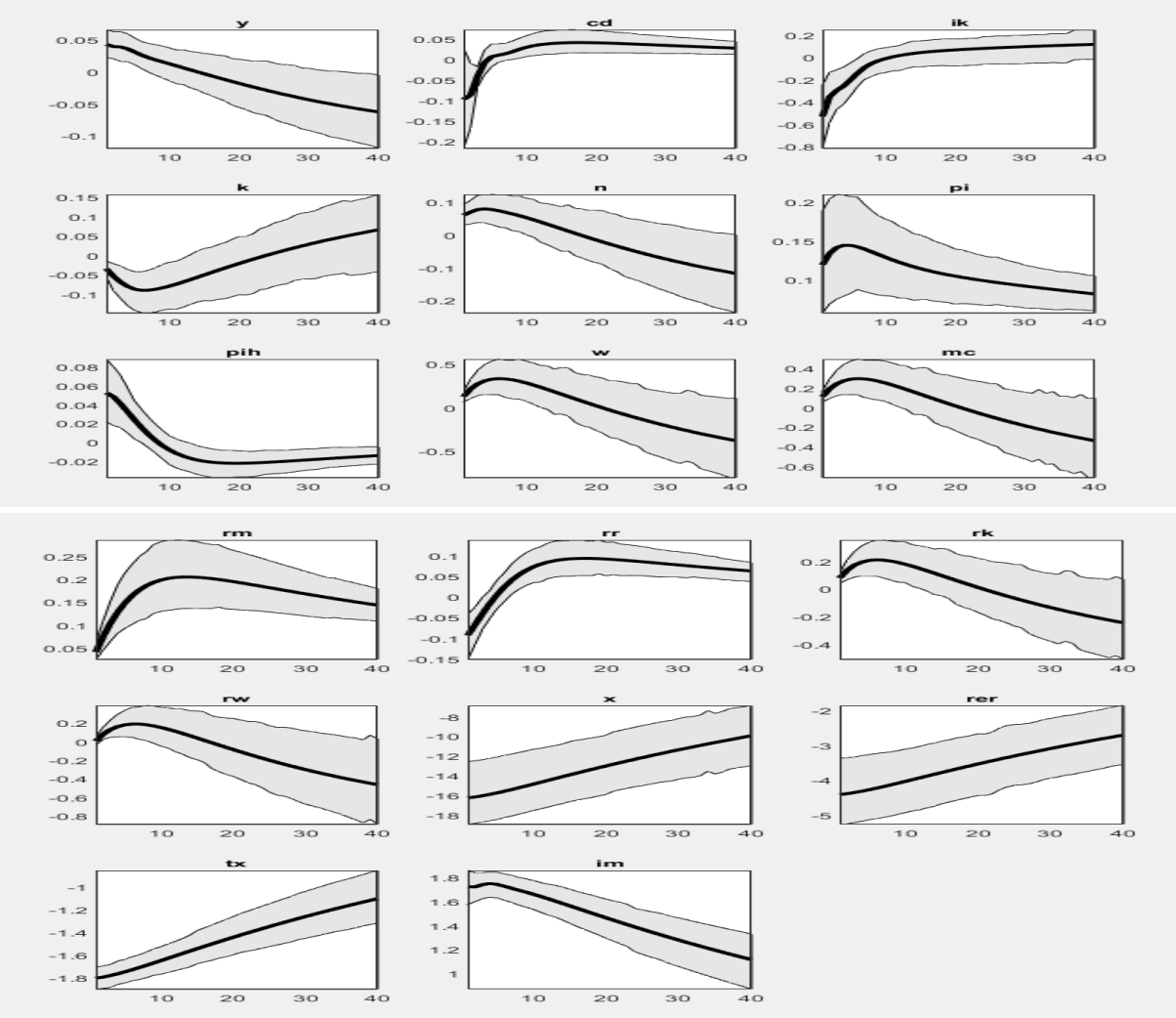


Note: y is output; cd is overall consumption; ik is investment, k is capital input; n is labour supply (or employment); pi is overall inflation; pih is domestic inflation; w is nominal wage; mc is marginal cost; rm is nominal interest rate; rr is real interest rate; rk is rental rate of capital; x is terms of trade; rer is real exchange rate (where + means depreciation; - means appreciation); tx is export; im is imports (i.e. consumption of imported goods);

6.3.4.3 Government Spending Shock

Figure 6.4 display impulse response of a positive government consumption shock. The posterior estimate for the size of the shock is 3.941 and is set to be highly persistent with $\rho_g = 0.985$. Aggregate output increases in response to an increased government spending shock. Firms respond by increasing demand for both capital and labour (employment) inputs in order to meet the rising demand for output, resulting in higher nominal wage and cost of capital (rent). Marginal cost increases as costs of inputs (wage and rental rate of capital) rise. Inflation increases as firms pass on the higher marginal cost into prices. In response to rising inflation, monetary authority responds by raising nominal interest rate. The rise in interest rate boosts private investment, dampens aggregate household consumption and strengthens the local currency. Consistent with economic theory, the gain in the domestic currency induces negative net exports, reinforcing a subsequent drop in output towards its steady level. In the context of Ghana, we observe a net crowding-out effect of expansionary fiscal policy on household consumption. In line with permanent income hypothesis, households seem to save or invest the transitory income emanating from government spending amid concerns of fiscal solvency.

Figure 6.4: Impulse Responses to Positive Government Expending Shock



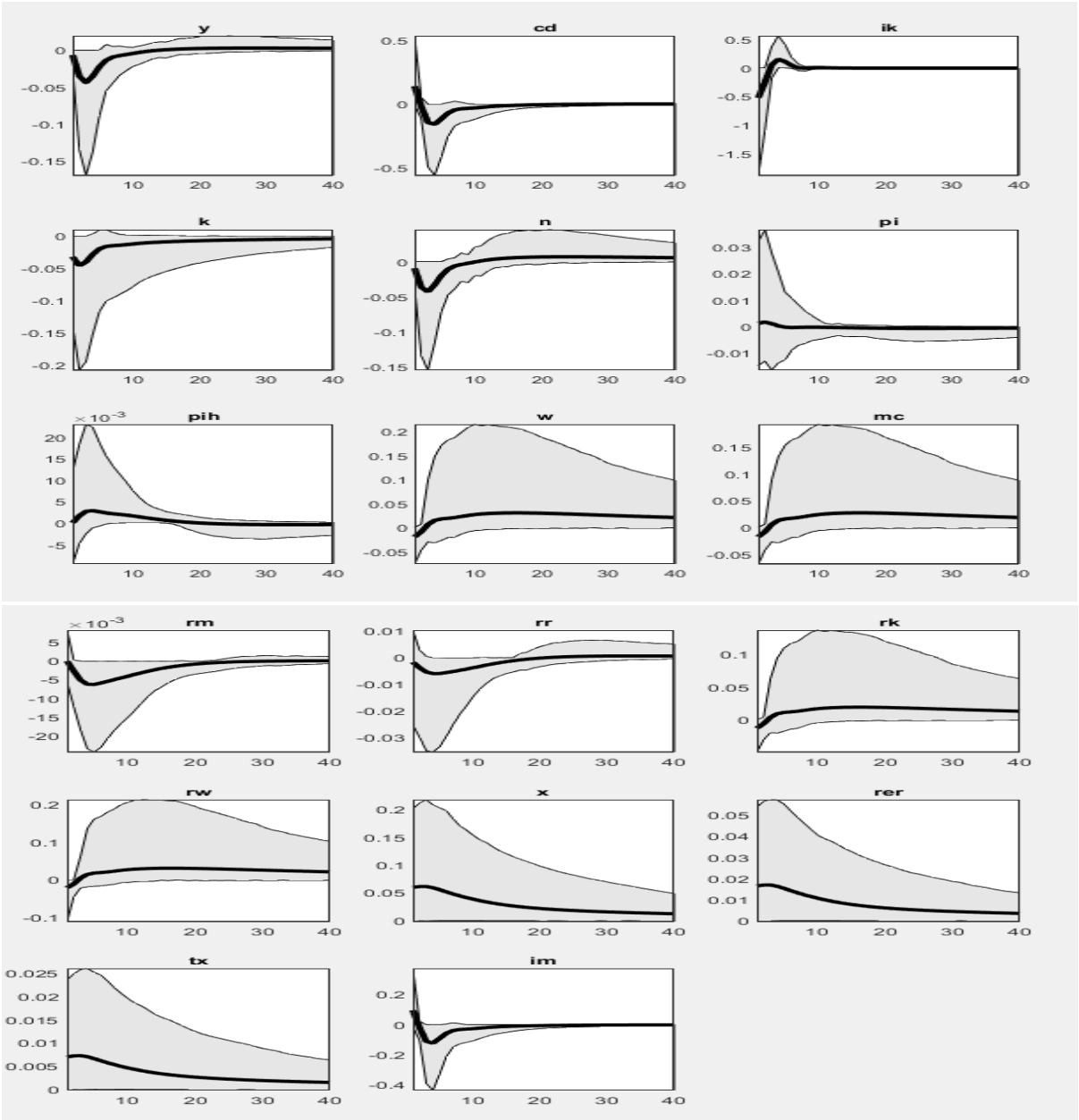
Note: y is output; cd is overall consumption; ik is investment, k is capital input; n is labour supply (or employment); pi is overall inflation; pih is domestic inflation; w is nominal wage; mc is marginal cost; rm is nominal interest rate; rr is real interest rate; rk is rental rate of capital; x is terms of trade; rer is real exchange rate (where + means depreciation; - means appreciation); tx is export; im is imports (i.e. consumption of imported goods);

6.3.4.4 Preference Shock

Figure 6.5 shows impulse responses to a positive preference shock. It is a typical demand shock. The posterior estimate for the size of the shock is 0.29 and is estimated to be very persistent with $\rho_{\zeta c} = 0.936$. A positive preference shock immediately induces an increase in household consumption, crowds-out investment and capital accumulation. Labour supply (or employment) also drops on impact as an increase consumption demand reduces households unwilling to work (marginal disutility of working). The slowdown in employment (labour supply) induces a decline in both nominal wage and marginal cost on impact. However, inflation immediately increases on the back of rising households' consumption subsequently props up both wage (nominal and real) and marginal cost. Monetary policy responds to rising inflation and marginal cost by raising nominal interest rate. Although the effect of

preference shock on output is somewhat muted on impact, both consumption and output subsequently decline following an upward adjustment in policy interest rate. Since the policy adjustment of nominal interest rate is less than proportionate to the increase in inflation, real interest rate decline. Negative real interest rate triggers real exchange rate depreciation on impact, leading a simultaneous improvement in terms of trade to stimulate output recovery towards its steady state level.

Figure 6.5: Impulse Responses to Positive Preference Shock

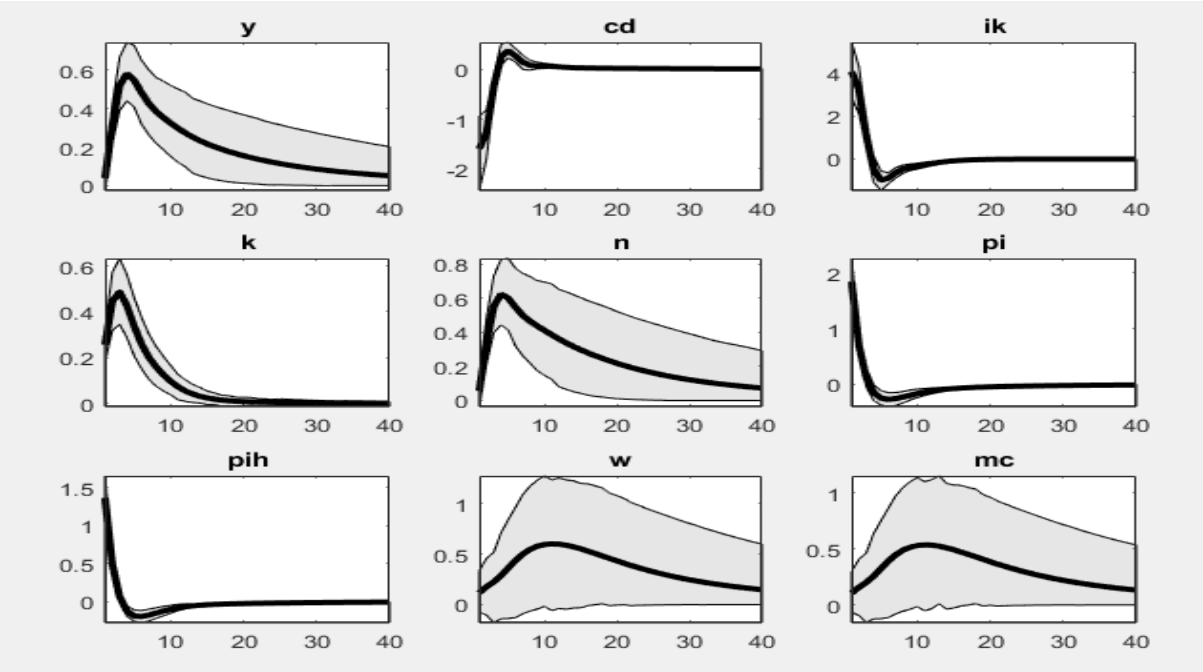


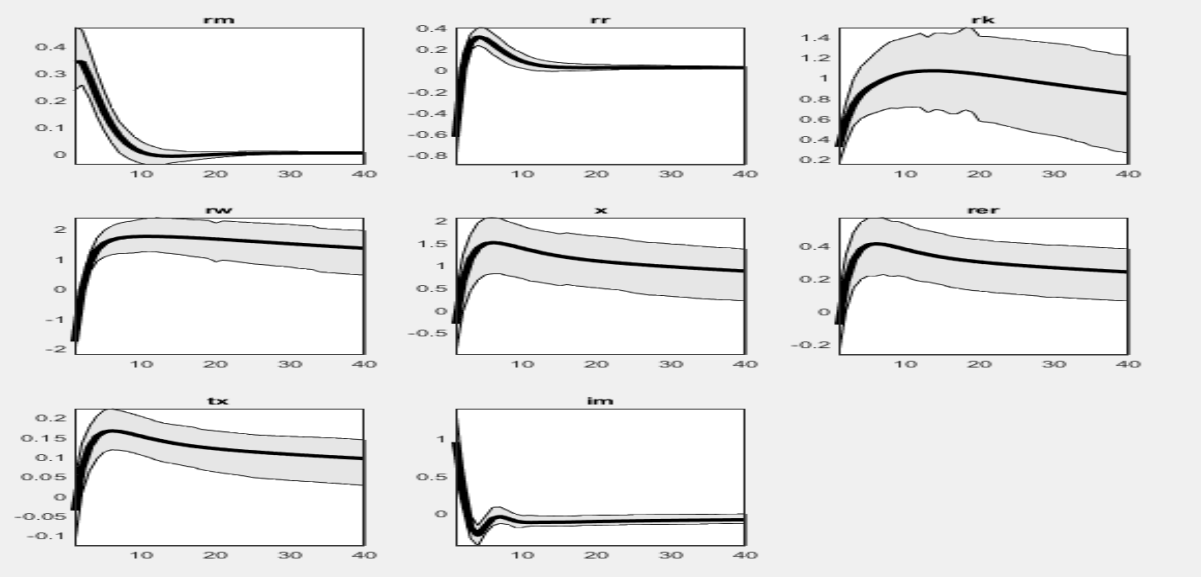
Note: y is output; cd is overall consumption; ik is investment, k is capital input; n is labour supply (or employment); pi is overall inflation; pih is domestic inflation; w is nominal wage; mc is marginal cost; rm is nominal interest rate; rr is real interest rate; rk is rental rate of capital; x is terms of trade; rer is real exchange rate (where + means depreciation; - means appreciation); tx is export; im is imports (i.e. consumption of imported goods);

6.3.4.5 Domestic Price Mark-Up Shock

Figure 6.6 shows impulse responses to a rise in the domestic price mark-up shock. The posterior estimate for the size of the shock is 1.015 and is set to be very persistent with $\rho_p = 0.98$. A positive domestic price mark-up shock immediately raises both domestic inflation and overall inflation, leading to lower household's consumption. The surge in overall inflation instigates a rise in nominal wage and hence raises marginal cost. The rise in nominal wage increase household's willingness to work, resulting in a contemporaneous rise in employment/labour supply. The monetary authority responds to price surges (inflation, nominal wage and marginal cost) by increasing nominal interest rate. r, because the authority pursues interest rate smoothing rule, real interest rate moderately decline on impact as the increase in nominal interest rate is outweighed by the extent of increase in price levels. The subsequent rapid drop in inflation relative to nominal interest rate leads to an increase real interest rate. The positive rate interest rate makes domestic investment attractive, underpinning the rise in investment alongside real exchange rate appreciation. The terms-of-trade worsens as a result of real appreciation (decreased export relative to imports). However, the pickup in investment supported by the subsequent gradual correction in households' consumption (towards to the steady state level) outstrips the deterioration in net exports, resulting in hump shape increase in output.

Figure 6.6: Responses to Adverse Domestic Price Mark-Up Shock



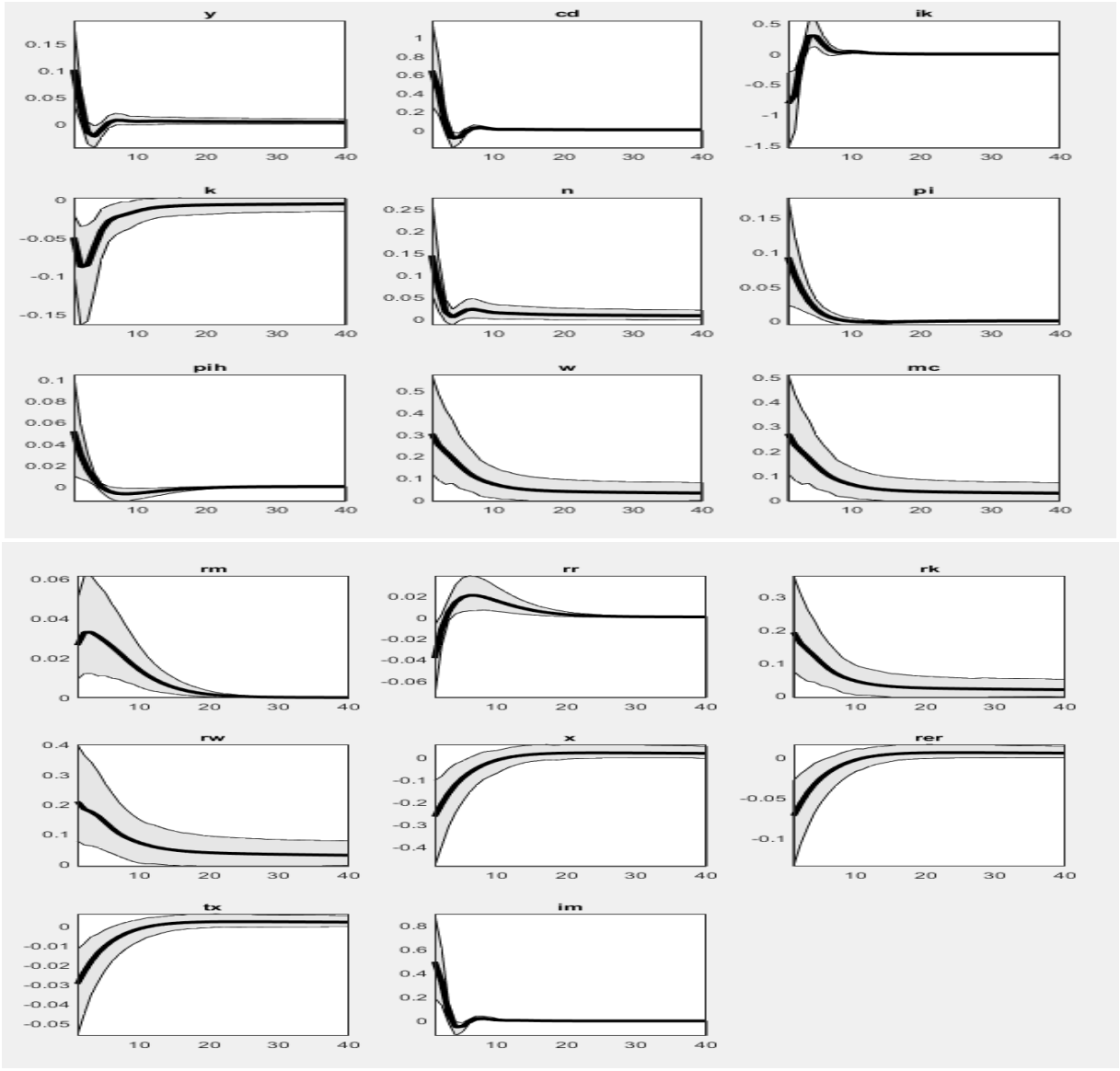


Note: y is output; cd is overall consumption; ik is investment, k is capital input; n is labour supply (or employment); pi is overall inflation; pih is domestic inflation; w is nominal wage; mc is marginal cost; rm is nominal interest rate; rr is real interest rate; rk is rental rate of capital; x is terms of trade; rer is real exchange rate (where + means depreciation; - means appreciation); tx is export; im is imports (i.e. consumption of imported goods);

6.3.4.6 Wage Mark-Up Shock

Figure 6.7 also depicts impulse responses from a positive wage mark-up shock. The posterior estimate for the size of the shock is 0.188 and is assumed to have no autoregressive structure, following Smets and Wouters (2002, 2007). The impulse response functions from wage mark-up shock are qualitatively akin to that of the domestic price mark-up shock. In the first, nominal and real wage increase on impact, leading to instantaneous rise in both consumption and labour supply. Marginal cost increases as nominal wage rises. This, together with an increased household consumption, causes inflation to rise. Monetary policy immediately response strongly to the inflationary pressures induced by positive wage mark-up shock by increasing nominal interest rate. Real interest rate increases in effect which in turn causes real exchange rate appreciation. Net export worsens due to real exchange rate appreciation, consistent with economic theory as import becomes cheaper relative to export. Output however increases on impact of positive wage mark-up shock as the pickup in private consumption outweighs the combined drops in investment and net exports.

Figure 6.7: Impulse Responses to Positive Wage Mark-up Shock



Note: y is output; cd is overall consumption; ik is investment, k is capital input; n is labour supply (or employment); pi is overall inflation; pih is domestic inflation; w is nominal wage; mc is marginal cost; rm is nominal interest rate; rr is real interest rate; rk is rental rate of capital; x is terms of trade; rer is real exchange rate (where + means depreciation; - means appreciation); tx is export; im is imports (i.e. consumption of imported goods);

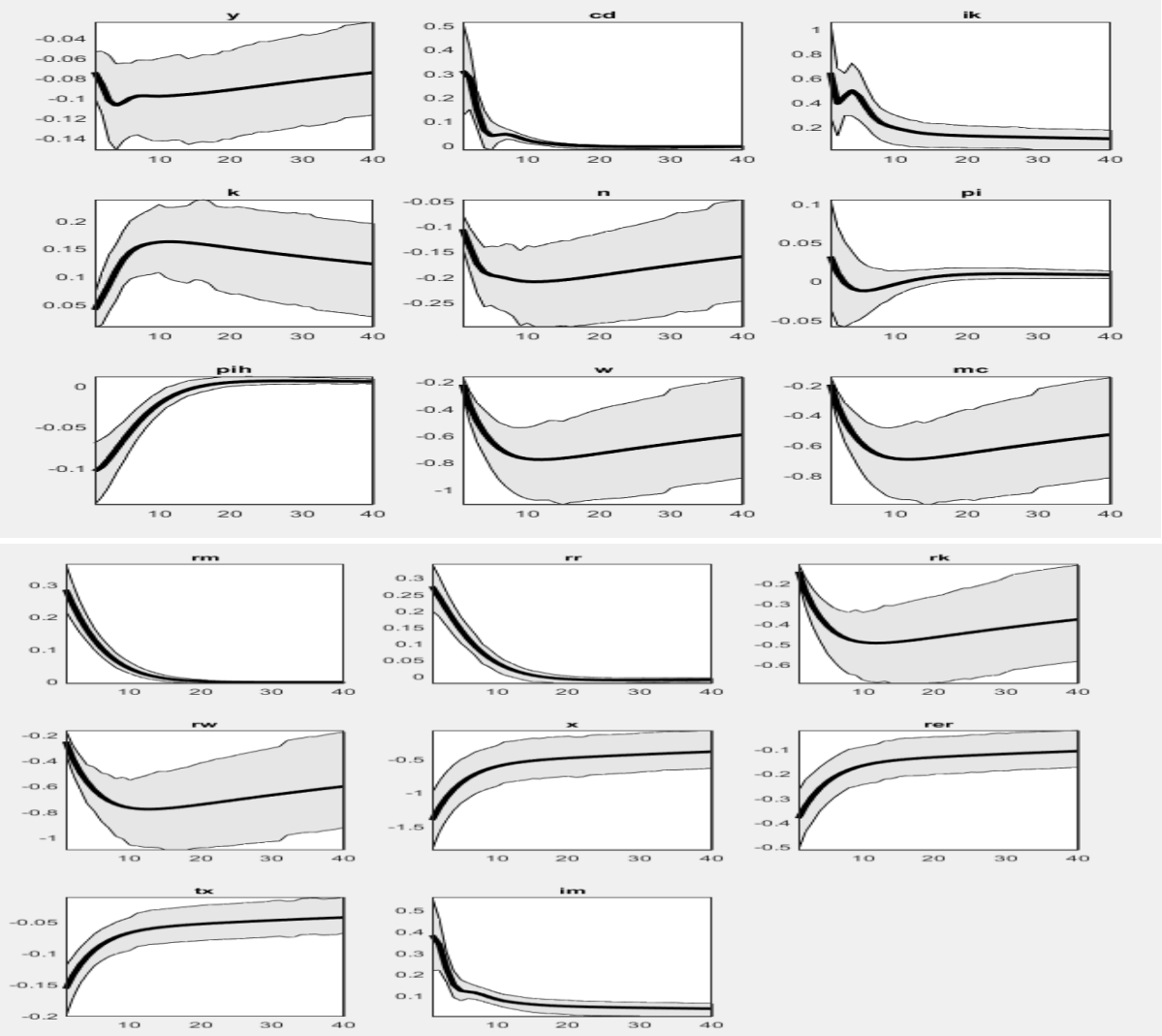
6.3.4.7 Domestic Monetary Policy Shock

Graph 6.8 presents the effect of domestic monetary policy contraction (i.e. positive interest rate shock). The posterior estimate for the size of the shock is 0.32. Because there is no autoregressive structure associated with shock, the gradual decrease back to the steady state is driven by interest rate smoothing but not the persistent of the shock itself. Consistently, the unexpected contractionary monetary policy leads to a rise in short-run interest rates (both nominal and real). Real exchange rate appreciates on the

back of positive real interest rate. A stronger domestic currency contemporaneously deteriorates net exports.

Output declines as a result of negative net exports, causing firms to curtail employment. The decline in costs of labour inputs shrinks marginal cost and hence, induces a fall in domestic inflation. The appreciation in the domestic currency raises households' net worth to boost private consumption especially of imports goods and this is facilitated by the estimated high degree of trade openness ($\Omega = 0.687$). The qualitative result implies that high degree of openness considerably impairs the effectiveness of monetary policy to restrain private consumption. Although contractionary monetary policy shock generates a decline in output and domestic inflation which is consistent with economic theory, it rather causes overall inflation to inch up contemporaneously. This suggests that the NK model with representative agent is not able resolve the problem of price puzzle for the Ghanaian macroeconomy.

Figure 6.8: Impulse Responses to Positive Domestic Monetary Policy Shock



Note: y is output; cd is overall consumption; ik is investment, k is capital input; n is labour supply (or employment); pi is overall inflation; pih is domestic inflation; w is nominal wage; mc is marginal cost; rm is nominal interest rate; rr is real interest rate; rk is rental rate of capital; x is terms of trade; rer is real exchange rate (where + means depreciation; - means appreciation); tx is export; im is imports (i.e. consumption of imported goods);

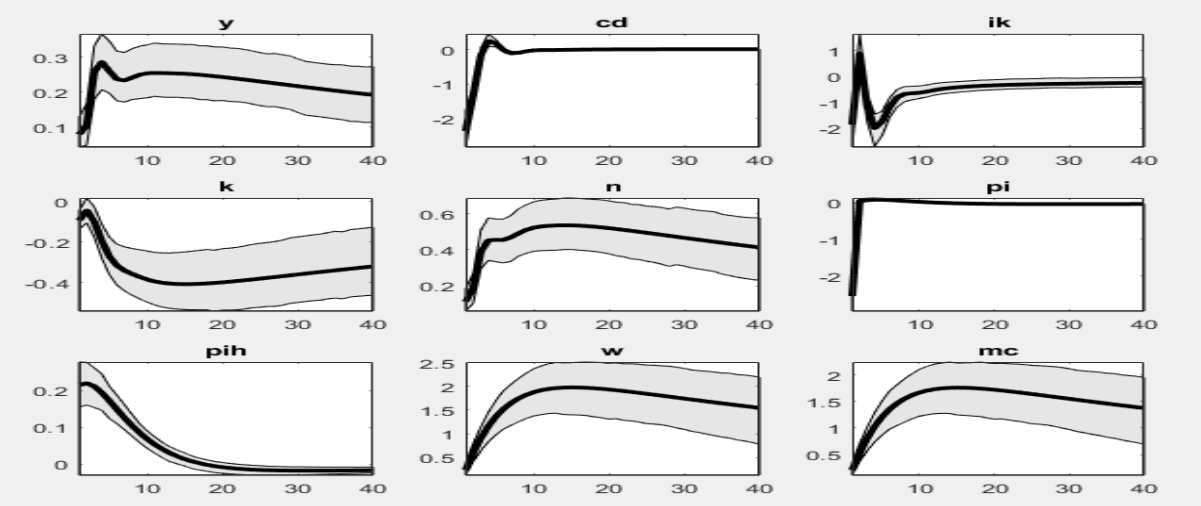
6.3.5 Foreign Spillovers

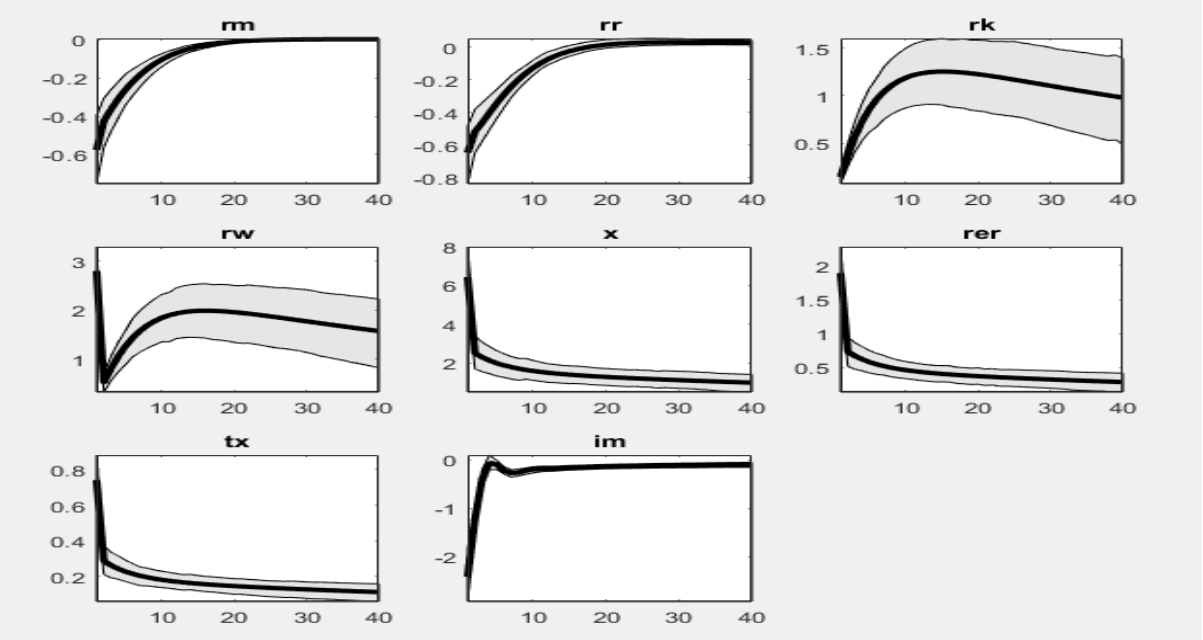
We now turn to illustrate the macroeconomic responses to shocks originating from the foreign economy, so as to understand especially how the monetary authority reacts to foreign spillovers.

6.3.5.1 Exchange Rate Risk Premium Shock

Figure 6.9 presents the impulse responses of unanticipated reduction in exchange rate risk premium or favourable UIP shock. The posterior estimate for the size of the shock is 3.551 with no autoregressive structure. Consistent with international macroeconomic theory, a real exchange rate appreciates and terms-of-trade (net export) worsens following a favourable risk premium shock (i.e. nominal exchange rate appreciation). Output decreases immediately on the back of negative net export. Firms' demand for inputs of production declines on account of lower aggregate output, leading to a fall on costs of inputs and a decreasing marginal cost. A drop in marginal cost induces firms to lower prices. In response, policy (nominal) interest rate is reduced in a bid to stimulate economic activity and bring prices back to their steady state level. On the other hand, private consumption of both domestic and imported goods increases as local currency appreciation raises the net worth of households (as they are also assumed to hold unhedged foreign debt). Thus, the immediate decline in aggregate output amid drop in risk premium because the negative impact on net exports outweighed the boost in private consumption.

Figure 6.9: Impulse Response to Positive UIP Shock (RER Appreciation)





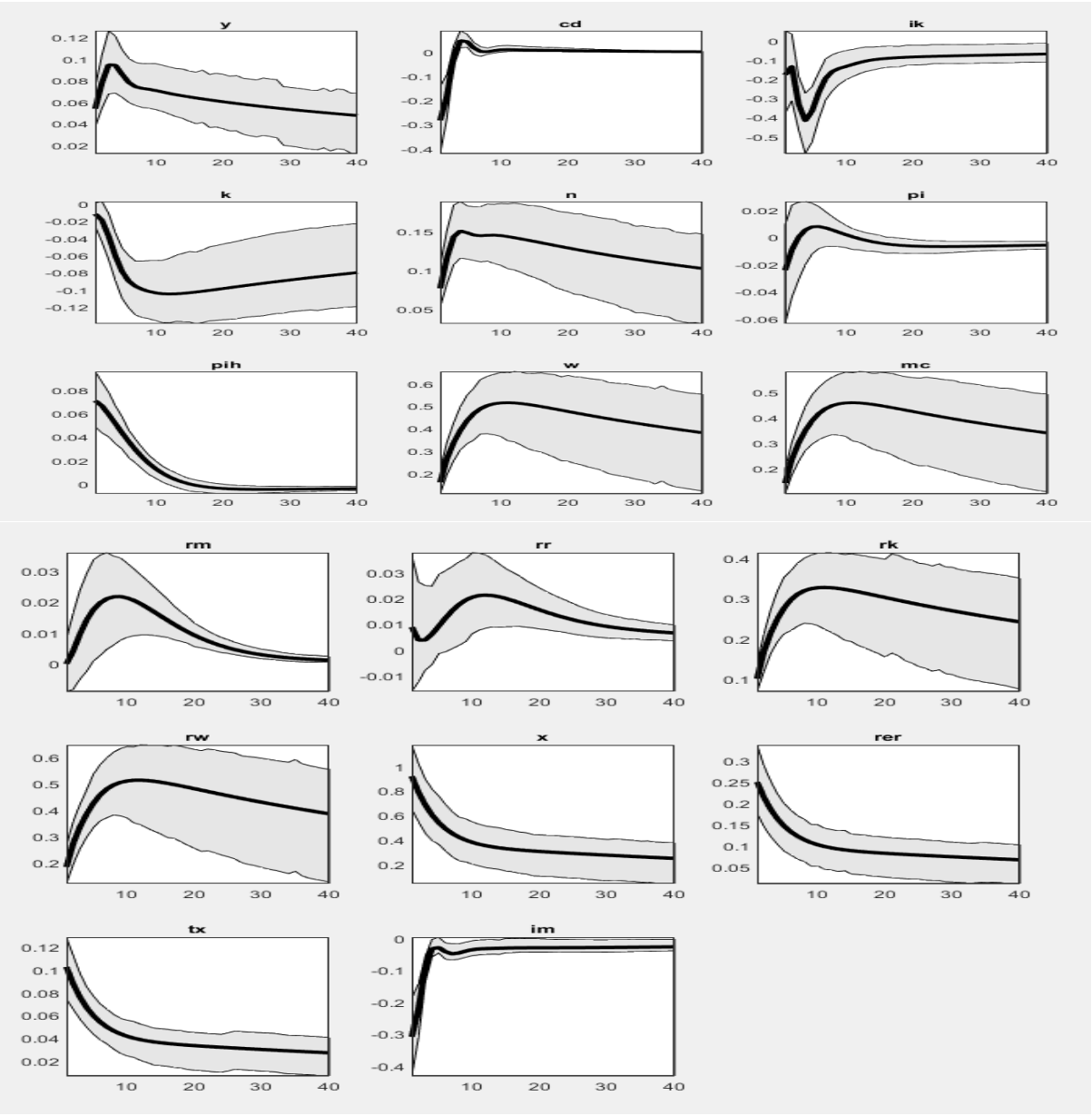
Note: y is output; cd is overall consumption; ik is investment, k is capital input; n is labour supply (or employment); pi is overall inflation; pih is domestic inflation; w is nominal wage; mc is marginal cost; rm is nominal interest rate; rr is real interest rate; rk is rental rate of capital; x is terms of trade; rer is real exchange rate (where + means depreciation; - means appreciation); tx is export; im is imports (i.e. consumption of imported goods);

6.4.5.1 Contractionary Foreign Monetary Policy Shocks

Figure 6.10 illustrates impulse responses associated with unanticipated foreign monetary policy contraction (rate hike). The posterior estimate for the magnitude of the shock is 0.202 with no autoregressive structure. Domestic currency depreciates on impact of foreign monetary policy contraction, boosting net export and output. The rise in aggregate output induces firms to increase demand for factor of production which in turn raises cost of factor inputs and hence, a surge in marginal cost. Inflation increases on the back of rising marginal cost.

Overall private consumption declines as depreciated local currency reduces the net worth of households. This is underpinned by the decline in imports (via improved trade competitiveness) and a subdued consumption of domestic good (due to higher domestic prices). In response, domestic monetary authority raises nominal interest rate to stimulate private investments and strengthen the local currency. The subsequent gain in local currency dampens aggregate output thereafter and hence steers inflation towards its steady level.

Figure 6.10: Impulse Responses to a Positive Foreign Monetary Policy Shock



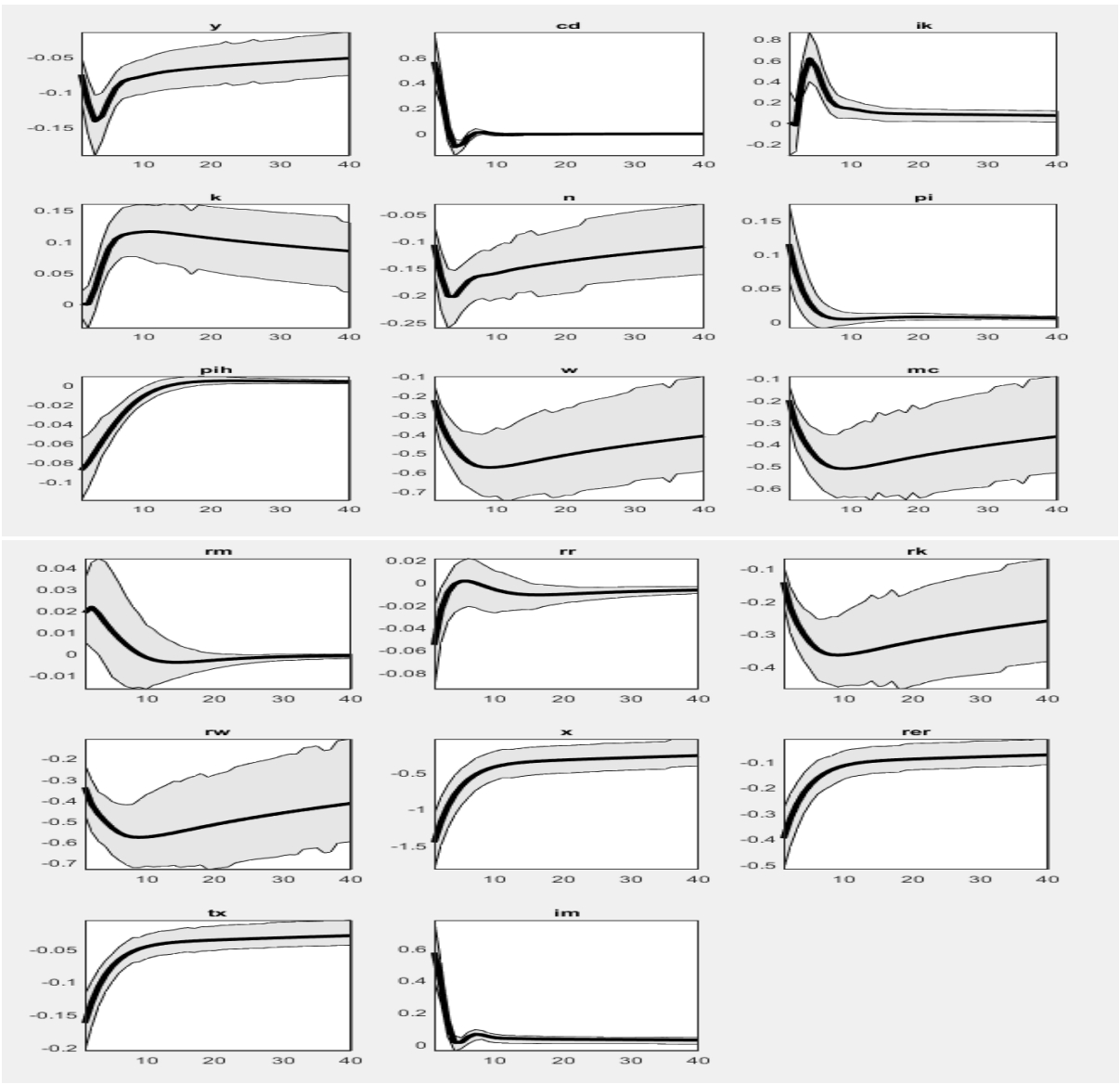
Note: y is output; cd is overall consumption; ik is investment, k is capital input; n is labour supply (or employment); pi is overall inflation; pih is domestic inflation; w is nominal wage; mc is marginal cost; rm is nominal interest rate; rr is real interest rate; rk is rental rate of capital; x is terms of trade; rer is real exchange rate (where + means depreciation; - means appreciation); tx is export; im is imports (i.e. consumption of imported goods)

6.4.5.2 Foreign Inflation Shock

Figure 6.11 presents a qualitative impulse response to a temporary positive foreign inflation shock. Here, we define foreign inflation shock as a temporary shock that raises foreign inflation but depresses foreign output. This definition closely followed other studies, notably Meloliana (2015), Charnavoki and Dolado (2014), Ferroni and Mojon (2014) Baumeister and Peersman (2013). The posterior estimate for the size of the shock is 0.442. Positive foreign inflation shock leads to a hump-shape decline in output via next-export channel alongside a pickup in overall inflation. In response to rising

overall inflation, monetary authority adopts tightening policy stance by raising nominal interest rate which in turns triggers real appreciation in the domestic currency. The strengthening in the domestic currency worsens the competitiveness of domestic firms and hence boosts the consumption of imported goods. The immediate pick-up in imports relative to exports supports induces aggregate private consumption to increase on impact. Real wage declines on the back rising overall inflation relative to the fall in nominal wage which increased household's marginal disutility of working, reflecting in a decline in labour supply.

Figure 6.11 Impulse Responses to a Positive Foreign Inflation Shock

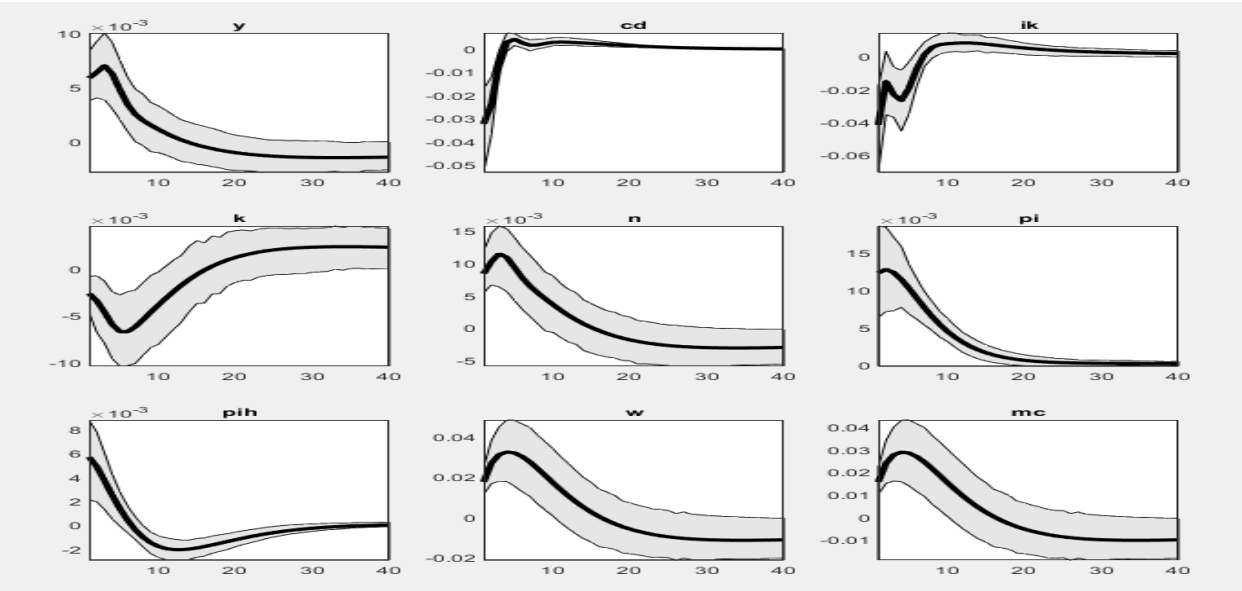


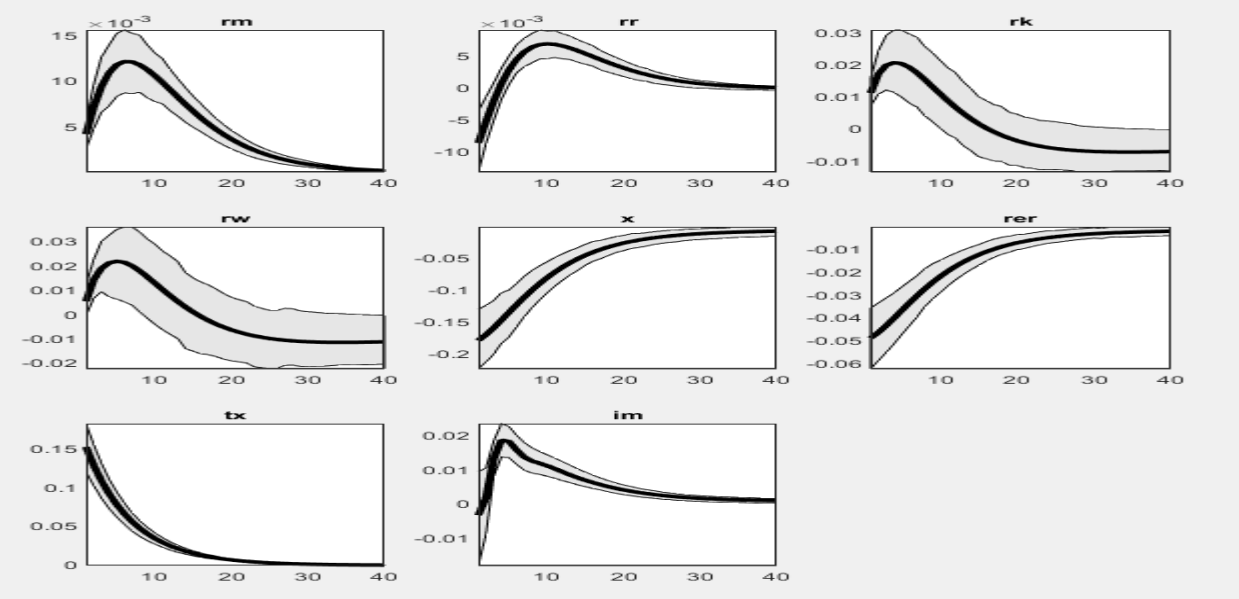
Note: y is output; cd is overall consumption; ik is investment, k is capital input; n is labour supply (or employment); pi is overall inflation; pih is domestic inflation; w is nominal wage; mc is marginal cost; rm is nominal interest rate; rr is real interest rate; rk is rental rate of capital; x is terms of trade; rer is real exchange rate (where + means depreciation; - means appreciation); tx is export; im is imports (i.e. consumption of imported goods);

6.4.5.3 Foreign Demand (Output) Shock

Figure 6.12 presents a qualitative impulse response to a temporary positive foreign demand (output) shock. In this chapter, a positive foreign output shock is assumed to be a temporary foreign non-oil demand shock that raises foreign output but reduces foreign inflation. The posterior estimate for the size of the shock is 0.235. This assumption closely follows other studies in the literature, notably Charnavoki and Dolado (2014), Gambetti, Pappa and Canova (2005), and Ferroni and Mojon (2014). The qualitative responses to temporary impulse from foreign demand shock are approximately akin to that of UIP shock, although the domestic responses to the former shock appear to be insubstantial. A notable qualitative difference, however, is that a temporary positive foreign demand shock boosts domestic output via exports channel. In line with the UIP shock, the boost in output due to a positive foreign demand shock leads to rising inflation, wages (nominal and real), marginal cost and rental rate of capital. In agreement with economic theory, monetary policy responds appropriately by raising nominal interest rate, although the degree of policy adjustment appears to be very modest compared to the pickup in inflation, leading to a decline in real interest rate. Likewise, both domestic consumption and investment are instantly crowded-out following positive foreign demand shock on the account of rising inflation, negative real interest rate and rising cost of capital. The immediate pickup in nominal and real wage increase household's incentive to work, leading a rise in labour supply.

Figure 6.12: Impulse Responses to a Positive Foreign Output Shock





Note: y is output; cd is overall consumption; ik is investment, k is capital input; n is labour supply (or employment); pi is overall inflation; pih is domestic inflation; w is nominal wage; mc is marginal cost; rm is nominal interest rate; rr is real interest rate; rk is rental rate of capital; x is terms of trade; rer is real exchange rate (where + means depreciation; - means appreciation); tx is export; im is imports (i.e. consumption of imported goods);

6.4 Relative importance of structural shocks

In Table 6.5, we report the relative average contribution of each of the structural shocks to the forecast error variance of the endogenous variables at various horizons. In all, there are two supply shocks (i.e. productivity shock and labour supply shock), four mark-up shocks (i.e. domestic price mark-up shock, wage mark-up shock, UIP shock and foreign inflation shocks), demand shocks (i.e., preference shock and foreign output shock) and three policy shocks (i.e. domestic policy shock, government spending shock and foreign policy shock). The time horizon considered are short run for period t= 4 quarters (i.e. 1 year); medium run for period t=12 quarters (i.e. 3 years) and long run for period t=100 quarters (i.e. 25 years).

A close examination of the table shows that the dominant drivers of output (in descending order) are price mark-up shock, labour supply shock, domestic monetary policy shock, productivity shock, foreign inflation shock and foreign policy shock across the forecast horizon (i.e. short-medium-long run). Productivity shock has limited average influence on aggregate fluctuation in Ghana (even in the short run), while domestic monetary policy still matters for economic growth. The average contribution of domestic monetary policy shock to variations in output is primarily via its implication on cost of labour and capital inputs. The table also reveals the main determinants of consumer inflation (CPI) to be exchange rate risk premium (UIP) shock and domestic price mark-up shock with average shares of 55% and 39.5% respectively in short-to-long run horizons. This finding suggests that by observing the

UIP shock and responding accordingly, the central bank of Ghana could offset the shock and in that way contain inflation. The predominant influence of UIP shock in the variations in CPI inflation is largely driven by the estimated high degree of openness in Ghana. This also suggests that the exchange rate is leading conduit for the volatility spillovers from the foreign economy. Concerning monetary policy function, the dominant determinants of nominal interest rate in the short-term horizon are domestic monetary policy and price mark-up shocks, with contributions of 50% and 38% respectively. Other contributors are government spending shock and labour supply shock with respective shares of 4.9% and 4.7%. The shares of both domestic monetary policy and price mark-up shocks however moderated in the medium-to-long run, while that of government spending shock gained significantly to emerge as the dominant driver in the long run. This observation surmises that the continuous large fiscal overruns have considerable debilitating impact on monetary policy stabilization effort in Ghana.

Table 6.5: Forecast Error Variance Decomposition (%)

	Productivity Shock	Price Mark-up Shock	Gov't Spending Shock	Pref. Shock	Labour Supply Shock	Wage Mark-up Shock	UIP Shock	Dom. Policy Shock	For. Output Shock	For. CPI Shock	For. Policy Shock
	Period	**t=4**									
Output	8.30	41.48	1.46	1.04	24.78	0.66	1.19	8.75	0.02	7.74	4.59
Consumption	4.06	17.77	0.92	1.63	43.92	1.30	19.35	4.62	0.02	4.47	1.93
Investment	0.56	33.52	0.18	1.89	52.53	0.52	8.64	0.69	0.00	0.98	0.48
Capital input	0.30	36.70	0.12	2.22	58.16	0.37	0.84	0.41	0.00	0.56	0.32
Labour Input	4.70	41.20	2.25	0.72	15.56	1.29	1.47	14.03	0.03	11.71	7.04
Consumer Inflation	0.34	39.24	0.32	0.04	1.65	0.08	57.99	0.10	0.00	0.20	0.03
Dom. inflation	0.85	94.05	0.16	0.03	1.64	0.11	0.05	1.49	0.00	0.97	0.66
Marginal Cost	22.34	5.88	2.92	0.30	16.26	4.08	2.04	21.37	0.03	15.37	9.40
Nominal Int. Rate	0.59	37.79	4.91	0.11	4.66	0.67	0.22	49.94	0.03	0.38	0.71
	4.67	**38.63**	**1.47**	**0.89**	**24.35**	**1.01**	**10.20**	**11.27**	**0.01**	**4.71**	**2.80**
	Period	**t=12**									
Output	4.40	50.88	1.31	0.96	19.19	0.32	0.56	10.21	0.01	7.01	5.14
Consumption	4.02	18.38	0.93	1.62	43.69	1.29	19.08	4.55	0.02	4.48	1.95
Investment	0.64	35.04	0.21	1.84	50.86	0.57	8.39	0.80	0.00	1.11	0.54
Capital input	0.17	28.40	0.07	3.11	66.73	0.21	0.50	0.27	0.00	0.33	0.19
Labour Input	3.69	50.63	1.90	0.48	9.38	0.58	0.62	15.29	0.01	9.99	7.42
Consumer Inflation	0.35	40.71	0.82	0.06	2.28	0.08	55.20	0.18	0.00	0.26	0.06
Domestic inflation	0.83	93.38	0.19	0.06	2.19	0.11	0.06	1.53	0.00	0.99	0.68
Marginal Cost	8.17	17.47	1.73	0.80	32.96	1.11	0.59	18.08	0.01	10.95	8.12
Nominal Int. Rate	0.54	28.45	24.67	0.11	5.66	0.60	0.25	35.68	0.09	1.28	2.67
	2.53	**40.37**	**3.54**	**1.00**	**25.88**	**0.54**	**9.47**	**9.62**	**0.02**	**4.04**	**2.97**
	Period	**t=100**									
Output	3.79	50.47	3.59	0.88	17.94	0.26	0.45	10.68	0.01	6.61	5.31
Consumption	4.02	18.39	0.99	1.62	43.64	1.29	19.05	4.55	0.02	4.48	1.96
Investment	0.63	34.80	0.21	1.94	51.09	0.56	8.33	0.79	0.00	1.10	0.54
Capital input	0.13	21.38	0.07	6.06	71.20	0.15	0.39	0.21	0.00	0.25	0.15
Labour Input	2.87	45.08	4.43	0.94	18.28	0.38	0.42	13.27	0.01	7.91	6.40
Consumer Inflation	0.35	39.90	3.15	0.06	2.33	0.08	53.43	0.28	0.00	0.30	0.11
Domestic inflation	0.84	92.68	0.26	0.07	2.50	0.11	0.06	1.68	0.00	1.07	0.74
Marginal Cost	3.86	18.18	3.72	4.04	48.17	0.43	0.26	10.54	0.01	5.95	4.84
Nominal Int. Rate	0.29	15.70	58.11	0.08	4.02	0.32	0.14	18.76	0.06	0.79	1.74
	1.86	**37.40**	**8.28**	**1.74**	**28.80**	**0.40**	**9.17**	**6.75**	**0.01**	**3.16**	**2.42**
OAC	**3.02**	**38.80**	**4.43**	**1.21**	**26.34**	**0.65**	**9.61**	**9.21**	**0.01**	**3.97**	**2.73**

Note: OAC means overall average contribution; Dom denotes Domestic and For. means Foreign; Pref. denotes Preference

6.5 Historical Shock Decomposition

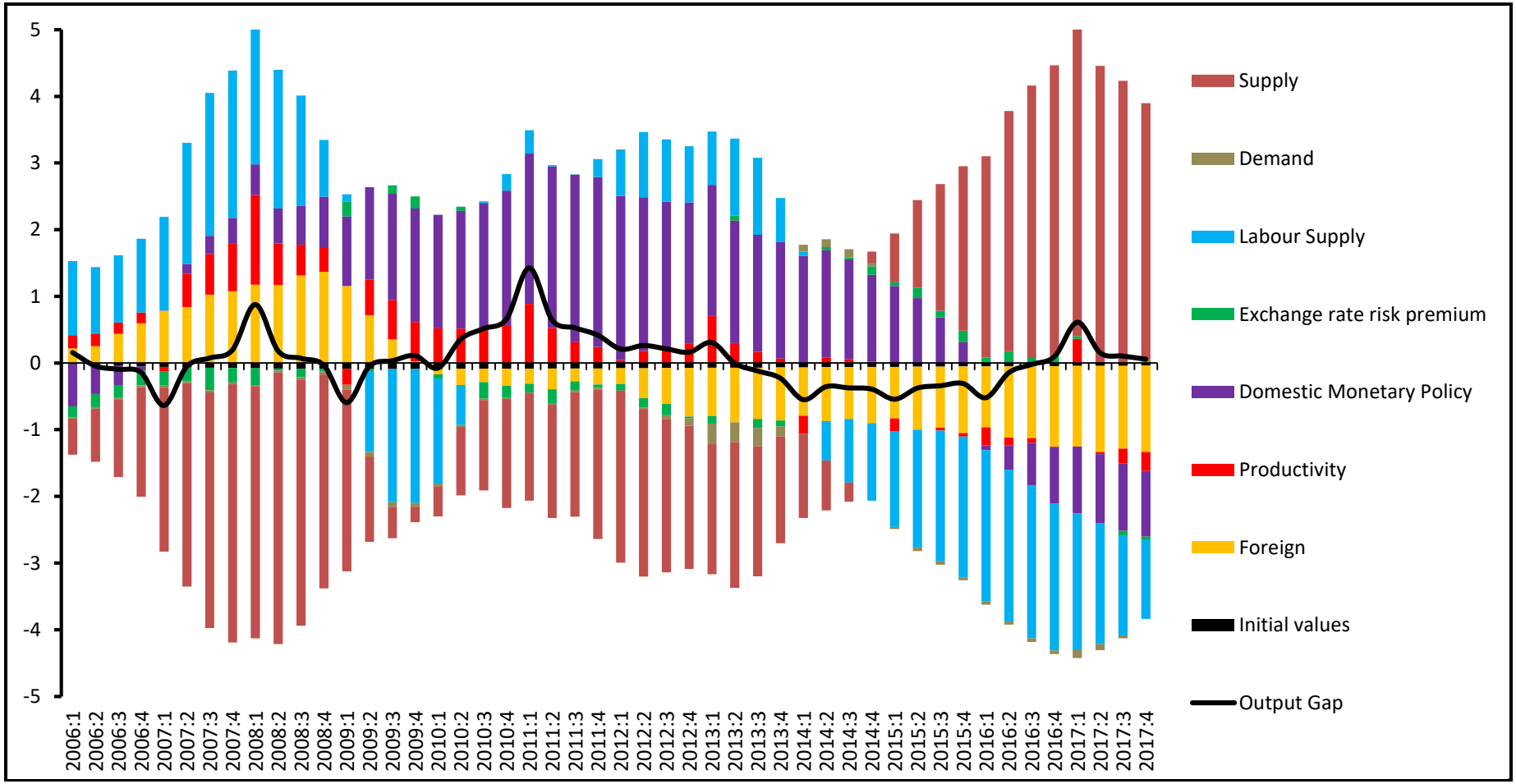
The preceding analysis focuses on average (or static) contribution of shocks to the variations in the key macroeconomic variables. It however does not highlight time-varying or historical contribution of shocks which is essential for the interpretation of historical evolution of these variables. In addition, the averaging method may possibly mask salient periodic contributions of some structural shocks over the entire spectrum of the interested macroeconomic variable. Consequently, we further explore the historical (time-varying) contribution of shocks to inflation and output gap by utilizing the Kalman filter (KF), given the state space representations and the parameter estimates of the model. The analysis of historical shock decomposition may bring to light the model's interpretation of chronological developments in these variables.

Figure 6.13 displays the historical shock decomposition of economic growth for the period 2006-2017. A thorough examination of the model's estimate reveals that developments surrounding the productivity shock predominantly influenced Ghana's GDP growth for the 12- year period. This seems to suggest that productivity shock remains an important driver to GDP gap despite its relatively smaller value in preceding static analysis. For instance, the below-trend GDP growth the period 2006 to mid-2007 was instigated by waning technological gains supported by adverse supply shock and stronger domestic currency (implying reduction in risk premium shock). The model estimates also suggest that the strong recovery in economic activities from mid-2007 to the third quarter of 2008 was driven by strong technological improvement in tandem with favourable international developments which outstripped adverse supply shocks. Throughout these periods, the labour supply shock also provided upward pressures on output gap. The significant technological gain is mainly driven by the substantial infrastructural developments towards the hosting of African Cup of Nations (AFCON in 2008) and the Golden Jubilee celebration in 2007. On the other hand, the below-trend GDP from the late-2008 to early-2009 is attributed to a decline in productivity, weaker aggregate demand and adverse supply shocks, broadly activated by the onset of the global financial crisis in late-2008. However, the model accredited the subsequent above-trend growth of Ghanaian GDP for the period between mid-2009 and early-2013 (except for 2010:1) to robust technological gains and supportive monetary policy environment which more than countered the adverse supply, risk premium and foreign shocks. Additionally, the labour supply shock contributed negatively and positively to growth during the periods 2009:3-2010:2 and 2010:3-2013:1 respectively. It seems also reasonable that the favourable impact of the onset of Ghana's crude oil production and exports in 2011 on GDP growth becomes

apparent in the model's estimates. Moreover, a decline in productivity and an adverse labour supply shock rendered a downward pressure on the output gap between mid-2013 and the third-quarter of 2016. During this period demand shock placed downward pressure on GDP growth (except in the year 2014 where it had a positive influence). The downward pressure is attributable to the significant slowdown in private and public consumption spending as well as large negative net exports recorded during the era. Notably, the drop in public spending during the period is broadly linked to the post-election (2012) fiscal consolidation as well as fiscal constrained imposed by IMF conditionality following the bailout of government of Ghana in 2015. General loss of confidence and political uncertainty in 2016 may have also contributed to the downward pressure on output from demand shock in 2016. It is apparent that the risk premium shock exerted a positive effect on GDP growth during this period (expect for the year 2013), reflecting the impact of the huge exchange rate depreciation experienced between 2014 and 2015. Furthermore, the subsequent above-trend GDP growth is furthermore attributed to productivity changes, supported by favourable supply shock and expansionary monetary policy shock. The model's estimates also reveal that foreign related shocks have exerted downward pressure on Ghanaian's GDP growth since 2010.

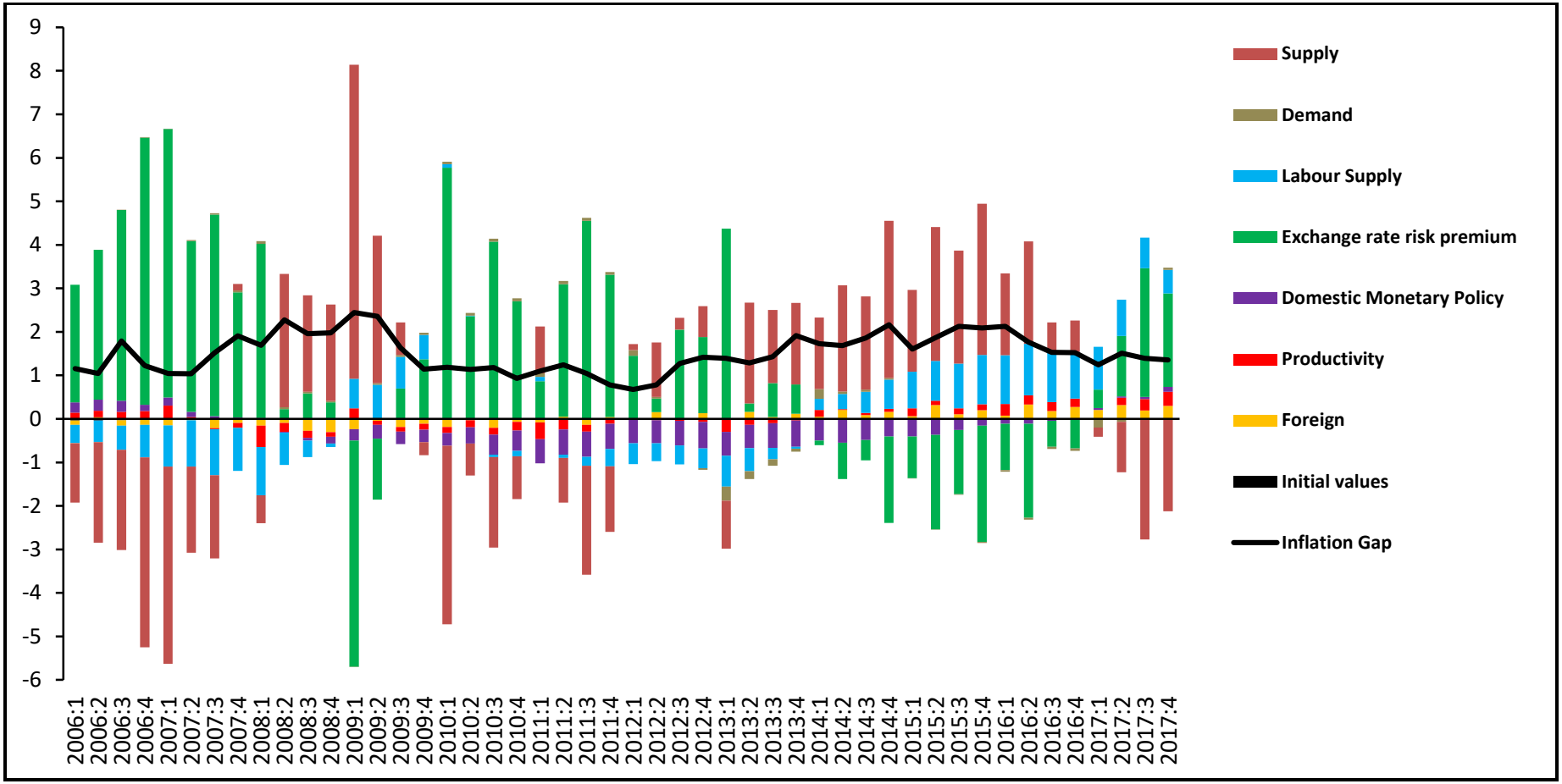
The historical shock decomposition of consumer (CPI) inflation in Figure 6.14 highlights the main shocks that contributed to inflation's deviation from the steady state for the period 2006-2017. In the context of the model, the general drop in consumer inflation from 2006 to mid-2007 is ascribed to a considerable reduction in risk premium shock which led to cedi appreciation. This together with favourable supply-side shocks generated disinflationary pressures during the era. The surge in consumer price inflation after mid-2007 to mid-2009 is attributed to unfavourable supply-side shock and escalating exchange rate risk premium. The rise in adverse supply-side shock is partly driven by rising international commodity prices (particularly oil price) and the resultant increase in domestic fuel price over the period. Conversely, the onset of global financial crisis in late-2008 led to financial (particularly, portfolio) outflow which increased the exchange rate risk premium and hence, induced significant cedi depreciation. The drop in consumer inflation in the late-2009 through to the first quarter of 2012 is attributed to a fall in international commodity price (oil price), lower risk premium (linked to oil production and export in 2011) and favourable supply-side shocks. Throughout these periods, the labour supply shock has exerted downward pressures on consumer inflation, except the year 2009. The subsequent upsurge in consumer inflation from mid-2012 to mid-2016 is associated with adverse supply-side shocks and an escalating risk premium (leading to rapid cedi depreciation).

Figure 6.13: Historical Shock Decomposition of Output Gap



Note: Supply is a combination of wage and price mark-up shocks; Foreign is made up of foreign output, inflation and monetary policy shocks; Demand is a combination of government spending shock and preference shock;

Figure 6.14: Historical Shock Decomposition of Consumer Inflation Gap



Note: Supply is a combination of wage and price mark-up shocks; Foreign is made up of foreign output, inflation and monetary policy shocks; Demand is a combination of government spending shock and preference shock;

As well, the labour supply shock broadly induced upward pressure on inflation during the period. Consumer inflation falls since late-2016 as the cedi strengthened considerably on the back of a lower risk premium, as well as favourable supply-side and labour supply shocks. The lower risk premium for the period was boosted by enhanced investor confidence following a smooth transition to a political regime in 2017.

6.6 Conclusion

This chapter ascertains the suitability of a small-open general equilibrium model with full optimizing consumers for monetary policy analysis in developing economies that are saddled with large unbanked (or financially constraint) population. Ghana is a representative developing economy while the Euro Area is chosen as the foreign economy due to its sizeable share of Ghana's external trade. The empirical analysis reveals a number of important findings. A striking finding is that the shocks that are important for output variations are domestic price mark-up, labour supply, domestic monetary policy and productivity shocks. This observation reveals that monetary policy matters for economic growth in Ghana. The dominant determinant of overall inflation is nominal exchange rate risk premium (UIP) shock. In the case of estimated interest rate, the price mark-up shock, domestic monetary policy shock and government spending shock are the main determinants. This is vivid indication that fiscal policy dynamics have non-trivial impact on the efficacy of monetary policy in ensuring overall macroeconomic stability in Ghana. Consequently, it is expedient for strong policy coherence between monetary and fiscal authorities in Ghana so as to inure a sustained price and macroeconomic stability in the economy.

The collective result strongly suggests that a forward-looking policy rule - where policy reacts to output gap and one-quarter-ahead inflation forecast deviation from desired level - is the most appropriate policy rule for Ghana. This empirical finding reinforces that the use of other policy rules (such as the standard contemporaneous rule or the backward-looking rule or the augmented rules with exchange rate or foreign interest rate) are inclined to generate less plausible estimates for policy inference in the context of Ghana.

Another striking result is that monetary response to deviation in inflation from target is consistent with the Taylor Principle with a mean of 1.704 and a 95% credible interval of 1.2 and 2. The impulse response functions yield some salient results. Notably, positive government spending shock boosts output growth and private investments but crowds-out private consumption. The latter observation is a clear endorsement of Ricardian Equivalence hypothesis as consumption is assumed to be totally

dependent on permanent income but not temporal windfalls from government. Another important finding is that monetary policy responses to macroeconomic shocks are broadly consistent with economic theory as policy tightens (or eases) stance amid adverse (or favourable) shock. While contractionary monetary policy stance tends to successfully depress both output and domestic inflation (via the exchange rate channel), it rather increases private consumption contemporaneously (also through the exchange rate channel). This latter evidence is conceivable as contractionary monetary policy shock leads to a drop in real wage. In contrast, exchange rate appreciation following contractionary monetary policy shock generates greater wealth or favourable balance sheet effect (especially of households with foreign currency denominated assets/liabilities). The unconventional increase in private consumption following contractionary monetary policy shock implies that the exchange rate induced wealth/financial balance sheet effect outweighs that of the drop in real wage.

Yet, there is conspicuous evidence that monetary policy shock is prone to price puzzle as consumer (overall) inflation increase contemporaneously and only returns to the steady state after about twenty (20) periods following contractionary policy shock. Besides, it appears that a shock to government expenditure does not allow for many variables to return to their steady-state values. It is therefore unconceivable to suggest to policy makers to make use of this model for monetary policy analysis as it does not yield meaningful impulse response functions. Consequently, the chapter articulates that the general equilibrium model with representative consumers is practically not suitable for monetary policy analysis in Ghana as contractionary monetary policy impulse is not able to induce disinflation contemporaneously and hence, contradicting the standard economic theory. These deficiencies therefore call for a more suitable model that capture some other notable features of developing economies (including but not limited to, a reasonable share of non-optimizing households) and are able to generate meaningful impulse response functions for monetary policy investigation in these economies.

CHAPTER SEVEN

Macro-Implications of Non-Ricardian Consumers on Monetary and Fiscal Policy Transmissions in Ghana:

Application of New Keynesian Model with heterogeneous Agents

7.0 Introduction

Consumption behaviour of households remains one of the thriving research areas in the macroeconomic literature. Among others, the Permanent Income Hypothesis (PIH), espoused by Friedman (1957), offers explanation to household consumption patterns. A consumer's permanent income is determined by their assets: physical (property), financial (shares, bonds) and human (education and experience). These assets affect the ability of consumers to earn income. Consequently, transient variations in disposable income (like temporal government spending) do not considerably impact consumption patterns as they do not alter expected permanent income. Only longer-lasting changes in income will have a large effect on spending. The policy implications of the PIH is that (i) only changes in policy that affect permanent income can also influence current consumption and (ii) only unanticipated changes in policy can impact consumption since expected lifetime income has already counted in everything expected about the future (Hall, 1979). The PIH departs from the traditional Keynesian emphasis on the marginal propensity to consume which asserts that agent consumes a certain constant fraction of additional increase in current income.

The PIH hypothesis fundamentally underpins neoclassical growth models (i.e. the Ramsey–Cass–Koopmans model, or standard RBC) and the overlapping generation (OLG) models which are based on optimizing households that seek to maximize their objective functions subject to a budget constraint. The maximization of the objective function yields a standard consumption Euler equation. In such models, the PIH suggests that consumption follows a random walk with trend such that the only factor affecting future consumption is the current consumption (Hall, 1979). Using postwar US data to validity the PIH, Hall (1979) concluded in affirmative that the real disposable income has no significant power in predicting consumption. Since then, several authors have also tested the relevance or validity of the PIH using several econometric techniques (predominantly two stage least squares) based on different versions of the consumption Euler equation. Notable studies such as Hayashi (1989), Runkle (1991), Blinder and Deaton, (1985), Auchauer (1993), DeJuan and Seater (1999), Hahm and Steigerwald (1999), Weber (1998, 2000) and Basu and Kimball (2002) found empirical support for the PIH. These studies report a small estimate for rule-of-thumb consumers with average value ranging

from 0.11 to 0.23 but some of the individual estimates were statistically insignificant. In view of that, the standard New Keynesian models, until recently, has focused predominantly on representative agents (henceforth, RANK) with the aforementioned view that the latter agents are essentially permanent income consumers and therefore not responsive to changes in transitory income.

Nevertheless, a great deal of recent empirical micro and macro level evidence suggests that a significant fraction of households face binding borrowing constraints. They unveil large sensitivity of consumption to transitory changes in income, even though the PIH theory posits that these income dynamics should be smoothed. Some prominent examples of micro-level evidence on excess sensitivity are Parker (1999), Souleles (1999), Shapiro and Slemrod (2003a, 2003b, 2009), Johnson et al (2006), Parker et al. (2013), and Broda and Parker (2014). Other studies based on macroeconomic time-series also provide evidence against PIH. They include Flavin (1981), Hall and Miskhin (1982), DeLong and Summers (1986), Jappelli and Pagano (1989), Lusardi (1989), Campbell and Mankiw (1989, 1990, 1991, henceforth CM), Auerbach and Hassett (1991), Cushing (1992), Graham (1993), Carroll, Fuhrer and Wilcox (1994), Carroll and Dunn (1997), Fuhrer (2000), Gali et al (2007), Kiley (2010) and Palas (2017). On average, they report a statistically significant estimate for the rule-of-thumb coefficient ranging from 0.33 to 0.60.

In addition, several contemporary macro studies (including Misra and Surico 2014; Kaplan and Violante, 2014; Cloyne and Surico 2016; Kaplan et al., 2018, henceforth KMV) also find considerable heterogeneity in consumption responses across the population, driven by the level of liquid wealth and the composition of household balance sheets. It is similarly argued that the relative strength of monetary policy can be properly gauged within a framework that offers a better representation of household consumption and household finances than the RANK models (Kaplan and Violante, 2014; KV). Mankiw (2000) therefore proposed that economic model should allow for the cohabitation of optimizing and non-optimizing (or rule-of-thumb) households (HANK). Even though the empirical literature provides evidence both for and against the PIH, the consensus view is that consumption and current income are considerably linked and also there is an imperfect consumption smoothing (Mankiw, 2000). Several reasons for the presence of non-Ricardian consumers have been documented in the extant literature. These include (i) myopia, consumers' inability to create reasonable expectation (see Mankiw, 2000); (ii) A very high subjective discount factor for low income families than richest one (Lawrence, 1991); (iii) The presence of liquidity constraint which make borrowing impossible for some consumers; (iv) households that carry zero net worth (assets) for many periods will set their consumption equal to current disposable income (Browning and Lusardi, 1996; Mankiw, 2000); and

(v) a sizeable portion of households possess no stock or bonds and have neither checking nor a saving account and therefore very unlikely for these households to believe that they can borrow money to smooth consumption (Deaton, 1991).

In keeping with the approach advocated by Mankiw (2000), numerous researches have incorporated rule-of-thumb dynamics in their NK model for policy analysis. Notable examples of DSGE models with a coexistence of Ricardian and non-Ricardian households are Coenen and Straub (2005), Gali et al (2004, 2007), Forni et al (2006), Jakab and Vilagi (2008), Ratto et al. (2009), Branch and McGough (2009), Colciago (2011), Swarbrick (2012), Stahler and Thomas (2012), Dagher et al. (2010, 2012), Marto (2013), Kaplan and Violante (2014, KV), Kaplan, Violante and Weidner (2014, KVW), Palas (2017), Naraidoo, Schaling and Tesfaselassie (2017) and Kaplan, Moll and Violante (2018, KMV). Although quite contemporary, the HANK literature has already granted significant insights into policy issues, such as the effectiveness of the channels by which government spending and conventional monetary policy affect the economy. The works by Bassetto, 1999[96], Gali et al. (2007) and Forni et al. (2006) have also highlighted the presence of liquidity constraints as an additional market imperfection. The introduction of non-Ricardian behaviour in the model could give rise to a role for fiscal stabilization, since liquidity constrained households do not respond directly to interest rate signals (Ratto et al. 2009). Using a model that only a fraction of Ricardian agents satisfy their intertemporal Euler equation, KMV argued that the Ricardian agents intertemporally increase current consumption following an expansionary monetary policy stance (i.e. policy-induced fall in the interest rate). The increased spending by optimizing agents raises the income and the spending of borrowing-constrained agents. They refer to the induced increase in spending by borrowing-constrained agents as the indirect effect of monetary policy. They argue further that the indirect effect on output is larger than the direct effect on output because the latter effect is via a conduit that mirrors the Keynesian multiplier.

Besides the foregoing discussion, we find that the standard DSGE model with representative agent in preceding chapter does not generate meaningful impulse response functions as the monetary policy shock that is prone to price puzzle. Additionally, shock to government expenditure does not allow many variables to return to their steady-state values. Consequently, the RANK model is not suitable for monetary policy investigation in Ghana. Motivated by the observed deficiencies in the preceding chapter and the recent trends in NK literature, this chapter investigates whether general equilibrium model with a coexistence of Ricardian and non-Ricardian consumers is rather appropriate for monetary policy analysis in Ghana. This chapter thus assesses the effect of non-Ricardian consumers on the

[96] http://users.nber.org/~bassetto/research/opttax/combinedwpversion.pdf

transmission of monetary and fiscal policy to the real sector in Ghana. The design of heterogeneous agent's small-open economy model builds on previous works done in this area, notably by Almeida (2009), KMV (2014), KV (2010) and KVM (2018), etc. The model exhibits the same features as in the preceding chapter except for the coexistence of Ricardian and non-Ricardian (or rule-of-thumb) consumers. Our model is used to address a number of relevant policy questions. First, it is of interest to ascertain how the introduction of rule of-thumb consumers influences the responses of aggregate private consumption to changes in government spending? In other words, does Ricardian equivalence hold in the context of Ghana? The Bank of Ghana pursues inflation targeting (IT) as a monetary policy framework and relies on a RANK-type model even though the economy is saddled with a considerable amount of unbanked population (See, Dagher et al., 2010). It is therefore of substantial interest to ascertain the implications of rule-of-thumb consumers on the efficacy of monetary policy instrument (short-term interest rate) as a stabilizing macroeconomic anchor in Ghana. The intuition is that the monetary policy is very effective when there are less non-Ricardian consumers.

In terms of contributions to the literature, the quantitative determination of the share of non-Ricardian household is an important empirical contribution. The implementation of complementary approaches, such as two-stage least regression techniques (GMM) based on the augmented theoretical Euler equation and sensitivity analysis based on the computed marginal likelihoods of several HANK models, to determine the suitable share of rule-of-thumb households in Ghana is an important methodological contribution worth mentioning. Yet, another important empirical contribution is the determination of the appropriate monetary policy rule associated with the HANK-DSGE model for Ghana. In this case, we examine a total of forty one (41) DSGE models with different monetary policy rules, alternative prior distributions of and restrictions on the Calvo parameters as well as the share of non-Ricardian consumers. The chapter also contributes to the on-going debates regarding the relative superiority of the RANK vs. HANK models for the Ghanaian context and beyond.

7.1 Related Literature

A vast empirical literature accentuates that the important implications of heterogeneous household behaviours on monetary and fiscal policies. For that reason, the presence of rule-of-thumb (ROT) households increase output persistence and weakens the impact of shock on output. Kaplan, Violante and Weidner (2014, KVW) also argued that the ROT consumers have a high MPC out of transitory income changes, which could justify the high correlation between consumption and the transitory component of income growth, even for anticipated income shocks. In addition, KVW state that ROT

consumers are the source of misalignment between movements in the interest rate and aggregate consumption growth since the Euler equation does not hold for such consumers.

Using model with sticky prices, Gali et al (2004) evaluate the implication of rule-of-thumb consumers on monetary policy transmission. They emphasize that the stabilizing factors linked to changes in real interest rate do not directly affect the action of non-optimizing consumers. On one hand, the authors argued that the Taylor principle becomes deficient in guaranteeing stability and unique equilibrium when there is a large share of rule-of-thumb household (higher than 0.57 in their calibrated model). They admonish that central bank should permit rule-of-thumb behaviour in its model and accordingly increase the reaction of interest rate to inflation. Utilizing a sticky price DSGE model, Marto (2013) also affirmed that the region of indeterminacy starts when the share of rule-of-thumb household exceeds 0.64. In contrast, Colciago (2011) asserts that the Taylor principle is adequate to generate a unique equilibrium provided the DSGE model has sufficient degree of price and wage rigidities. Besides, KMV also examine the transmission mechanism from monetary policy to household consumption in a Heterogeneous Agent's New Keynesian (HANK) model. They found that the indirect effects of an unanticipated drop in interest rates outstrip the direct effects such as intertemporal substitution. This finding is a complete divergence to small- and medium-scale Representative Agent's New Keynesian (RANK) models, where the substitution channel drives almost all of the transmission from interest rates to consumption.

Another importance underpinning of the recent upsurge in DSGE model with rule-f-thumb behaviour is that the RANK models predict a crowding-out effect of positive government spending shock on private consumption which is at odds with empirical evidence based on VARs (e.g. Colciago, 2011, Gali et el., 2007). Unlike the optimizing agent, the ROT households recognize any increase in their disposable income but do not form expectations that current excessive government spending will be financed via higher taxation in future. In view of this, current consumption of the rule-of-thumb consumers increases following a positive government spending shock. As a result, the inclusion of non-Ricardian behaviours in DSGE model can conceivably coerce crowding-in effect.

Gali et el., (2007) also employed a DSGE model with non-optimizing household behaviour to investigate the effect of a government spending shock. They find that a reasonable value of roughly 0.25 is sufficient in the case of imperfect competitive labour markets. However, they indicate that in a perfectly competitive model only a reasonably high value of the ROT share guarantees a crowding-in effect of government spending on private consumption. The rise in private consumption following

increased government spending shock is supported by a strong response to real wage, which counterbalances the negative wealth effect and boosts consumption of non-optimizing households.

Using a model with sticky wage and labour adjustment cost along with ROT consumers, Ratto et al (2009) also found a negative response of consumption to a positive government shock. Their sensitivity analysis further shows that when the wage rigidities and labour adjustment cost were set to zero as in Gali et al (2007), the consumption response to increased government spending becomes positive. In line with Ratto et al (2009), Colciago (2011) argued that the high increase of the real wage in response to positive government shock (as exhibited in Gali et al., 2007) is at odds with empirical evidence. Colciago (2011) however concluded that the standard result (i.e. crowding-out effect of government spending on private consumption) is guaranteed when wage stickiness is incorporated in the model.

In contrast to the preceding studies which are predominantly closed economy models, Palas (2017) employed an open economy DSGE model with habit formation, price and wage rigidities and a lower share of non-Ricardian households to explore the implications of the latter on government spending shock for Czech Republic. The author found a positive co-movement of government spending and aggregate consumption for the Czech Republic. He argued further that the inclusion of non-optimizing behaviour does not significantly affect model determinacy when nominal wage stickiness is assumed. Under such scenario, the interest rate rule that satisfies the Taylor principle is adequate to guarantee a unique stable solution. The empirical estimates for the consumption sensitivity to changes in disposable income imply that a substantial share of income in Czech Republic goes to non-optimizing consumers.

The review points to lack of no unanimity regarding the ability of non-optimizing consumers to arouse a crowding-in effect in DSGE models. The empirical literature is however definite that the inclusion of non-Ricardian households in DSGE models subdues the decline in consumption by Ricardian household following increased government spending shock. It is also obvious that simple models are able to induce a crowding-in effect but these models tend to omit salient rigidities. Besides, such models often generate an increase in real wage following positive government spending shock which is empirically rejected (e.g. Colciago 2011). On the other hand, more complex models usually produce a crowding-in effect on consumption only for an unreasonably higher share of non-Ricardian consumers. Consequently, accurate determination or calibration of the share of non-Ricardian consumers is pivotal as small variation in the proportion of the latter agents has the tendency to yield divergent results qualitatively and also quantitatively (Marto, 2013). We also realized that only few

DSGE models with non-Ricardian consumers are open economy versions (notably, Naraidoo et al., 2017; Palas, 2017; Ratto et al., 2009), which motivates the focus of this chapter. Following much of the literature, we ascertain the monetary and fiscal implications for a small-open-economy (SOE) DSGE model with coexistence of non-Ricardian and Ricardian consumers. It is pertinent to ascertain whether rule-of-thumb consumers can still generate a positive co-movement between government spending and aggregate consumption in SOE-DSGE model or some other conditions have to be satisfied to generate this effect.

7.2 The Model with Rule-of-thumb consumers

The framework in this chapter is a small-open economy New Keynesian model with rule-of-thumb households. The model has two economies (Home and Foreign) that differ in terms of sizes. The home economy is insignificantly small relative to the foreign economy and hence the latter economy is treated as exogenous. The economy has two types of households, a continuum of firms producing differentiated intermediate goods, a perfectly competitive firm producing a final good, a central bank in charge of monetary policy, and a fiscal authority. Households in each economy consume both domestically produced goods and foreign (imported) goods. Except for the presence of rule-of-thumb consumers, our framework consists of a standard DSGE model with capital and staggered price setting à la Calvo (notably, Smets and Wouters, 2002, 2003, 2007; Kirchner and Tranamil, 2016).

7.2.1 Firm Behaviour

Akin to the preceding chapter, there is a continuum of monopolistically competitive intermediate firms, indexed by $j \in [0,1]$, that operate using the same technology and have identical per unit cost of production. An intermediate good firm produces intermediate goods using capital services (K_t) and labour services (N_t), following Cobb Douglas production function (in log deviation terms);

$$\hat{y}_t = \hat{u}_t + \lambda\hat{k}_t + (1-\lambda)\hat{n}_t \tag{7.1}$$

where $\hat{u}_t$ is the log total factor productivity which follows an AR(1) process as $\hat{u}_t = p_{\upsilon}\hat{u}_{t-1} + \varepsilon_t^u$ and p_{υ} is the autoregressive parameter of productivity with $|p_{\upsilon}| < 1$ while $\varepsilon_t^u \sim (0, \sigma_{\upsilon})$ signifies innovation. $\hat{k}_t$ and $\hat{n}_t$ denote log deviation (from the steady state) of rented physical capital and amount of differentiated labour hired respectively by the intermediate firms. FOCs for the cost minimization problem yield the respective demand functions for labour ($\hat{n}_t$) and capital ($\hat{k}_t$) inputs, and marginal cost ($\widehat{mc}_t$)[97] are expressed in log deviation term as:

[97] see Chapter 5 Appendix A1 for the detailed derivation of the equations for capital, labour and marginal cost via the cost minimization problem.

$$\hat{n}_t = \hat{y}_t + (1-\lambda)\hat{r}_t^{\kappa} - \hat{u}_t - \hat{w}_t \tag{7.2}$$

$$\hat{k}_t = \hat{y}_t + \lambda\hat{w}_t - \hat{r}_t^{\kappa} - \hat{u}_t \tag{7.3}$$

$$\widehat{mc}_t = (1-\lambda)\hat{w}_t + \lambda\hat{r}_t^{\kappa} - \hat{u}_t \tag{7.4}$$

Firm's profits (that are distributed to optimizing households) are expressed as $\Pi_t(j) = \big(P_{h,t}(j) - MC_t\big)Y_t(j)$ and the aggregate profit in the economy are given by $\Pi_t = \int_0^1 \Pi_t(j)dj$.

Following Calvo's (1983) staggered price setting, only a fraction of domestic intermediate firms with probability $(1-\vartheta_h)$ are allowed to re-optimize their price for each period and they choose the same optimal wage in each period because they have identical optimization problem. Each firm that does not re-optimize its price is assumed to index its price to last period's inflation. Gross domestic inflation equation is expressed in log-linearized terms as:

$$\hat{\pi}_{h,t} = \beta E_t\hat{\pi}_{h,t+1} + \frac{(1-\vartheta_h)(1-\beta\vartheta_h)}{\vartheta_h}\widehat{rmc}_{h,t} + \hat{\zeta}_t^p \tag{7.5}$$

where $\hat{\pi}_{h,t} = \hat{p}_{h,t} - \hat{p}_{h,t-1}$; and $\widehat{rmc}_{h,t} = \widehat{mc}_{h,t} - \hat{p}_{h,t}$ denotes real marginal cost. The mark-up shock is assumed to exhibit an AR(1) process, expressed (in log terms) as: $\hat{\zeta}_t^p = p_{\hat{\zeta}_t^p}\hat{\zeta}_{t-1}^p + \varepsilon_t^p$ where $p_{\hat{\zeta}_t^p}$ is the autoregressive parameter of productivity with $\left|p_{\hat{\zeta}_t^p}\right| < 1$ while $\varepsilon_t^p \sim (0, \sigma_p)$ signifies innovation.

There is also a competitive firm that produces the final good for consumption and investment[98] using a differentiated intermediate goods based on Dixit-Stiglitz aggregator

$$Y_t = \left[\int_0^1 Y_{j,t}^{\frac{\gamma_h}{\gamma_h - 1}} dj\right]^{\frac{\gamma_h - 1}{\gamma_h}} \tag{7.6}$$

where Y_t is a final good in period t; $Y_{j,t}$ for $j \in [0,1]$ is the intermediate inputs j; $\gamma_h > 1$ denotes the elasticity of substitution between differentiated intermediate goods. Taking as given the prices of all intermediate goods $(P_{j,t})$ and the final good price (P_t), the representative final good producer maximizes profits $P_tY_t - P_{j,t}\int_0^1 Y_{j,t}dj$ subject to the production function. The FOC of the maximization problem yields the factor demand function as $Y_{j,t} = Y_t\left(\frac{P_t}{P_{j,t}}\right)^{1-\gamma_h}$, $\forall j \in [0,1]$. The zero profit condition holds as the firm operates in a perfectly competitive market. Therefore, the pricing rule for the final good producer is $P_t = \left[\int_0^1 P_{j,t}^{\gamma_h} dj\right]^{\frac{1}{\gamma_h}}$.

[98] For simplicity, the thesis assumes that there are no imported goods for investment.

7.2.2 **Households Behaviour**

In line with the recent literature, a fraction $1-\psi$ of households are classified as intertemporal optimizers or Ricardian. This subset of households has access to capital markets where they can trade a full set of contingent securities, and buy and sell physical capital (which they accumulate and rent out to firms). The remaining fraction ψ is classified as the rule-of-thumb households. In line with Gali et al., (2007), we assume that rule-of-thumb consumers do not borrow (i.e. have no liabilities) nor save (i.e. own no assets) but they just consume their current income fully.

7.2.2.1 **Intertemporal Optimizers or Ricardian Consumers**

Each infinitely-lived optimizing household, R, seeks to maximize a lifetime utility function (as in Coenen and Straub, 2005; Smets and Wouters, 2002; Costa Jr., 2016; Palas, 2017):

$$\max_{C_t,N_t,K_{t+1},B_{t+1}} E_t \sum_{i=0}^{\infty} \beta^i \zeta_t^c \left[\left(\frac{C_{R,t} - hC_{R,t-1}}{1-\sigma_c} \right)^{1-\sigma_c} - \hat{\zeta}_t^n \frac{\left(N_{R,t}\right)^{1+\vartheta_l}}{1+\vartheta_l} \right], \tag{7.7}$$

subject to the budget constraint:

$$P_t C_{R,t} + P_t I_t + E_t\left(Q_{t,t+1} B_{\mathrm{R},t+1}\right) = W_t N_{\mathrm{R},t} - P_h T_{\mathrm{R},t} + B_{\mathrm{R},t} + R_{t+1}^{\kappa} K_{R,t} + \Pi_{R,t} \tag{7.8}$$

and the law of motion of capital ($K_{\mathrm{R},t+1}$):

$$K_{\mathrm{R},t+1} = (1-\varrho) K_{\mathrm{R},t} + I_{\mathrm{R},t} \tag{7.9}$$

where E_t is the expectation operator conditional on the information set available to households at time t; $C_{R,t}$, $N_{R,t}$ and $I_{\mathrm{R},t}$ are consumption, labour supply and investment respectively of Ricardian households; $E_t\left(Q_{t,t+1}\right)$ is stochastic discount factor for quantity of asset ($B_{\mathrm{R},t+1}$) held by Ricardian household (in line with Gali and Monacelli, 2005); σ_c is the intertemporal elasticity of substitution between consumption and leisure; ϑ_l is the inverse of the Frisch labour supply elasticity; ζ_t^c and $\hat{\zeta}_t^n$ are exogenous and stochastic preference shifters for consumption and labour supply respectively; The preference shifters follow the AR(1) process; $h \in (0,1)$ is the internal habit formation in consumption; W_t is the nominal wage for households; R_{t+1}^{κ} is the nominal rental rate on capital; $\Pi_{R,t}$ is the profits from intermediate goods producers and $T_{\mathrm{R},t}$ is the lump-sum taxes (net of transfers) paid by Ricardian households. Solving the maximization problem yields the following first order conditions (FOCs):

$$\frac{\partial L_R}{\partial C_{R,t}}: \quad \zeta_t^c \left(C_{R,t} - hC_{R,t-1}\right)^{-\sigma_c} - \wedge_{R,t} P_t = 0 \tag{7.10}$$

$$\frac{\partial L_R}{\partial N_{\mathrm{R},t}}: \quad -\beta \hat{\zeta}_t^n N_{\mathrm{R},t}^{\vartheta_l} + \beta \wedge_{R,t} w_t = 0; \tag{7.11}$$

$$\frac{\partial L_R}{\partial B_{R,t+1}}: \quad -E_t Q_{t,t+1} \wedge_{R,t} + \beta \wedge_{R,t+1} = 0; \tag{7.12}$$

$$\frac{\partial L_R}{\partial K_{\mathrm{R},t+1}}: -\wedge_{R,t} P_t + \beta \wedge_{R,t+1} (1-\varrho) E_t P_{t+1} + \beta \wedge_{R,t+1} E_t R^{\kappa}_{t+1} = 0 \tag{7.13}$$

$$\frac{\partial L_R}{\partial \wedge_{R,t}}: P_t C_{R,t} + P_t\left(K_{R,t+1} - (1-\varrho)K_{R,t}\right) + \frac{B_{\mathrm{R},t+1}}{R_t} = W_t N_{R,t} - P_h \mathrm{T}_{R,t} + R^{\kappa}_{t+1} K_{R,t} + B_{\mathrm{R},t} + \Pi_{R,t} \tag{7.14}$$

From equation (7.10), we have the Ricardian Lagrange multiplier as

$$P_t \wedge_{R,t} = \zeta^c_t \left(C_{R,t} - hC_{R,t-1}\right)^{-\sigma_c} \tag{7.15}$$

From equation (7.11) also we have an expression that equates real wage to marginal rate of substation between consumption and leisure as;

$$\frac{W_{R,t}}{P_t} = \frac{N^{\vartheta_l}_{\mathrm{R},t}}{\left[\left(C_{R,t} - hC_{R,t-1}\right)^{-\sigma_c}\right]} \left(\frac{\zeta^n_t}{\zeta^c_t}\right) \tag{7.16}$$

By substituting equation (7.15) into equation (7.11), we derive the Euler equation for public bond as

$$\Leftrightarrow \beta \left(\frac{C_{R,t+1} - hC_{R,t}}{C_{R,t} - hC_{R,t-1}}\right)^{-\sigma_c} \left(\frac{P_t}{P_{t+1}}\right) \left(\frac{\zeta^c_{t+1}}{\zeta^c_t}\right) = R_t \tag{7.17}$$

where $R_t = \frac{1}{E_t(Q_{t,t+1})}$ is gross interest payoff for holding public debt by Ricardian households in period t. Log-linearizing equations (7.17), (7.16) and (7.9) around a steady state levels yields the following

$$\hat{c}_{R,t} = \frac{h}{1-h}\hat{c}_{R,t-1} + \frac{1}{1-h}\hat{c}_{R,t+1} - \alpha^r\{E_t\hat{r}_{t+1} - E_t\hat{\pi}_{t+1}\} + \alpha^r\left(1 - \rho_{\hat{\zeta}^c_t}\right)\hat{\zeta}^c_t \tag{7.18}$$

$$\hat{w}_t - \hat{p}_t = \vartheta_l \hat{n}_{R,t} + \frac{\sigma_c}{(1-h)}\left[\hat{c}_{R,t} - h\hat{c}_{R,t-1}\right] + \hat{\zeta}^n_t - \hat{\zeta}^c_t \tag{7.19}$$

$$\hat{k}_{\mathrm{R},t+1} = (1-\varrho)\hat{k}_{\mathrm{R},t} + \varrho\hat{\imath}_{\mathrm{R},t} \tag{7.20}$$

where $\alpha^r = \frac{(1-h)}{(1+h)\sigma_c}$ and a hatted (^) variable denotes log-deviation of that variable from its steady state level. Particularly, equation (7.18) demonstrates the log-linearized consumption Euler equation. With external habit formation, the equation shows that consumption depends on a weighted average of past and future consumption. In addition, interest rate elasticity of consumption depends not only on the intertemporal elasticity of substitution but also on the habit persistence parameter. When $h = 0$, the equation (7.18) reduces to the standard forward-looking consumption equation. Equation (7.19) indicates that optimizing households equate the marginal cost of working, in consumption units, with the marginal benefit, the real wage, while equation (7.20) is the log-linearized law of motion of capital.

7.2.2.2 **Rule-of-Thumb or Non-Ricardian Households**

The *rule-of-thumb* households ψ do not own any assets nor have any liabilities, and just consume their current labor income. Different motivations for that behavior include myopia, lack of access to capital markets, fear of saving, ignorance of intertemporal trading opportunities, and so forth. Our assumptions imply an admittedly extreme form of *non-Ricardian* behavior among *rule-of-thumb* households, without invoking a specific explanation. Thus, the utility problem faced by the ROT households is expressed as

$$\max_{C_{\mathrm{NR},t},N_{\mathrm{NR},t}} E_t \sum_{i=0}^{\infty} \beta^i \left[\left(\frac{C_{\mathrm{NR},t}}{1-\sigma_c} \right)^{1-\sigma_c} - \hat{\zeta}_t^n \frac{\left(N_{\mathrm{NR},t}\right)^{1+\vartheta_l}}{1+\vartheta_l} \right] \tag{7.21}$$

Subject to the budget constraints

$$P_t C_{\mathrm{NR},t} = W_t N_{\mathrm{NR},t} - P_h T_{\mathrm{NR},t} \tag{7.22}$$

where $T_{\mathrm{NR},t}$ denotes the lump-sum taxes (net of transfers) paid by non-Ricardian consumers.

The FOC of the maximization problem of non-Ricardian households yields the following functions:

$$\frac{\partial L_{NR}}{\partial C_{NR,t}}: \quad {C_{NR,t}}^{-\sigma_c} - \wedge_{NR,t} P_t = 0 \tag{7.23}$$

$$\frac{\partial L_R}{\partial N_{\mathrm{R},t}}: \quad -\beta \hat{\zeta}_t^n N_{\mathrm{NR},t}^{\vartheta_l} + \beta \wedge_{NR,t} w_t = 0; \tag{7.24}$$

$$\frac{\partial L_R}{\partial \wedge_{NR,t}}: P_t C_{NR,t} - W_t N_{NR,t} + P_h \mathrm{T}_{NR,t} = 0 \tag{7.25}$$

From equation (7.10), we have the non-Ricardian Lagrange multiplier as

$$P_t \wedge_{R,t} = {C_{NR,t}}^{-\sigma_c} \tag{7.26}$$

Given equations (7.26) and (7.24), we derive an expression that equates real wage to marginal rate of substation between consumption and leisure as;

$$\frac{W_t}{P_t} = N_{\mathrm{NR},t}^{\vartheta_l} {C_{NR,t}}^{\sigma_c} \zeta_t^n \tag{7.27}$$

Similar log-linearization of equations (7.26), (7.25) and (7.27) around a steady state levels yields the respective expressions:

$$\widehat{\wedge}_{NR,t} = -\sigma_c \hat{c}_{NR,t} - \hat{p}_t \tag{7.28}$$

$$\hat{p}_t + \hat{c}_{NR,t} = \widehat{w}_t + \hat{n}_{NR,t} - (\hat{p}_h + \hat{t}_{NR,t}) \tag{7.29}$$

$$\widehat{w}_t - \hat{p}_t = \vartheta_l \hat{n}_{NR,t} + \sigma_c \hat{c}_{NR,t} + \hat{\zeta}_t^n \tag{7.30}$$

Equation (7.29) represents non-Ricardian household's consumption function which indicates that their consumption depends solely on real disposable income in each period. Equation (7.30) also indicates that the non-Ricardian households equally equate the marginal cost of working, in consumption units, with their marginal benefit, the real wage.

7.2.2.3 **Aggregation**

The aggregate level in per-capita terms of any household-specific variable $X_{h,t}$ is given by $X_t = \int_0^1 X_{h,t}dh = (1-\psi)X_{R,t} + \psi X_{NR,t}$ as households in each of the two groups are identical. Consequently, aggregate consumption is expressed (in a log deviation terms) as

$$\hat{c}_t = (1-\psi)\hat{c}_{R,t} + \psi\hat{c}_{NR,t} \tag{7.31}$$

Both categories of households consume same domestic produced ($\hat{c}_{\mathrm{H},t}$) and imported ($\hat{c}_{\mathrm{F},t}$) goods. The bundle of goods consumed by respective households is expressed in log terms as $\hat{c}_{R,t} = (1-\Omega)\hat{c}_{\mathrm{H},t} + \Omega\hat{c}_{\mathrm{F},t}$ and $\hat{c}_{NR,t} = (1-\Omega)\hat{c}_{\mathrm{H},t} + \Omega\hat{c}_{\mathrm{F},t}$. By assuming symmetry across good j, the corresponding optimal allocation of expenditure on domestic goods ($\hat{c}_{\mathrm{H},t}$) and foreign/imported goods ($\hat{c}_{\mathrm{F},t}$) based on the demand function are given by $\hat{c}_{\mathrm{H},t} = (1-\Omega)(-\eta(\hat{p}_{H,t} - \hat{p}_t) + \hat{c}_t)$ and $\hat{c}_{\mathrm{F},t} = \Omega(-\eta(\hat{p}_{F,t} - \hat{p}_t) + \hat{c}_t)$ respectively. The variable $\hat{p}_t$ is log deviation of aggregate price index (CPI) from the steady state for the home economy and is defined as:

$$\hat{p}_t = (1-\Omega)\hat{p}_{h,t} + \Omega\hat{p}_{F,t} \tag{7.32}$$

Aggregate labour supply ($\hat{n}_t$), capital stock ($\hat{k}_{\mathrm{R},t}$), private investment ($\hat{\imath}_{\mathrm{R},t}$), distributed profit to households ($\hat{\Pi}_{\mathrm{R},t}$) and bond holdings ($\hat{b}_{\mathrm{R},t}$) are respectively expressed (in log deviation from steady state) as;

$$\hat{n}_t = (1-\psi)\hat{n}_{R,t} + \psi\hat{n}_{NR,t} \tag{7.33}$$

with the labour market equilibrium been characterized by $\hat{n}_t = \hat{n}_{R,t} = \hat{n}_{NR,t}$

$$\hat{k}_{\mathrm{R},t} = (1-\psi)\hat{k}_{R,t} \tag{7.34}$$

$$\hat{\imath}_{\mathrm{R},t} = (1-\psi)\hat{\imath}_{R,t} \tag{7.35}$$

$$\hat{\Pi}_{\mathrm{R},t} = (1-\psi)\hat{\Pi}_{R,t} \tag{7.36}$$

and

$$\hat{b}_{\mathrm{R},t} = (1-\psi)\hat{b}_{R,t} \tag{7.37}$$

Finally, aggregate lump-sum taxes (net of transfers) are given by $\hat{t}_t = (1-\psi)\hat{t}_{R,t} + \psi\hat{t}_{NR,t}$.

7.2.2.4 **Staggered Nominal Wage Determination**

Similar to RANK model in the preceding chapter, each household supplies only one type of labour, indexed $j \in [0,1]$, in a monopolistic competitive market and therefore acts as price-setters in the labour market. This labour service is sold to a representative firm that aggregates these different types of labour ($N_{H,j}$) into a single labour input (N_t). All households face the same wage rigidity in the labour market. First, we assume that the wage is rigid and is based on Calvo (1983) staggered pricing

mechanism. In line with Calvo (1983) staggered pricing mechanism, a fraction of households with $(1-\theta_w)$ probability is randomly chosen to reset their wage each period. Households choose the optimal wage in each period because they have identical optimization problem. Households that are unable to reset wages, with probability of θ_w, maintain the wage level as in the previous period. Following the same approach in Appendix 6Ai3 of the preceding chapter, the log-linearized gross wage inflation equations for Ricardian and non-Ricardian households are derived respectively as:

$$\hat{\pi}_t^w = \beta E_t \hat{\pi}_{t+1}^w + \varpi\left\{-\left(\hat{w}_t - \hat{p}_t\right) + \vartheta_l \hat{n}_{R,t} + \alpha\left[\hat{c}_{R,t} - h\hat{c}_{R,t-1}\right] - \hat{\zeta}_t^c + \zeta_t^n\right\} + \zeta_t^w \quad (7.37)$$

and

$$\hat{\pi}_t^w = \beta E_t \hat{\pi}_{t+1}^w + \varpi\left\{-\left(\hat{w}_t - \hat{p}_t\right) + \vartheta_l \hat{n}_{NR,t} + \sigma_c\, \hat{c}_{NR,t} + \zeta_t^n\right\} + \zeta_t^w \quad (7.38)$$

where $\varpi = \frac{(1-\vartheta_w)(1-\beta\vartheta_w)}{\vartheta_w}$. Given equations (7.37) and (7.38), the gross wage inflation equation can further be written as:

$$\hat{\pi}_t^w = \beta E_t \hat{\pi}_{t+1}^w + \varpi\left\{-(\hat{w}_t - \hat{p}_t) + (1-\psi)\widehat{mrs}_{R,t} + \psi\widehat{mrs}_{NR,t} + \zeta_t^n\right\} + \hat{\zeta}_t^w \quad (7.39)$$

where $\widehat{mrs}_{R,t} = \vartheta_l \hat{n}_{R,t} + \alpha\left[\hat{c}_{R,t} - h\hat{c}_{R,t-1}\right] - \hat{\zeta}_t^c$; $\widehat{mrs}_{NR,t} = \vartheta_l \hat{n}_{NR,t} + \sigma_c \hat{c}_{NR,t}$; $\alpha = \frac{\sigma_c}{(1-h)}$; $\varpi = \frac{(1-\vartheta_w)(1-\beta\vartheta_w)}{\vartheta_w}$; $\hat{\pi}_t^w = \hat{w}_t - \hat{w}_{t-1}$; $\hat{\zeta}_t^w$ is the shock to the wage mark-up and is an IID-normal around a constant.

7.2.3 **Government**

Akin to the preceding chapter, the monetary authority set the short term interest rate, R_t following this augmented Taylor rule:

$$\hat{r}_t = \alpha_R \hat{r}_{t-1} + (1-\alpha_R)\left[\alpha_\pi \hat{\pi}_{t+1} + \alpha_y \hat{y}_t\right] + \mu_t^{fl} \quad (7.40)$$

with $\alpha_R, \alpha_y, \alpha_\pi \in [0,1]$ and α_R is the smoothing parameter or interest rate persistent; α_π, and α_y measure the sensitivity of short-term nominal interest rate to one-period-ahead inflation deviation from target or steady state ($\hat{\pi}_{t+1}$), and current output deviation from its steady state value ($\hat{y}_t$) respectively; and $\mu_t^{(.)}$ is monetary policy shock which exhibits an AR(1) process.

Likewise, the fiscal authority also faces the same budget constraint and fiscal rule as in equations (7.51) and (7.52) respectively in the previous chapter while public consumption expenditure $\hat{g}_t$ similarly evolves exogenously according to an AR(1) process.

7.2.4 **Foreign Economy and Risk Sharing**

The Euro Area is chosen as a representative foreign economy due to its sizeable share of Ghana's external trade (see, Akosah et al., 2018). Although the foreign economy has similar structure to the domestic economy, the latter economy is very small relative to the former economy. Consequently, we treat the foreign economy as exogenous to developments in the home economy. The foreign consumer price inflation ($\hat{\pi}^*$), nominal interest rate ($\hat{r}^*$) and output ($\hat{y}^*$), all as log-deviation from steady state, are given exogenously as AR(1) processes.

Foreign demand for export of consumption and investment goods from the domestic country, as log-deviation from steady state, is given by;

$$\hat{t}_t^x = -\eta(\hat{p}_{h,t} - [\hat{e}_t + \hat{p}_t^*]) + \hat{y}_t^* = \eta\hat{x}_t + \hat{y}_t^* \tag{7.41}$$

We assume that the elasticity of substitution between foreign goods and goods exported from domestic country, $\eta \in [0,1]$, is the same for consumption and investment. We do not decide how much of domestic export is used for consumption and investment in the foreign country. $\hat{e}_t$ denotes nominal exchange rate, $\hat{p}_{h,t} - \hat{e}_t$ is then the price of exported good denominated in the foreign currency. $\hat{p}_t^*$ denotes the price level in the foreign country. Conversely, domestic households also consume imported goods from the foreign economy and demand for imports is derived (in log terms) as:

$$\hat{t}_t^{IM} = -\eta(\hat{p}_{F,t} - \hat{p}_t) + \hat{c}_t = -\eta([\hat{e}_t + \hat{p}_t^*] - \hat{p}_t) + \hat{c}_t = -\eta\widehat{rer}_t + \hat{c}_t \tag{7.42}$$

where $\hat{p}_{F,t} = \hat{e}_t + \hat{p}_t^*$ is the price of foreign good denominated in the domestic currency.

Assuming the law of one price (LOOP), the price of domestic goods is expressed as

$$\hat{p}_{H,t} = \hat{p}_{F,t} = \hat{e}_t + \hat{p}_t^* \tag{7.43}$$

where ε_t is the nominal bilateral exchange rate between the home and foreign economy, in terms of the home currency. The terms of trade *(X)* is defined as the price of foreign goods ($P_{F,t}$) in terms of domestic goods ($P_{H,t}$) and is expressed in log terms as:

$$\hat{x}_t = e_t + \hat{p}_t^* - \hat{p}_{H,t} \tag{7.44}$$

Combining (7.43) and (7.44), we obtain an expression that links real exchange rate (expressed in terms of the domestic currency) to terms of trade and relative domestic price to CPI as:

$$\widehat{rer}_t = (1 - \Omega)\hat{x}_t \tag{7.45}$$

Assuming complete international financial market and identical utility functions for foreign and domestic optimizing households, we obtain uncovered interest rate parity (UIP), in log terms, as:

$$\hat{r}_t - \hat{r}_t^* = E_t\Delta\hat{e}_{t+1} + \hat{u}_t^{uip} \tag{7.46}$$

where $\hat{u}_t^{uip}$ denotes unfavorable exchange rate risk premium shock.

In line with Gali (2015), the overall (consumer) inflation is linked to domestic inflation and terms of trade as

$$\hat{\pi}_t = \hat{\pi}_{H,t} + \Omega\Delta\hat{x}_t \tag{7.47}$$

where $\hat{\pi}_t = \hat{p}_t - \hat{p}_{t-1}$ and $\hat{\pi}_{H,t} = \hat{p}_{H,t} - \hat{p}_{H,t-1}$.

7.2.5 **Equilibrium Condition**

All goods produced by firms are consumed by households. Final home goods are partly exported (T_t^x) and partly consumed by domestic households. On the other hand, portion of consumption goods in the home economy is imported from the foreign economy. As a result, the goods market clearing condition for the home economy requires that domestic output equals aggregate (private) consumption (C_t), private investment (I_t), public expenditure (G_t) and net export ($\mathrm{T}_t^x - \mathrm{T}_t^{IM}$). The market clearing condition is expressed in log deviation from the steady state as

$$Y_{ss}\hat{y}_t = C_{ss}\hat{c}_t + I_{ss}\hat{\imath}_t + G_{ss}\hat{g}_t + \mathrm{T}_{ss}^x\,\hat{\mathrm{t}}_t^x - \mathrm{T}_{ss}^{IM}\hat{\mathrm{t}}_t^{IM} \tag{7.48}$$

where subscript "ss" denotes a steady state level of a variable in question. Further substituting of equations (7.41) and (6.42) results in a log-linearized expression for equilibrium condition in the home economy as;

$$\hat{y}_t = (\phi_C - \Omega\phi_{IM})\hat{c}_t + \phi_i\hat{\imath}_t + \phi_{IM}\eta\widehat{rer}_t + \phi_x(\eta\hat{x}_t + \hat{y}_t^*) + \phi_g\hat{g}_t \tag{7.49}$$

where $\phi_C = \frac{C_{ss}}{Y_{ss}}$; $\phi_i = \frac{I_{ss}}{Y_{ss}}$; $\phi_x = \frac{T_{ss}^x}{Y_{ss}}$; $\phi_{IM} = \frac{IM_{ss}}{Y_{ss}}$ and $\phi_g = \frac{G_{ss}}{Y_{ss}}$.

7.3 **Empirical Strategy and Data**

This chapter applies the same Bayesian estimation strategy as in the preceding chapter. Likewise, we employ the same dataset as in the preceding chapter comprising domestic real GDP (Y), private consumption (C), government consumption spending (G), private investment (I), consumer inflation (π) and nominal interest rate (R). Thus, the Bayesian estimates of the NK-DSGE model parameters are conditional on the information set:

$$\hat{z}_t = [\hat{y}_t, \hat{c}_t, \hat{g}_t, \hat{\imath}_t, \hat{\pi}_t, \hat{r}_t,] \tag{6.50}$$

The hat (^) above a variable denotes its log deviation from steady state. As standard in the Bayesian estimation techniques, sample period 2000Q1-2007Q2 is utilized as training data while the period 2007Q3-2017Q4 is used for the out-of-sample analysis with the latter coinciding with the fully-fledged IT regime.

7.4 Empirical Results and discussions

7.4.1 **Determining non-Ricardian share**

Campbell and Mankiw (1989) estimate the share of rule-of-thumb (ROT) consumer using a simple Euler equation that relates change in log consumption (Δc_t) to only changes in log disposable income (Δy_t), as follows: $\Delta c_t = \mu + \psi \Delta y_t + e_t$, where ψ denotes the share of ROT. Some authors (notably, Basu and Kimball, 2002; Gali et al., 2007) argued that CM's Euler equation is overly simplified and is derived from the utility function that overlooks intertemporal or intratemporal non-separability[99] of consumption and labour. Consequently, such studies argued that the CM estimates are likely to suffer from omitted variable bias. Therefore, several studies have included additional important variables by estimation an augmented Euler equation as follows; $\Delta c_{t+1} = \mu + \psi \Delta y_{t+1} + \sum_{i=1}^{k} \varsigma_i X_i + e_{t+1}$, where Δc_{t+1} is expected change in log consumption, Δy_{t+1} is expected changes in log disposable income, X_i's are other variables included in the regression (such as habit persistence, real asset returns, labour hours work) and ς_i's are the slope coefficients.

Weber (2000) also assessed the importance of rule-of-thumb using various non-separable utility functions that also include habit persistence a variable in X. Utilizing GMM techniques, Weber (2000) deduces that the inclusion of habit formation in consumption generates statistically insignificant estimates of the share of rule-of-thumb households. Intuitively, the rationale for the consumption habit persistence is that households get accustom to a particular level of consumption and are more reluctant to reduce it. Nevertheless, Fuhrer (2000) emphasizes that households' utility function should still account for both habit persistence and Rule-of-Thumb behaviour as these two properties produce diverse effects. On one hand, Ricardian households with consumption habit formation tend to react slowly and try to even out change in their consumption. On the other hand, the rule-of-thumb households react instantaneously (and adjust one-for-one) to variations in their current disposable income. Using GMM estimation technique to test the relevance of both habit persistence and rule-of-thumb behaviour in consumption utility function, Fuhrer (2000) asserts that both properties are statistically significant and the share of the rule-of-thumb households was estimated to range from 0.26 to 0.29.

Following Campbell and Mankiw (1989), we estimate the share of rule-of-thumb household's consumption on aggregate consumption based on the theoretical Euler equation since we have only

[99] Intratemporal non-separable utility function allows the consumer to decide about the level of consumption while considering also the level of labour and vice versa. Intertemporal non-separable utility function is where the current level of utility is negatively affected by the previous level of consumption.

macroeconomic data available. The log-linearised theoretical Euler equation for Ricardian households from the optimizing problem can be simply written as;

$$E_t\Delta c_{t+1} = h\Delta c_t + \omega\{E_t r_{t+1} - E_t\pi_{t+1}\} + \omega\rho \quad (7.51)$$

where $\omega = \frac{1-h}{\sigma_c}$; $\rho = log\beta$; $c_t = logC_t$; $r_{t+1} \approx \log(1 + r_{t+1})$ and $\pi_{t+1} \approx \log(1 + \pi_{t+1})$.

It is implied that a fraction ψ of the overall income (y) originated from the non-Ricardian households as they consume all their income. As a consequent, we derive aggregate consumption by augmenting the theoretical consumption Euler equation in (7.51) to allow for the coexistence of both habit persistence and hand-to-mouth behaviour. Thus, the aggregate consumption formula in this thesis is given by:

$$E_t\Delta c_{t+1} = (1-\psi)[h\Delta c_t + \omega\rho + \omega\{E_t r_{t+1} - E_t\pi_{t+1}\}] + \psi E_t\Delta y_{t+1} \quad (7.52)$$

Equation (7.52) permits us to discriminate between these two different sources of consumption predictability (Palas, 2017). We substitute the expected values with ex-ante value and thus assume a perfect foresight as in line DSGE framework (as in Palas, 2017). Since changes in income and consumption tend to affect each other instantaneously, it is highly probable that the variable describing change in income (Δy_{t+1}) is endogenous. To avert potential endogeneity problem, proper sets of instruments are therefore warranted while the model has to be estimated through two stage least square (TSLS or 2SLS) method, particularly the Generalized Methods of Moments (GMM) estimation technique[100]. Also, to avoid the problem of serial correlation and to achieve exogeneity, we glean from the empirical literature to utilize variables that are lagged at least ones as instrument set within our GMM estimation.

The goal is to estimate equation (7.52) with a prime focus on the parameter ψ. There is a contrary evidence of permanent income hypothesis if the estimate for parameter ψ is economically and statistically significant. In that case, we can conclude that a segment of consumers do not intertemporally optimize consumption. It is imperative to note that we cannot interpret the parameter as the precise share of non-Ricardian household since we use aggregate macro data and also employ a log-linear approximation of the Euler equation. Notwithstanding, the estimate of ψ is a good guess for the share of non-Ricardian households and it is still essential parameter for the theoretical Euler equation and for the calibration of our DSGE model.

[100] Havranek and Sokolova (2016) provide a survey of the econometric techniques (including GMM) used in the estimation of the share of rule of thumb consumers based on either a first-order or second-order approximation model. Out of the 2788 estimates of excess sensitivity that they collected, 885 are computed using micro data and 1903 are computed using macro data. The overall mean of all the estimates is 0.4. They also found that various studies had used GMM (25% of the estimates), TSLS (45% cases), OLS (17% cases), maximum likelihood (10%) and switching regression methods.

Table 7.1 reports the GMM estimates for the share of non-optimizing households using eight different sets of instrumental variables (described at the bottom of the table). A striking finding from the table is that the parameter for the non-optimizing consumers, ψ, is statistically significant at 5% for the instrument set except for model VII. Nevertheless, the t-statistic for ψ in model VII is greater than one which surmises that the parameter is still important in the model. The estimates of the coefficients (h, ω) are significant and correctly signed except for ω in model VII which is insignificant. From the table, estimates for the share of non-Ricardian consumers range from 0.339 to 0.425, with a mean of 0.4 which is consistent with the prior value used by Dagher et al (2010, 2012).

Table 7.1: Estimated Coefficient using 2SLS Model

$$E_t\Delta c_{t+1} = (1-\psi)[h\Delta c_t + \omega log\beta + \omega\{E_t r_{t+1} - E_t\pi_{t+1}\}] + \psi E_t\Delta y_{t+1}$$

Coefficient	(I)	(II)	(III)	(IV)	(V)	(VI)	(VII)
h	0.705	0.698	0.707	0.725	0.724	0.730	0.350
	[14.76]*	[14.36]*	[15.26]*	[17.92]*	[18.51]*	[19.47]*	[4.81]*
ω	0.121	0.175	0.172	0.157	0.150	0.147	0.027
	[2.37]**	[3.17]*	[3.53]**	[3.94]*	[3.68]*	[3.73]*	[0.47]
ψ	**0.369**	**0.407**	**0.425**	**0.384**	**0.419**	**0.402**	**0.339**
	[2.10]**	[2.01]**	[2.34]**	[2.28]**	[2.26]**	[2.28]**	[1.13]
	Model Diagnostics						
Adj. R-squared	0.548	0.549	0.546	0.551	0.545	0.548	0.230
Instrument rank	11	11	13	14	12	13	11
Over-identifying restriction test							
p-value	0.208	0.204	0.365	0.449	0.364	0.442	0.251
Cragg-Donald							
Statistic	**11.42**	**7.68**	**19.37**	**14.98**	**13.76**	**17.43**	**5.03**
Stock-Yogo TSLS Critical value							
5%	*16.8*	*16.8*	***19.12***	*19.4*	*17.35*	*19.12*	*18.3*
10%	***9.64***	*9.64*	*10.69*	***10.78***	***9.85***	***10.69***	*10.43*
20%	*5.83*	***5.83***	*6.23*	*6.22*	*5.87*	*6.23*	*6.22*
30%	*4.45*	*4.45*	*4.62*	*4.59*	*4.44*	*4.62*	***4.69***

Note: Estimated by GMM with data sample 2001Q1-2017q4. *, ** & *** denotes 1%, 5% & 10% respectively, while the values in square brackets are t-statistics. Model's standard errors & covariance are computed using HAC weighting matrix. Models I-VII used log changes in consumption (c) and output (y) as well as expected real interest rate, rr_{t+1}, (computed as expected nominal policy rate, rm_{t+1}, minus expected inflation, π_{t+1}), while Model VIII utilized log deviation of the variables from their respective steady state values (indicated by ^ on a variable). Instrument sets for the models are

(I): $\Delta c_{t-1}, \Delta c_{t-2}, \Delta c_{t-3}, \Delta c_{t-4}, \Delta c_{t-5}, rr_t, rr_{t-1}, rr_{t-2}, rr_{t-3}$ and Δy_{t+2}.

(II): $\Delta c_{t-1}, \Delta c_{t-2}, \Delta c_{t-3}, \Delta c_{t-4}, rr_{t-1}, rr_{t-2}, rr_{t-3}\ rr_{t-4}, \Delta y_{t+2}$ and π_{t-1}.

(III): $\Delta c_t, \Delta c_{t-1}, \Delta c_{t-2}, \Delta c_{t-3}, \Delta c_{t-4}, rr_t, rr_{t-1}, rr_{t-2}, rr_{t-3,}\ rr_{t-4}, \Delta y_{t+2,}$ and π_t.

(IV): $\Delta c_t, \Delta c_{t-1}, \Delta c_{t-2}, \Delta c_{t-3}, \Delta c_{t-4}, rr_t, rr_{t-1}, rr_{t-2}, rr_{t-3}\ rr_{t-4}, \Delta y_{t+2}, \pi_t$ and π_{t-1}.

(V): $\Delta c_{t-1}, \Delta c_{t-2}, \Delta c_{t-3}, \Delta c_{t-4}, rr_t, rr_{t-1}, rr_{t-2}, rr_{t-3}, \Delta y_t, \Delta y_{t+2}$ and π_{t-1}.

(VI): $\Delta c_t, \Delta c_{t-1}, \Delta c_{t-2}, \Delta c_{t-3}, \Delta c_{t-4}, rr_t, rr_{t-1}, rr_{t-2}, rr_{t-3}\ \Delta y_t, \Delta y_{t+2}$ and π_{t-1}.

(VII): $\hat{c}_t$, $\hat{c}_{t-1}$, $\hat{c}_{t-2}$, $\hat{c}_{t-3}$, $\hat{c}_{t-4}$, $\hat{\pi}_t$, $\hat{\pi}_{t-1}$ $\hat{rr}_t$,$\hat{y}_t$ and $\hat{y}_{t-1}$.

As a standard approach, we also take into account potential violations in model assumptions. First, we evaluate the overidentifying restriction test (J-test). Analysis of the model diagnostics reveals that the overidentifying restriction assumption is satisfied as the p-values for J-test are all statistically insignificant. Second, since we used both contemporaneous and lagged variables in some cases, our instruments are likely to be weak. Inferences based on the IV estimates can be biased when we have weak instruments. For that reason, it is important to test for the presence of weak instruments. We thus assess the validity of the instruments using Cragg-Donald statistic (Cragg and Donald, 1993) and the corresponding Stock-Yugo TSLS critical values (Stock and Yugo, 2005). This test has null hypothesis that the instruments are weak. If the test statistic exceeds the critical value, then the null is rejected. From the table, we can only reject the null hypothesis in model III if we select a strict level of maximal bias relative of OLS of 5%. On the other hand, if we select level of maximal bias relative of OLS of 10%, we can also reject the hypothesis of weak instrument for instrument sets in models I, IV, V & VI but still cannot reject the null of weak instrument for models II & VII. However, the null of weak instruments can only be rejected for models II and VII if we select level of maximal bias relative of OLS of 20% and 30% respectively.

To some extent, our estimates provide adequate evidence against permanent income hypothesis and that there are non-Ricardian consumers in the Ghanaian economy. Although consistent with the developing economy's literature, this conclusion should however be made with caution as there is also evidence of serial autocorrelation of the expected error term driven by the inclusion of contemporaneous variables in the instrument sets. In cases when we exclude the contemporaneous variables or ignore Δy_{t+2} in the instrument sets or use relatively small instrument sets, we obtain even negative values or values higher than 0.8. Nonetheless, we still accentuate that the GMM estimates provide quite meaningful results on two fronts. First, the Cragg-Donald statistics exceed the corresponding critical values even at the strict level of the test (particularly model III), signifying that our instruments are conceivably not wholly incorrect. Second, our estimates are close to the range of estimates (0.29 to 0.4) obtained by Adam (2011) for Czech Republic while our prior mean of 0.4 is also consistent with the prior value often used in the literature (for instance Dagher et al., 2010, 2012).

Importantly, since we can only reject the hypothesis of weak instrument in model III of Table 7.1 if we select a strict level of maximal bias relative of OLS of 5% (in Table 7.1), we prefer to use a prior mean of 0.425 and a standard error of 0.25 for the share of non-Ricardian consumers (ψ). Yet, to obtain

the best model fit for Ghanaian macroeconomic dataset, we carry out sensitivity analysis that includes several alternative prior means for ψ such as 0.25, 0.3, 0.34, 0.4, 0.5, 0.55, 0.6 and 0.7.

Having obtained the prior mean for non-Ricardian consumers using standard two-stage least squares, we validate such estimate using general equilibrium model. As a result, Table 7.2 reports the prior distribution of the remaining parameters of our heterogeneous-agent's DSGE model for Ghana. The prior assumptions for the remaining parameters of the model broadly follow the extant empirical literature. All the variances of the shocks are assumed to have an inverted Gamma distribution with a degree of freedom equal to 2 in order to guarantee a positive variance. All the autoregressive parameters for the shocks have beta distribution with prior mean 0.8 and standard error of 0.15. The sets of parameters for technology, utility (or preference) and pricing settings are assumed to have either Normal or Beta distribution. The means of these parameters are set within a range of 0 and 1, as pertains in the extant literature.

In addition, as indicated in Table 3.5 and Table 3.6 (in Chapter Three), the steady-state private consumption output ratio (φ_c) is calibrated at 0.78 while steady-state government-consumption-output (φ_g), investment-output (φ_i), exports-output (φ_x), and imports-output (φ_m) ratios are estimated at 0.188, 0.166, 0.294 and 0.438 respectively. Capital-output ratio (φ_k) is also estimated at 2.92 (see Table 3.5), while the depreciation rate of capital, ϱ, is quantified as 0.056 per quarter based on the steady-state formula $\varrho = \varphi_i/\varphi_k$, yielding an equivalent annual depreciation on capital of 22%.

Table 7.2: Calibrated Parameters of the Baseline model

Parameter	Description	Prior Distribution			
		type	mean	std. error	Source/Method
σ_c	Inverse elast. of inter-temporal subst.	normal	2.00	0.38	Costa Jr. (2016); Dagher et al (2010)
σ_l	Marginal disutility of labour supply	normal	2.00	0.75	Bondzie et al., (2014); Dagher et al (2010); SW (2002)
η	Elast. of subs. btn home & foreign goods	normal	2.00	0.75	SW (2002); Gali et al. (2001); Costa Jr. (2016)
h	External consumption habit formation	beta	0.60	0.20	Guerron-Quintana & Nason (2012), and KT (2016)
λ_y	Elast. of Capital in production	normal	0.30	0.08	Dagher et al. (2012)
θ_w	Calvo wage parameter	beta	0.75	0.15	SW (2002); Gali et al. (2001); Costa Jr. (2016)
θ_h	Calvo price parameter	beta	0.75	0.15	SW (2002); Gali et al. (2001); Costa Jr. (2016)
α_π	Interest rate sensitivity to Inflation gap	normal	1.40	0.25	Standard value
α_y	Interest rate sensitivity to output gap	normal	0.13	0.35	Airaudo et al., (2016)
α_r	AR coeff. for Domestic Monetary Policy	beta	0.80	0.15	Standard value
Ω	Degree of openness	beta	0.72	0.025	Estimated based on total trade scaled by GDP
β	Discount Factor	beta	0.98	0.01	Estimated to obtain annual interest rate of 7.8%
ϱ	Depreciation rate of capital	normal	0.05	0.03	Estimated based on great ratios
v_u	Productivity Shock	invg	0.13	2.00	SW (2002)
v_g	Government Spending Shock	invg	0.14	2.00	SW (2002)
$v_{\pi h}$	Domestic Price Mark-up Shock	invg	0.02	2.00	SW (2002)
v_r	Domestic Interest Rate Shock	invg	0.13	2.00	SW (2002)
v_{tot}	Nominal Exchange Rate (UIP) Shock	invg	0.24	2.00	SW (2002)
$v_{\zeta w}$	Domestic Wage Mark-up Shock	invg	0.24	2.00	SW (2002)
$v_{\zeta c}$	Preference Shock	invg	0.26	2.00	SW (2002)
$v_{\zeta n}$	Labour Supply Shock	invg	1.00	2.00	SW (2002)

η_{r^*}	Foreign Interest rate Shock	invg	0.10	2.00	SW (2002)
η_{y^*}	Foreign output Shock	invg	0.20	2.00	SW (2002)
η_{π^*}	Foreign inflation Shock	invg	0.30	2.00	SW (2002)
ρ_u	AR coeff. for Productivity Shock	beta	0.80	0.15	SW (2002)
ρ_g	AR coeff. for Gov't Spending Shock	beta	0.80	0.15	SW (2002)
$\rho_{\pi h}$	AR coeff. for Domestic Mark-up Shock	beta	0.80	0.15	SW (2002)
$\rho_{\zeta c}$	AR coeff. for Preference Shock	beta	0.80	0.15	SW (2002)
$\rho_{\zeta n}$	AR coeff. for Labour Supply Shock	beta	0.80	0.15	SW (2002)

Note: SW denotes Smet & Wouters; KT is Kirchner & Tranamil; elast. and subst. denote elasticity and substitution respectively. AR coeff. represents autoregressive coefficient. Invg is inverted gamma

Table 7.3 reports the relative marginal likelihoods of forty (40) alternative HANK-DSGE models, compared to that of the preferred RANK-DSGE model in the preceding chapter. The alternative models are derived based on three main factors. First, we consider nine (9) different prior means for the share of rule-of-thumb households (i.e. $\psi = 0.25, 0.34, 0.4, 0.425, 0.45, 0.5, 0.55, 0.6, \text{and } 0.7$). Second, we impose either a forward-looking or contemporaneous monetary policy rules. And finally, we consider alternative distributions for some parameters whose prior means are difficult to pin down in the extant literature. In this latter case, we focus on the parameters for the Calvo price (θ_h) and wage (θ_w) as well as the elasticity of substitution between intermediate goods (γ_h) and between labour inputs (γ_w). More precisely, we assume either uniform or beta distribution for θ_h, θ_w, γ_h and γ_w. This assumption of a uniform distribution amounts to considering an uninformative prior, while the assumption of a beta distribution amounts to considering an informative prior. In this chapter, the model with the highest marginal likelihood (based on average value of the Geweke modified Harmonic mean and the Laplace transformation estimators) is adjudged the most appropriate for the Ghanaian macroeconomy.

Table 7.3: Model Comparison and Selection based on Marginal Likelihoods

DSGE	Prior Mean for ψ	Prior Distributions for $\theta_w, \theta_h, \gamma_w, \gamma_h$	Taylor Rule	Marginal Likelihood		
				Laplace	Hm	Average
Mod1	0.00	beta (θ_h, θ_w) & unif (γ_h, γ_w)	Forward-Looking	-633.0	-617.9	-625.5
Mod2	0.25	unif (θ_h, θ_w) & beta (γ_h, γ_w)	Forward-Looking	-530.9	-527.2	-529.1
Mod3	0.25	(θ_h, θ_h)=0 & beta (γ_h, γ_w)	Forward-Looking	-1189.3	-1081.6	-1135.5
Mod4	0.25	unif (θ_h, θ_w); beta (γ_h, γ_w) & $\alpha_y = 0$	Contemporaneous*	-532.5	-530.9	-531.5
Mod5	0.30	unif (θ_h, θ_w) & beta (γ_h, γ_w)	Forward-Looking	-539.0	-526.5	-532.8
Mod6	0.30	(θ_h, θ_h)=0 & beta (γ_h, γ_w)	Forward-Looking	-638.4	-636.9	-637.7
Mod7	0.30	unif (θ_h, θ_w); beta (γ_h, γ_w) & $\alpha_y = 0$	Contemporaneous*	-531.9	-530.0	-530.9
Mod8	0.34	unif (θ_h, θ_w) & beta (γ_h, γ_w)	Forward-Looking	-539.5	-536.1	-537.8
Mod9	0.34	beta (θ_h, θ_w) & unif (γ_h, γ_w)	Forward-Looking	-550.5	-542.4	-546.5
Mod10	0.34	unif (θ_h, θ_w) & beta (γ_h, γ_w)	Contemporaneous	-546.4	-544.2	-545.3
Mod11	0.34	beta (θ_h, θ_w) & unif (γ_h, γ_w)	Contemporaneous	-566.1	-538.2	-552.2
Mod12	0.34	unif (θ_h) & beta (γ_h, γ_w)	Forward-Looking	-549.9	-542.7	-546.3
Mod13	0.34	(θ_h, θ_h)=0 & beta (γ_h, γ_w)	Forward-Looking	-542.7	-536.2	-539.5
Mod14	0.34	unif (θ_h, θ_w) & beta (γ_h, γ_w)	Forward-Looking	-650.2	-639.3	-644.8
Mod15	0.34	unif (θ_h, θ_w); beta (γ_h, γ_w) & $\alpha_y = 0$	Contemporaneous*	-531.4	-527.8	-529.6
Mod16	0.40	unif (θ_h, θ_w) & beta (γ_h, γ_w)	Forward-Looking	-534.1	-525.0	-529.6
Mod17	0.40	beta (θ_h, θ_w) & unif (γ_h, γ_w)	Forward-Looking	-554.8	-543.5	-549.2
Mod18	0.40	unif (θ_h, θ_w) & beta (γ_h, γ_w)	Contemporaneous	-544.8	-529.8	-537.3

Mod19	0.40	beta (θ_h, θ_w) & unif (γ_h, γ_w)	Contemporaneous	-678.4	-561.9	-620.2
Mod20	0.40	unif (θ_h) & beta (γ_h, γ_w)	Forward-Looking	-549.6	-544.4	-547.0
Mod21	0.40	(θ_h, θ_h)=0 & beta (γ_h, γ_w)	Forward-Looking	-650.2	-639.3	-644.8
Mod22	0.40	unif (θ_h, θ_w); beta (γ_h, γ_w) & $\alpha_y = 0$	Contemporaneous*	-968.4	-861.6	-915.0
Mod23	**0.425**	***unif (θ_h, θ_w) & beta (γ_h, γ_w)***	***Forward-Looking***	*-492.4*	*-495.1*	***-493.8***
Mod24	0.425	unif (θ_h, θ_w) & beta (γ_h, γ_w)	Contemporaneous	-559.3	-527.7	-543.5
Mod25	0.425	beta(θ_h, θ_w) & beta (γ_h, γ_w)	Forward-Looking	-609.2	-556.2	-582.7
Mod26	0.425	beta (θ_h, θ_w) & unif (γ_h, γ_w)	Forward-Looking	-544.9	-539.0	-542.0
Mod27	0.425	unif (θ_h, θ_w) & unif (γ_h, γ_w)	Contemporaneous	-503.5	-645.8	-574.7
Mod28	0.425	unif (θ_h, θ_w) & unif (γ_h, γ_w)	Forward-Looking	-518.2	-499.5	-508.9
Mod29	0.425	unif (θ_h) & beta (γ_h, γ_w)	Forward-Looking	-539.1	-539.0	-539.1
Mod30	0.425	unif (θ_h, θ_w) & beta (γ_h, γ_w)	Forward-Looking	-650.2	-639.3	-644.8
Mod31	0.425	unif (θ_h, θ_w); beta (γ_h, γ_w) & $\alpha_y = 0$	Contemporaneous*	-517.4	-492.3	-504.9
Mod32	0.45	unif (θ_h, θ_w) & beta (γ_h, γ_w)	Forward-Looking	-539.2	-521.5	-530.4
Mod33	0.45	(θ_h, θ_h)=0 & beta (γ_h, γ_w)	Forward-Looking	-657.3	-647.9	-652.6
Mod34	0.50	unif (θ_h, θ_w) & beta (γ_h, γ_w)	Forward-Looking	-509.6	-490.5	-500.1
Mod35	0.50	(θ_h, θ_h)=0 & beta (γ_h, γ_w)	Forward-Looking	-684.7	-644.1	-664.4
Mod36	0.50	unif (θ_h, θ_w); beta (γ_h, γ_w) & $\alpha_y = 0$	Contemporaneous*	-569.4	-527.7	-548.6
Mod37	0.55	unif (θ_h, θ_w) & beta (γ_h, γ_w)	Forward-Looking	-583.0	-558.7	-570.9
Mod38	0.55	(θ_h, θ_h)=0 & beta (γ_h, γ_w)	Forward-Looking	-737.3	-659.2	-698.3
Mod39	0.60	unif (θ_h, θ_w) & beta (γ_h, γ_w)	Forward-Looking	-749.0	-607.8	-678.4
Mod40	0.60	(θ_h, θ_h)=0 & beta (γ_h, γ_w)	Forward-Looking	-653.9	-653.8	-653.9
Mod41	0.70	unif (θ_h, θ_w) & beta (γ_h, γ_w)	Forward-Looking	-590.2	-545.1	-567.7

Note: ψ denotes the share of hand-to-mouth or non-Ricardian households; θ_h and θ_w denote Calvo parameters for sticky price and wages respectively. γ_h is the elasticity of substitution between differentiated intermediate goods; γ_w represents the elasticity of substitution between differentiated labour; unif denotes uniform distribution, while beta is beta distribution; Model1 is RANK DSGE model; (θ_h, θ_h) = 0 implies HANK-DSGE models with flexible price and wage (perfect competition); while Mod12, 20 & 29 are HANK-DSGE models with sticky price and flexible wage. Each estimate is derived through 300,000 MH-MCMC draws with 5 parallel block chains. Hm is harmonic mean estimator; α_y implies interest rate sensitivity to changes in current output gap. Contemporaneous policy rule is whereby monetary authority responses to current inflation and output gaps. The superscript * indicates that central bank only cares about inflation stability and hence, does not respond to variations in output gap (i.e. $\alpha_y = 0$). That is, the. Forward-looking policy rule is whereby authority responds to one-period-ahead inflation deviation from target and current output deviation from gap.

It can be concluded from the table that the heterogeneous agents DSGE models (HANKs) generally outperform the models with representative agent (RANK). Another notable observation is that the HANK models with price and wage rigidities have a better fit for the Ghanaian macro-dataset than simple models with either flexible prices and wages or flexible wages alongside sticky prices. It is also conspicuous that the HANK model with forward-looking policy rule generates a higher marginal likelihood than the models with contemporaneous policy rule. Here, the forward-looking policy rule is the Taylor rule where the monetary policy authority reacts to one-period-ahead inflation deviation (from its steady state) along with the output gap. This supports the early empirical finding regarding the RANK models in the preceding chapter. Across the various shares of the rule-of-thumb households considered, we find that HANK model with (1) a forward-looking policy rule, (2) a uniform

distribution for Calvo parameters (θ_h & θ_w) and (3) beta distribution for γ_h and γ_w offers the overall best fit for the Ghanaian datasets.

Above all, the HANK model with the highest average marginal likelihood is **Mod23** with $\psi = 0.425$**.** This indicates that the most appropriate DSGE model for the Ghanaian dataset considered is the HANK model with nominal price and wage rigidities, a 42.5% share of rule-of-thumb households (in line with GMM estimates) and a forward-looking monetary policy rule. Our empirical findings therefore challenge the assumption of 40% share of rule-of-thumb households assumed for Ghana by other studies (notably, Dagher et al. 2010, 2012). Since our estimates reveal that assumption of 40% share of rule-of-thumb households tends to deteriorate the marginal likelihood, we can construe that studies with such assumption have the proclivity to generate less plausible estimates for policy inference.

7.4.2 **The posterior estimates of model parameters**

Table 7.4 presents sets of posterior estimates (mode and mean). Panel A of Table 7.4 provides the estimates based on preferred HANK model (i.e. Mod23)[101] that incorporates Calvo price and wage rigidities, 42.5% share of rule-of-thumb households, habit formation in Ricardian consumption and forward-looking monetary policy rule. The figures in Appendix 7Ai-ii display the graphical multivariate and univariate convergence diagnostics respectively for the preferred HANK model, derived through the Metropolis-Hastings algorithm based on 300000 draws with 5 parallel block chains. Both figures exhibit no serious convergence problems and the parameter convergence is more successful for the HANK model when compared to that of RANK model in the preceding chapter. The information in the Baseline HANK model is also graphically exhibited in Appendix 7Aiii. The figure plots the prior distribution, the posterior distribution and the probability curve for a normal distribution with mean as the posterior mode and the corresponding Hessian-based estimate as standard error. The plots indicate that there is a considerable amount of information contained in the datasets that can be utilized to update our prior beliefs about the model parameters. In addition, the posterior marginal densities are pictorially much more concentrated than the prior densities, except for four parameters whose posterior and the prior densities broadly coincide.

In line with the RANK model, the posterior values for all the shock parameters are fairly different from their prior values, signifying that the estimates draw important information from the data. On a whole, it appears that the data are quite informative about the stochastic processes for the exogenous

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disturbances as indicated by the lower variance of the posterior distribution relative to the prior distribution. The Baseline HANK model suggests that preference, monetary policy, labour supply and productivity shock processes are very persistent, while government spending shock has the least persistent parameter. For the behavioural parameters, it appears that the data are quite informative on the behavioural parameters, and this is reflected by the lower variance of the posterior distribution relative to the prior distribution with the exception of the Calvo parameters.

The external consumption habit stock, h, is estimated at 0.224 which is below the prior mean and the corresponding estimate for the RANK model (0.32). By implication, the Ricardian household's willingness to smooth consumption is found to lower in the HANK model than in the RANK model without non-Ricardian households. The posterior mean estimate of the intertemporal elasticity of substitution (σ_c) is lower than one and below the assumed prior mean. It is however larger than the corresponding estimate in the RANK model. Likewise, the HANK estimate for the inverse elasticity of substitution for labour, σ_l, is much greater than unity (2.757). It is higher than the prior mean but lower the corresponding level attained for the RANK model (σ_l =3.835). The elasticity of substitution between home and foreign goods (η) is estimated to be 0.533, below the prior mean and the corresponding estimate for the RANK model (0.85). The posterior mean estimate for the parameter characterizing the degree of openness, Ω, is 0.683 which is also lower than the assumed prior mean and the corresponding value in the RANK model (0.69). The estimated mean for Ω indicates that the Ghanaian economy is small but very open.

There is however a considerable degree of Calvo price and wage stickiness for the preferred HANK model relative to the RANK model. The average duration of wage contracts is estimated to about two quarters whereas the average duration of price contracts is much longer at approximately two years. Although the greater stickiness in price relative to wage appears to be somewhat counterintuitive, this is similar to the findings of Smets and Wouters (2002) for Euro Area. Notwithstanding, the greater price stickiness relative to wages turns out to be a very robust finding of the estimated model. As argued by Smets and Wouters (2002), the greater stickiness in price than in wage is partly attributable to the underlying specification of the process driving marginal cost. In essence, the assumption of constant return to scale implies that marginal cost curve is flat and same for all intermediate firms. Conversely, marginal disutility of labour implies that the individual households face an upward-sloping marginal cost of labour supply. For a given elasticity of prices to real marginal cost, these dynamics have a tendency to bias upward the estimate of Calvo price stickiness. The posterior mean

for the discount factor, β, is estimated at 0.98, somewhat comparable to the RANK model. This implies annual steady state real interest rate of 7.6%.

Particularly, the posterior mean for interest rate elasticity to inflation, α_π, is estimated as 1.73 with 95% credible range of (1.48 – 2.0). This illustrates that the value for α_π satisfies the so-called Taylor Principles as it is greater than one and close to values suggested by Taylor (1993). The posterior mean of the coefficient of the lagged interest rate, α_r, is estimated to be 0.78, suggesting high degree of interest rate smoothing. Also, the response to output gap, α_y, is estimated to be 0.586, higher than the prior distribution and exceeds the upper limit of the empirical range for less developed countries (0.1 and 0.5).

From the table, the posterior mean for the share of rule-of-thumb (or non-Ricardian) consumers is estimated to be 0.464 with a 95% confidence interval of [0.429 0.501]. The estimate is higher than the prior mean of 0.425 and indicated that approximately 46.4% of the households in Ghana are saddled with some forms of financial constraints and hence rely solely on their labour income. Our estimate for the share of rule-of-thumb household is larger than the 0.4 value assumed in the empirical literature (including Dagher et al., 2010, 2012) for Ghana. Our sensitivity analysis reveals that this estimate is robust and hence any studies that assume values outside the estimated range of 0.429 and 0.501 are inclined to yield sub-optimal values for economic inference.

Table 7.4: Prior and Estimated Posterior Distributions for HANK model

	Est. Max. Posterior		Posterior Distr. MH		
	mode	std. error	Mean	5%	95%
v_u	0.378	0.035	0.389	0.291	0.486
v_g	3.965	0.066	3.917	3.760	4.000
$v_{\pi h}$	0.085	0.275	0.094	0.050	0.144
v_r	0.304	0.039	0.302	0.226	0.383
v_{tot}	0.092	0.358	0.150	0.048	0.306
$v_{\zeta w}$	0.115	0.081	0.210	0.100	0.452
$v_{\zeta c}$	3.626	0.350	3.740	3.352	4.000
$v_{\zeta n}$	0.364	0.169	0.465	0.260	0.718
η_{r^*}	0.202	0.022	0.199	0.160	0.242
η_{y^*}	0.242	0.024	0.237	0.190	0.289
η_{π^*}	0.415	0.041	0.454	0.363	0.552
ρ_u	0.866	0.087	0.891	0.748	1.000
ρ_g	0.476	0.112	0.483	0.323	0.648
$\rho_{\pi h}$	0.738	0.067	0.762	0.678	0.844
$\rho_{\zeta c}$	0.990	0.015	0.986	0.978	0.990

$\rho_{\zeta n}$	0.789	0.075	0.832	0.693	0.985
ρ_{vr}	0.937	0.034	0.934	0.883	0.986
σ_c	0.957	0.087	0.943	0.902	0.981
σ_l	2.647	0.453	2.757	1.884	3.684
η	0.500	0.250	0.533	0.500	0.597
h	0.215	0.030	0.224	0.189	0.258
λ_y	0.300	0.001	0.300	0.298	0.302
θ_w	0.488	0.057	0.508	0.382	0.639
θ_h	0.874	0.067	0.870	0.831	0.905
α_π	1.853	0.181	1.743	1.481	2.000
α_y	0.535	0.207	0.586	0.275	0.918
α_r	0.558	0.060	0.551	0.500	0.596
Ω	0.670	0.024	0.683	0.643	0.726
γ_w	0.679	0.041	0.743	0.634	0.840
γ_h	0.712	0.038	0.758	0.673	0.852
β	0.990	0.006	0.976	0.961	0.990
ϱ	0.048	0.008	0.058	0.042	0.075
ψ	0.463	0.016	0.464	0.429	0.501
Marginal likelihood (Laplace)				-492.4	
Marginal likelihood (Harmonic mean)				-495.1	
CARPC	0.26	0.27	0.27	0.26	0.27

Note: CARPC denotes current acceptance rate per chain

7.4.3 Relevant structural shocks to Ghana's Business Cycles

In Table 7.5, we report results of the relative contribution of each of the structural shocks to the forecast error variance of the key endogenous variables for the baseline model. The time horizon considered are short run for period t= 4 quarters (i.e. 1 year); medium run for period t=12 quarters (i.e. 3 years) and long run for period t=100 quarters (i.e. 25 years).

It is conspicuous of the table that the dominant drivers of output across the forecast horizon (i.e. short-medium-long run) in sequential terms are productivity shock price mark-up shock, preference shock, domestic monetary policy shock and foreign inflation shock. This implies that domestic monetary policy still important for economic growth in the short-to-long time horizons, even though the impact is rather modest compared to the RANK model. The somewhat moderate influence of domestic monetary policy on output is conceivable as the former tends to impact only fraction of households in the HANK model. The contribution of productivity shock to output is via marginal cost, while that of domestic monetary policy shock is via Ricardian consumption, nominal interest rate and inflation.

In the case of consumer inflation, the main determinants are price mark-up shock, domestic monetary policy shock, preference shock and foreign inflation shock across the forecast horizons. Price mark-up shock is a leader for consumer inflation with average shares of 54% in short-to-long run horizons,

while domestic monetary policy shock has a leading contribution (72%) to variations in domestic inflation. The dominant determinants of nominal interest rate in the forecast horizon are price mark-up shocks and domestic monetary policy, with some support from productivity shock, preference shock, labour supply shock and foreign CPI shock. The share of price mark-up shocks leads the variations in nominal interest rate in the short-to-medium run, while domestic monetary policy shock emerges as the lead contributor to variation in nominal interest rate in the long run.

Table 7.5: VD of Baseline HANK-DSGE Model with Calvo Price and Wage Rigidities

	Prod. Shock	Price Mark-up Shock	Gov't Shock	Pref. Shock	Labour Supply Shock	Wage Mark-up Shock	UIP Shock	Dom. Policy Shock	Foreign Output Shock	Foreign CPI Shock	Foreign Policy Shock
	Period	***t≤4***									
Output	40.00	24.56	0.57	17.13	4.49	1.23	0.00	3.05	0.23	6.36	2.38
Consumption	3.33	8.73	13.99	45.94	17.53	1.32	0.03	5.21	0.08	3.10	0.75
Ricardian	6.09	15.75	24.00	6.87	28.61	2.12	0.04	9.66	0.14	5.42	1.31
Non-Ricardian	1.10	3.01	4.89	81.19	6.28	0.48	0.01	1.65	0.03	1.09	0.26
Consumer Inflation	0.32	59.93	1.89	2.42	5.11	0.46	1.17	18.74	0.09	8.65	1.23
Domestic inflation	2.98	19.38	1.61	1.35	0.77	0.04	0.00	63.51	0.06	6.57	3.73
Nominal Wage	8.82	20.48	0.50	44.13	13.14	1.22	0.00	4.57	0.20	4.94	2.00
Marginal Cost	24.70	16.91	0.41	36.53	10.78	1.02	0.00	3.78	0.16	4.07	1.64
Nominal Int. Rate	4.99	56.18	0.93	1.34	8.27	1.24	0.01	20.63	0.03	5.81	0.56
	10.26	**24.99**	**5.42**	**26.32**	**10.55**	**1.01**	**0.14**	**14.53**	**0.11**	**5.11**	**1.54**
	Period	***t≤12***									
Output	30.11	23.96	0.42	26.35	3.63	0.67	0.00	6.35	0.26	5.70	2.56
Consumption	1.66	4.32	6.66	71.34	8.33	0.63	0.01	5.05	0.04	1.55	0.40
Ricardian	5.77	14.11	21.35	6.61	25.54	1.90	0.04	18.37	0.13	4.94	1.25
Non-Ricardian	0.44	1.22	1.91	92.00	2.44	0.19	0.00	1.23	0.01	0.45	0.12
Consumer Inflation	0.71	55.67	1.55	6.33	4.40	0.40	0.90	21.63	0.07	7.30	1.02
Domestic inflation	3.32	11.76	0.94	2.25	0.52	0.03	0.00	73.92	0.05	4.38	2.83
Nominal Wage	9.55	13.65	0.20	59.44	6.16	0.30	0.00	6.13	0.15	2.95	1.47
Marginal Cost	19.12	12.18	0.18	53.23	5.48	0.27	0.00	5.48	0.13	2.63	1.31
Nominal Int. Rate	4.01	43.85	0.81	2.68	5.73	0.88	0.01	37.55	0.05	3.88	0.56
	8.30	**20.08**	**3.78**	**35.58**	**6.91**	**0.59**	**0.11**	**19.52**	**0.10**	**3.75**	**1.28**
	Period	***t≤100***									
Output	22.87	13.84	0.24	49.93	2.50	0.38	0.00	5.38	0.15	3.22	1.48
Consumption	0.65	1.61	2.43	88.64	3.05	0.23	0.01	2.65	0.01	0.58	0.15
Ricardian	5.65	12.73	19.33	8.28	23.18	1.73	0.04	23.35	0.12	4.46	1.13
Non-Ricardian	0.15	0.40	0.61	97.27	0.78	0.06	0.00	0.55	0.00	0.14	0.04
Consumer Inflation	1.65	46.86	1.31	14.52	3.75	0.34	0.76	23.78	0.06	6.10	0.86
Domestic inflation	4.04	8.91	0.72	6.49	0.46	0.02	0.00	73.81	0.04	3.34	2.18
Nominal Wage	6.00	4.35	0.06	82.41	2.23	0.09	0.00	3.41	0.05	0.92	0.49
Marginal Cost	11.34	4.07	0.06	77.79	2.09	0.08	0.00	3.20	0.05	0.87	0.46
Nominal Int. Rate	3.81	36.59	0.68	3.99	4.88	0.75	0.01	45.46	0.05	3.23	0.55
	6.24	**14.37**	**2.83**	**47.70**	**4.77**	**0.41**	**0.09**	**20.18**	**0.06**	**2.54**	**0.82**
OAC	**8.11**	**19.25**	**3.84**	**37.38**	**7.05**	**0.63**	**0.11**	**18.71**	**0.09**	**3.65**	**1.18**

The baseline variance decomposition analysis broadly accentuates the significant weights of both fiscal and monetary policy shocks on the Ghanaian macro-dynamics. We further carried out sensitivity

analysis to ascertain whether similar conclusion can be reached for alternative HANK-DSGE frameworks without Calvo price and wage rigidities. Thus, we first seek to determine whether the relative contributions of shock change dramatically in Alternative Scenario I where both prices and wages are fully flexible. This amounts to considering a perfectly competitive HANK-DSGE model for Ghana. Table 6.6 displays the variance decomposition of shocks of Alternative Scenario I. We find notable similarity and dissimilarities for the estimated variance decompositions between the baseline model and Alternative Scenario I. One notable difference is that the Alternative Scenario I (in Table 7.6) points to an inconsequential contribution of domestic price mark-up shock to changes in the endogenous variables. Another important difference is that contribution from exchange rate risk premium (UIP) shock increased when prices and wages are fully flexible than when they are rigid. In terms of similarities, both classes of models strongly accentuate the important influences of fiscal and monetary policy shocks in Ghanaian business cycles. On the whole, the most important structural shock to business cycles in Scenario I is preference shock and this is followed sequentially by domestic monetary policy shock, labour supply shock, government spending shock, UIP shock and productivity shock.

Table 7.7 also displays the variance decomposition of shocks based on Alternative Scenario II where wages are fully flexible but prices are sticky. In the case of Alternative Scenario II, contribution of preference shock is however negligible across all forecast horizons, contrary to the outcome in the baseline model and the Alternative Scenario I. Similar to Alternative Scenario I, exchange rate (i.e. UIP shock) contribution to business cycle (output) increases in Scenario II. Consistent with the baseline model, the Alternative Scenario II identifies domestic price mark-up shock as one of the important drivers of business cycles in Ghana. On a whole, we identify domestic monetary policy shock as the most dominant driver of Ghanaian business cycle when wages are fully flexible and prices are sticky. This is followed sequentially by domestic price mark-up shock, labour supply shock, government spending shock and UIP shock.

Consequently, the empirical analysis predominantly reinforces the important influences of domestic monetary policy and government spending shocks on business cycle (output) developments in Ghana. This finding is particularly robust to the inclusion or otherwise of Calvo rigidities in small-open-economy HANK-DSGE model for Ghana.

Table 7.6: VD of HANK-DSGE Model with Flexible Prices and Wages

	Prod. Shock	Price Mark-Up Shock	Gov't Spending Shock	Pref. Shock	Labour Supply Shock	UIP Shock	Dom. Policy Shock	Foreign Output Shock	Foreign CPI Shock	Foreign Policy Shock
	Period	***t≤4***								
Output	4.08	0.02	15.96	27.99	25.51	5.88	18.96	0.01	1.03	0.54
Overall Consumption	1.53	0.01	7.33	27.94	31.77	10.36	20.11	0.05	0.61	0.30
Ricardian	12.16	0.04	24.72	29.52	8.94	4.53	18.29	0.01	1.16	0.64
Non-Ricardian	12.24	0.05	44.05	10.94	21.66	1.59	8.51	0.07	0.54	0.36
Consumer Inflation	8.10	0.05	17.45	23.04	19.68	12.13	17.60	0.03	1.29	0.65
Domestic inflation	9.71	0.06	20.45	24.12	23.58	3.76	16.57	0.03	1.12	0.61
Nominal Wage	8.95	0.04	19.51	23.58	23.12	5.69	17.29	0.01	1.18	0.63
Marginal Cost	11.62	0.04	18.94	22.89	22.45	5.52	16.79	0.01	1.14	0.61
Nominal Int. Rate	0.65	0.00	4.40	0.86	2.57	44.69	43.95	0.02	1.79	1.07
	7.67	***0.03***	***19.20***	***21.21***	***19.92***	***10.46***	***19.79***	***0.03***	***1.10***	***0.60***
	Period	***t≤12***								
Output	6.32	0.02	14.97	28.94	24.37	5.65	18.22	0.01	0.99	0.52
Overall Consumption	2.28	0.02	6.52	33.63	27.60	9.70	19.35	0.09	0.54	0.27
Ricardian	12.73	0.03	23.62	30.21	9.70	4.37	17.60	0.01	1.12	0.62
Non-Ricardian	11.54	0.07	40.97	13.98	19.98	2.48	9.97	0.16	0.51	0.35
Consumer Inflation	8.12	0.05	17.36	23.21	19.66	12.07	17.54	0.03	1.30	0.67
Domestic inflation	9.72	0.06	20.39	24.17	23.57	3.76	16.53	0.03	1.14	0.64
Nominal Wage	10.06	0.06	19.69	23.11	22.57	5.62	17.01	0.01	1.21	0.67
Marginal Cost	11.57	0.05	19.36	22.72	22.19	5.53	16.70	0.01	1.19	0.66
Nominal Int. Rate	0.79	0.00	4.13	1.83	2.64	41.81	44.21	0.05	2.56	1.97
	8.13	***0.04***	***18.56***	***22.42***	***19.14***	***10.11***	***19.68***	***0.04***	***1.17***	***0.71***
	Period	***t≤100***								
Output	7.83	0.02	14.64	28.64	23.91	5.52	17.95	0.01	0.97	0.51
Overall Consumption	2.94	0.09	6.38	34.07	27.11	9.48	19.02	0.10	0.53	0.27
Ricardian	13.43	0.03	23.36	30.06	9.63	4.31	17.44	0.01	1.11	0.61
Non-Ricardian	11.63	0.18	40.59	14.36	19.82	2.46	9.94	0.17	0.51	0.35
Consumer Inflation	8.15	0.05	17.35	23.22	19.65	12.06	17.53	0.03	1.30	0.67
Domestic inflation	9.76	0.06	20.38	24.17	23.56	3.75	16.52	0.03	1.14	0.64
Nominal Wage	10.78	0.12	19.49	22.91	22.37	5.56	16.89	0.01	1.20	0.68
Marginal Cost	11.58	0.12	19.34	22.72	22.16	5.52	16.68	0.01	1.19	0.67
Nominal Int. Rate	1.35	0.00	4.08	2.05	2.64	41.35	43.79	0.06	2.58	2.10
	8.61	***0.07***	***18.40***	***22.47***	***18.98***	***10.00***	***19.53***	***0.05***	***1.17***	***0.72***
OAC	***8.13***	***0.05***	***18.72***	***22.03***	***19.35***	***10.19***	***19.67***	***0.04***	***1.15***	***0.68***

Table 7.7: Variance Decomposition of HANK-DSGE Model with Flexible Wages and Sticky Prices

	Prod. Shock	Price Mark-Up Shock	Gov't Spending Shock	Pref. Shock	Labour Supply Shock	UIP Shock	Dom. Policy Shock	Foreign Output Shock	Foreign CPI Shock	Foreign Policy Shock
	Period	***t≤4***								
Output	1.76	21.68	11.05	0.00	17.21	10.41	37.41	0.02	0.38	0.08
Overall Consumption	4.78	23.87	5.43	0.00	1.20	15.52	48.71	0.02	0.38	0.08
Ricardian	5.83	23.85	12.37	0.00	5.24	11.55	40.62	0.02	0.42	0.09
Non-Ricardian	3.84	24.62	17.48	0.00	16.43	11.88	24.93	0.01	0.65	0.16
Consumer Inflation	1.58	38.55	5.54	0.00	5.49	8.16	40.29	0.00	0.28	0.11
Domestic inflation	1.76	42.20	5.52	0.00	5.59	1.81	42.53	0.00	0.40	0.19
Nominal Wage	6.15	22.63	12.95	0.00	16.65	11.31	29.67	0.03	0.48	0.12
Marginal Cost	8.29	22.12	12.65	0.00	16.27	11.05	29.00	0.03	0.47	0.11

Nominal Int. Rate	0.63	15.19	4.08	0.00	4.71	4.71	69.56	0.00	0.75	0.37
	3.85	***26.08***	***9.67***	***0.00***	***9.87***	***9.60***	***40.30***	***0.01***	***0.47***	***0.15***
	Period	***t≤12***								
Output	2.64	14.68	7.45	0.00	13.74	7.01	54.14	0.01	0.26	0.06
Overall Consumption	2.23	11.32	2.62	0.00	0.72	7.07	75.79	0.01	0.19	0.04
Ricardian	4.02	16.51	8.55	0.00	3.82	8.00	58.72	0.02	0.30	0.07
Non-Ricardian	3.27	24.96	13.70	0.00	12.99	10.12	34.10	0.01	0.67	0.18
Consumer Inflation	1.32	31.42	4.65	0.00	4.45	6.53	51.25	0.00	0.26	0.11
Domestic inflation	1.26	29.41	3.97	0.00	3.93	1.37	59.58	0.00	0.31	0.16
Nominal Wage	6.34	24.96	12.80	0.00	14.43	10.47	30.37	0.03	0.49	0.12
Marginal Cost	7.38	24.69	12.66	0.00	14.27	10.35	30.03	0.02	0.48	0.12
Nominal Int. Rate	0.25	3.05	0.74	0.00	0.80	1.37	93.30	0.00	0.31	0.18
	3.19	***20.11***	***7.46***	***0.00***	***7.68***	***6.92***	***54.14***	***0.01***	***0.36***	***0.12***
	Period	***t≤12***								
Output	2.48	6.66	3.38	0.00	7.91	3.18	76.24	0.01	0.12	0.03
Overall Consumption	0.80	3.91	0.90	0.00	0.28	2.41	91.61	0.00	0.07	0.02
Ricardian	1.86	7.46	3.88	0.00	1.81	3.64	81.17	0.01	0.13	0.03
Non-Ricardian	2.51	18.48	10.17	0.00	9.79	7.56	50.84	0.01	0.50	0.13
Consumer Inflation	0.81	18.64	2.78	0.00	2.57	3.76	71.24	0.00	0.15	0.06
Domestic inflation	0.62	13.80	1.88	0.00	1.81	0.63	81.06	0.00	0.14	0.07
Nominal Wage	5.46	19.35	9.78	0.00	10.89	7.98	46.07	0.02	0.37	0.09
Marginal Cost	5.65	19.31	9.76	0.00	10.86	7.96	45.98	0.02	0.37	0.09
Nominal Int. Rate	0.09	0.78	0.19	0.00	0.23	0.32	98.27	0.00	0.08	0.05
	2.25	***12.04***	***4.75***	***0.00***	***5.13***	***4.16***	***71.39***	***0.01***	***0.21***	***0.06***
OAC	***3.10***	***19.41***	***7.29***	***0.00***	***7.56***	***6.89***	***55.28***	***0.01***	***0.35***	***0.11***

7.4.4 Government Spending Shock

In Figure 7.1, we report the baseline macroeconomic implications of increased government consumption spending. The shock of moderately persistent with $\rho_g = 0.483$. It is clearly evident in the figure that the increase in government spending drives immediate increase in both output and labour demand, albeit moderately and also crowds-out consumption and investment of Ricardian consumers. As a result, nominal wages increase contemporaneously on account of the immediate increase in supply demand. In line with extant empirical literature (e.g. Colciago 2011), however, real wage decline considerably (amid labour market rigidities) following positive government spending shock leading to decline in the purchasing power of rule-of-thumb consumers. Consistently, it can be seen that the consumption of rule-of-thumb consumers declines immediately and is one-for-one to the drop in real wage. Instinctively, the response pattern of private consumption to increased government spending shock is highly dependent on the form of the fiscal policy rule and on how the real wage is determined in the labour market (see, Coenen and Straub, 2005). That is, the literature clearly articulates that the quantitative impact of a government spending shock (financed by taxes) on private consumption largely depends on the degree of debt financing and on whether the real wage increases or decreases on impact. The baseline decline in real wage following increased government spending

shock is consistent with empirical evidence (see Coenen and Straub, 2005). The drop in real wage adversely affects the purchasing power of consumers, and hence decreasing the consumption of especially the ROT consumers. This together with large negative wealth effect on Ricardian consumers generates contemporaneous fall in aggregate consumption following positive government spending shock. The significant drop in consumption couple with negative real marginal cost induces a downward pressure on prices. In response to disinflation, monetary authority cut interest rate in a bid to stimulate and support economic growth which results in real depreciation of the domestic currency along with a moderate improvement in net exports.

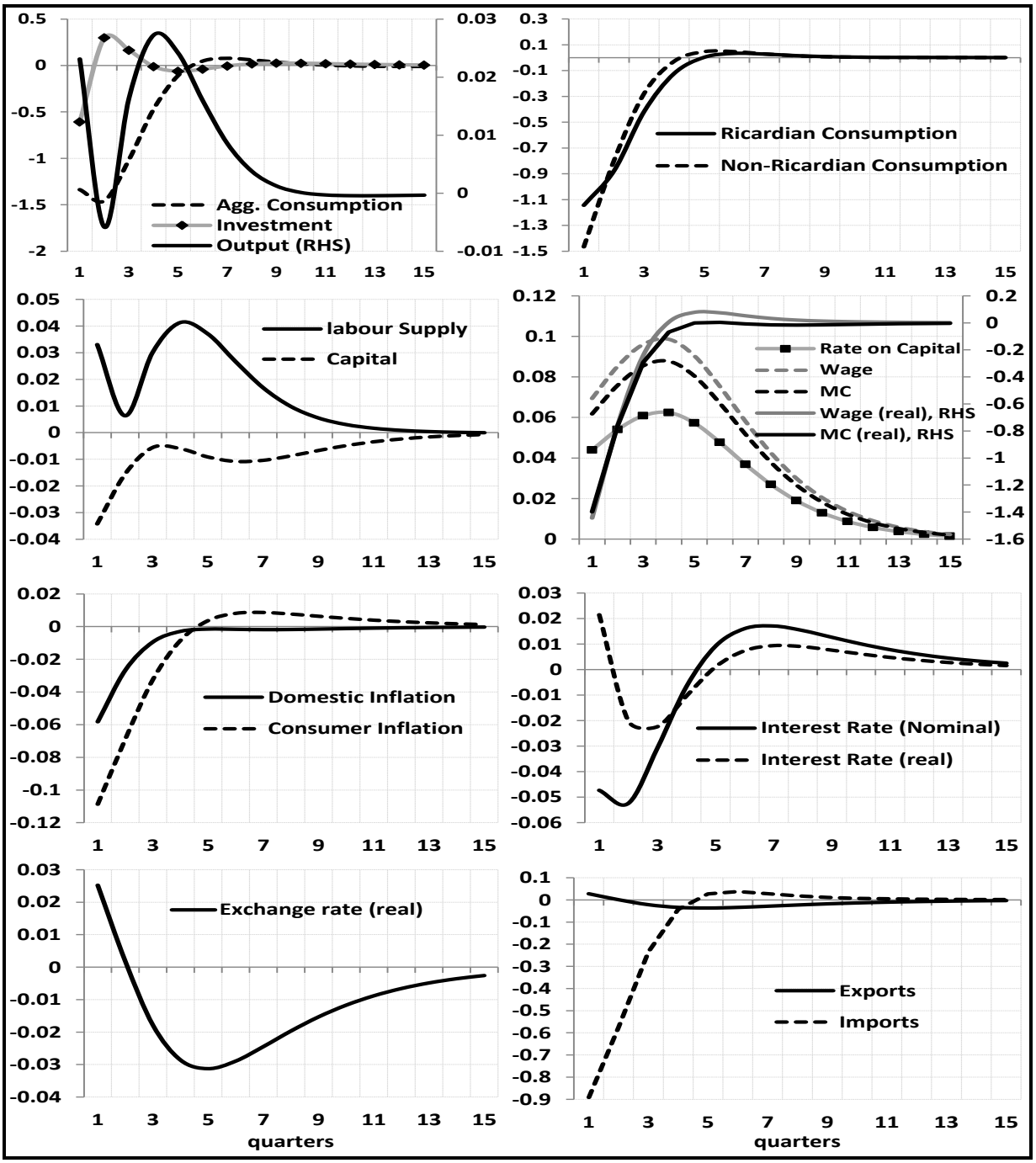
We can conclude that the baseline model with sticky price and wages provides ample evidence of crowding-out effect of increased government spending on aggregate private consumption in Ghana. This is driven by decline in consumption by optimizing households in line with the Ricardian Equivalence Hypothesis (REH) and strongly reinforced by a larger drop in consumption by rule-of-thumb consumers on the back of negative real wage. Our empirical evidence thus supports the strong negative co-movement between output and consumption predicted by the neoclassical model in response to changes in government spending.

Since baseline model contradicts the standard outcome of an increase in consumption of rule-of-thumb consumers following positive government spending shock, we further ascertain the degree of sensitivity of the relationship between consumption and government spending shock to changing market structure and different shares of rule-on-thumb consumer. Figure 7.2 displays the response of positive government spending shock for the baseline vis-à-vis two alternative scenarios where share of non-Ricardian consumers is 0.425 (i.e. $\psi = 0.425$). As aforementioned, Alternative Scenario I is a model with full flexible prices and wages (i.e. perfect competition), while Scenario II is model with sticky prices but flexible wages.

It can be seen from the figure that the private consumption-government spending nexus is less sensitive to variations in market structure. Even though we take the baseline model as the most empirically relevant scenario in this chapter, the negative link between the two is still obvious across the alternative scenarios. This reinforces evidence of crowding-out effects of positive government spending shock on aggregate private consumption, in line with the REH. Even so, we can see that the negative (i.e. crowding-out) effect of increased government spending shock on Ricardian consumption is much stronger in alternative models (i.e. Scenarios I & II) than in the baseline. This is driven by a greater negative wealth effect. In contrast, there is a stronger crowding-in (i.e. positive) effect of increased

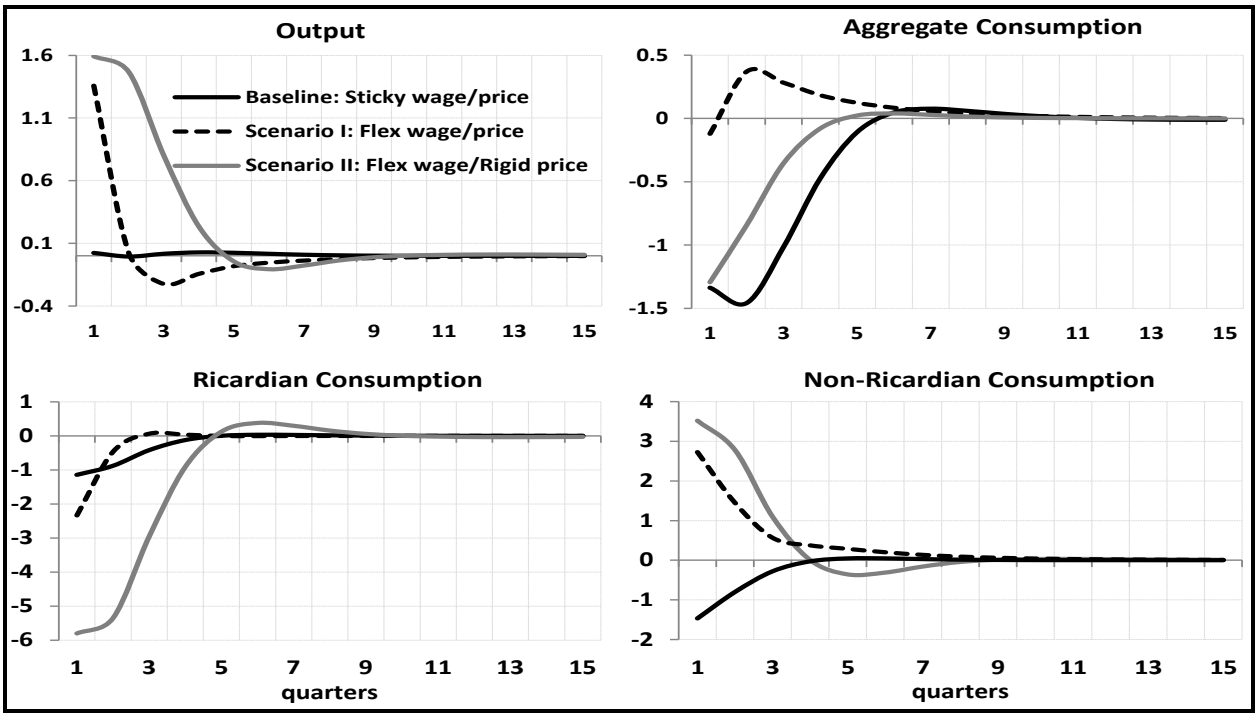
government spending on non-Ricardian consumers and this is induced by stronger income effect as real wage increases following government spending shock. Consequently, the non-Ricardian consumers substantially moderate the crowding-out effect on aggregate consumption especially in the simplest model (i.e. Scenario I) when compare to more complicated ones (i.e. both Scenario II and the Baseline model).

Figure 7.1: Baseline Effects of increased government spending



Note: MC denotes marginal cost

Figure 7.2: Sensitivity of consumption-government spending nexus to market structure



It is indeed apparent that an increased government spending shock leads to a hump-shape increase (i.e. crowding-in effect) in aggregate consumption (when both prices and wages are flexible (i.e. the simplest model) although there is an insubstantial contemporaneous crowding-out effect on aggregate consumption. In other words, Scenario I generates an immediate trivial negative response of aggregate consumption to government spending shock but the response becomes positive (with relatively larger magnitude) after the first period. In the nutshell, we observe that the crowding-out effect of government spending shock on consumption is more conspicuous in the more complex models than in the simple model. Our empirical result is consistent with the findings of Forni et al (2006), Ratto et al (2008), Colciago (2011), Stahler and Thomas (2012) and Palas (2017) but contradicts that of Swarbrick (2012) which found no crowding-in effect even in the simplest model.

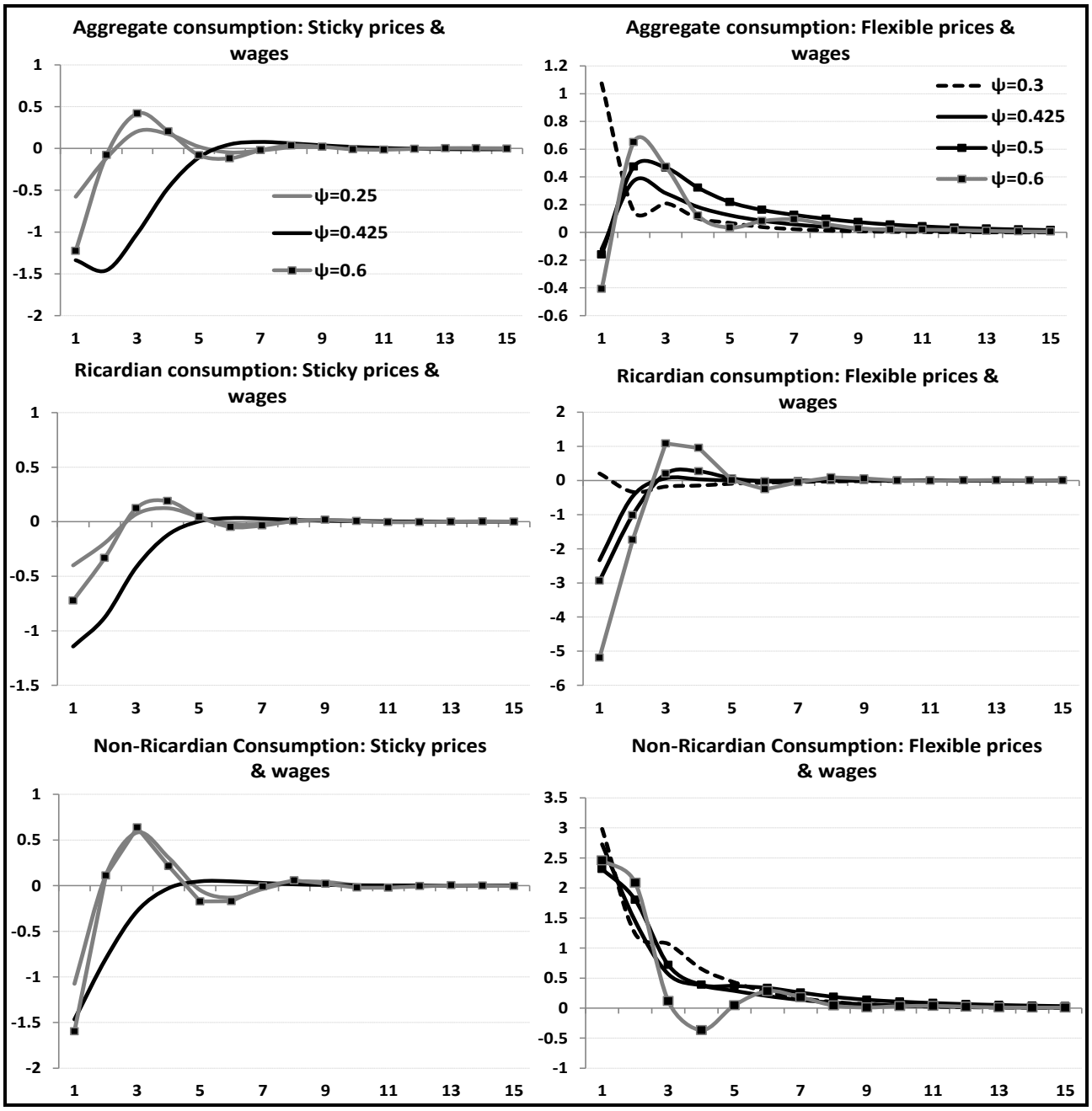
For robustness, we also investigate the sensitivity of the consumption-government spending nexus for the share of non-Ricardian consumers. Figure 7.3 displays consumption responds to positive government spending shock for alternative shares of non-Ricardian consumers based on both the baseline model and alternative Scenario I (i.e. the simplest model that has flexible prices and wages). Our baseline model (with sticky prices and wages) generates a crowding-out effect of fiscal expansion on private consumption when the share of no-Ricardian consumers is reasonably high, (i.e. $\psi \geq$

0.425). This empirical observation from this chapter contradicts the findings by Gali et al (2007)[102] but corroborates the findings of Algozhina (2012) with similar small-open economy setting. Besides, a reasonably low share of non-Ricardian consumers (i.e. $\psi = 0.25$) in our sticky prices and wages (i.e. the baseline) model still produces a crowding-out effect of fiscal expansion on private consumption in the context of Ghana. That is, public consumption spending shock still crowds-out private consumption in the sticky prices and wages model for a small-open developing economy like Ghana despite low or high fraction of rule-of-thumb households. Although this is against the conventional view of fiscal multiplier, the outcome seems plausible in this non-Ricardian setting given the decline in real wage.

Similarly, the alternative simple model (i.e. flexible prices and wages) indicates a negative link between private consumption and government spending shock (i.e. crowding-out effect), even when the share of non-Ricardian consumers is reasonably high, $\psi \geq 0.425$, in the small-open developing economy like Ghana. This observation also contradicts the findings by Gali et al (2007) that a reasonably high value of the ROT consumers in a competitive labour market generates a crowding-in effect of government spending shock on private consumption. Even though non-Ricardian consumption increases significantly in response to fiscal expansion, it could not more than offset the contraction in Ricardian consumption to induce a contemporaneous crowding-in effect of fiscal expansion on aggregate consumption in the simple model. However, the crowding-out effect is much stronger for the baseline (i.e. complex) model than for the simple (i.e. perfectly competitive) model, driven by a larger negative wealth effect in the former models. The moderate crowding-out effect of fiscal expansion on private consumption in the simple (i.e. perfectly competitive) model, reinforces the offsetting role of ROT behaviour on the conventional negative wealth and intertemporal substitution effects triggered by the fiscal expansion (Gali et al., 2007).

[102] Using a closed economy model, Gali et al., (2007) assert that an approximate share of $1/4$ for non-Ricardian consumers (i.e. $\psi = 0.25$) is sufficient to induce a crowding-in effect in a model with imperfectly competitive labour market. This is perhaps not surprising because in their non-competitive labour market, a typical union (representing a worker type z) sets the wage each period for its workers in order to maximize the objective function. Therefore, wages for all workers adjusts in each period for the case of Gali et al (2007), while only a fraction of workers are able to adjust their wage each period in our small-open economy model.

Figure 7.3: consumption-government spending nexus based on non-Ricardian share



Note: the baseline model includes ψ=0.25 while Scenario I does not.

7.4.5 Monetary policy shock

Figure 7.4 demonstrates the relative responses of key macroeconomic variables to an increase in domestic policy interest rate for the baseline model. In this chapter, the policy shock has an autoregressive component and therefore the gradual decrease back to the steady state is driven by the persistent of the shock itself. The temporary positive monetary policy shock raises the short-run interest rates (in nominal and real terms). The domestic currency strengthens as positive real (nominal) interest rate makes domestic investments more attractive and hence boosting international financial

inflows. The opposite effect is equally true for expansionary monetary policy shock (i.e. interest rate cut) with both prices and wages rigidities, as exhibited in Appendix 7Aiv.

Exchange rate remits dual effects on the macroeconomy, in line with standard economic theory. On one hand, terms-of-trade deteriorates on the back of stronger domestic currency which generates negative net exports and hence output. Labour demand falls owing to declining output which in turn reduced nominal wage and drag down marginal cost and prices. Since the drop in inflation outweighed the decline in nominal wages, real wage (or higher households' purchasing power) rises contemporaneously. The rise in purchasing power spawns a surge in non-Ricardian consumption. At the same time, domestic currency appreciation increases the net worth of optimizing households especially those holding foreign currency denominated bonds/assets, and hence increasing Ricardian consumption. The net effect is that aggregate consumption increases following domestic policy tightening.

In line with economic theory, we find that monetary policy is able to influence real economic variables in Ghana using its main policy instrument, the short-term nominal interest rate despite a sizeable share of non-Ricardian consumers. Nonetheless, our results provide compelling evidence that the exchange rate channel is fundamental medium through which short-term interest rate successfully impact the real economy (output and consumption) in Ghana. This empirical finding is consistent with the small-open macroeconomy literature and other studies (such as Akosah, 2015; Akosah and Dasah, 2015; Loloh, 2015; Kovanen, 2011; Acheampong 2005; Abradu-Otoo et al., 2003; etc.) on monetary policy transmission channels in Ghana using standard macroeconometric methods including VARs, VECM.

Similarly, Figure 7.5 compares whether the baseline responses of consumption, inflation and output to contractionary monetary policy shock differ substantial in the alternative scenarios based on share of non-Ricardian consumers is 0.425 (i.e. $\psi = 0.425$). Consistent with conventional wisdom, we find a robust negative effect of contractionary monetary policy shock (i.e. interest rate hike) on output across all market structures considered. However, the decline in output is more acute in the simple models compared to the baseline model. As well, the alternative models also reinforce a crowding-in effect of monetary policy shock on consumption. The positive effect on aggregate consumption is mainly driven by large increases in consumption of Ricardian consumers which far outweighed the drop in non-Ricardian consumer. The pickup in Ricardian consumption is attributable to an improved financial balance sheet effect at the back of real appreciation. However, the fall in non-Ricardian consumption in the simply models is due to relatively larger negative wealth effect. We can also be seen that inflation decline following unexpected monetary policy tightening for models with sticky price (i.e. the baseline

and Scenario II). For flexible price and wage model, monetary policy shock consistently has no influence of prices. In such model the rise in inflation is compelled by the positive consumption effect via the exchange rate channel.

Figure 7.6 also presents the sensitivity analysis of domestic monetary policy spillovers for different shares of non-Ricardian consumers using different market rigidities. It is clearly visible from the figure that contractionary monetary policy shock causes disinflation in the baseline model across the shares of non-Ricardian consumers considered. In addition, monetary policy shock crowds-in aggregate private consumption for various shares of non-Ricardian consumers, and this is driven by both Ricardian and Non-Ricardian consumption. The contemporaneous (or short run) effect on output growth is however sensitive to the share of non-Ricardian consumers especially for the baseline model. Yet, no such degree of sensitivity to the share of non-Ricardian consumers prevails for the alternative scenario where both price and wages are flexible. Nevertheless, positive monetary policy shock causes output to decline for the entire forecast horizons when the share of non-Ricardian consumers is from 0.4 to 0.5 for the baseline model. But for values outside this range, positive monetary policy shock generates increase output growth for the first two quarters and induces negative growth thereafter for the stick price and wages model. This implies monetary policy is still able to influence aggregate output and inflation in a way that is consistent with economic theory.

Figure 7.4: Effects of a contractionary monetary policy shock

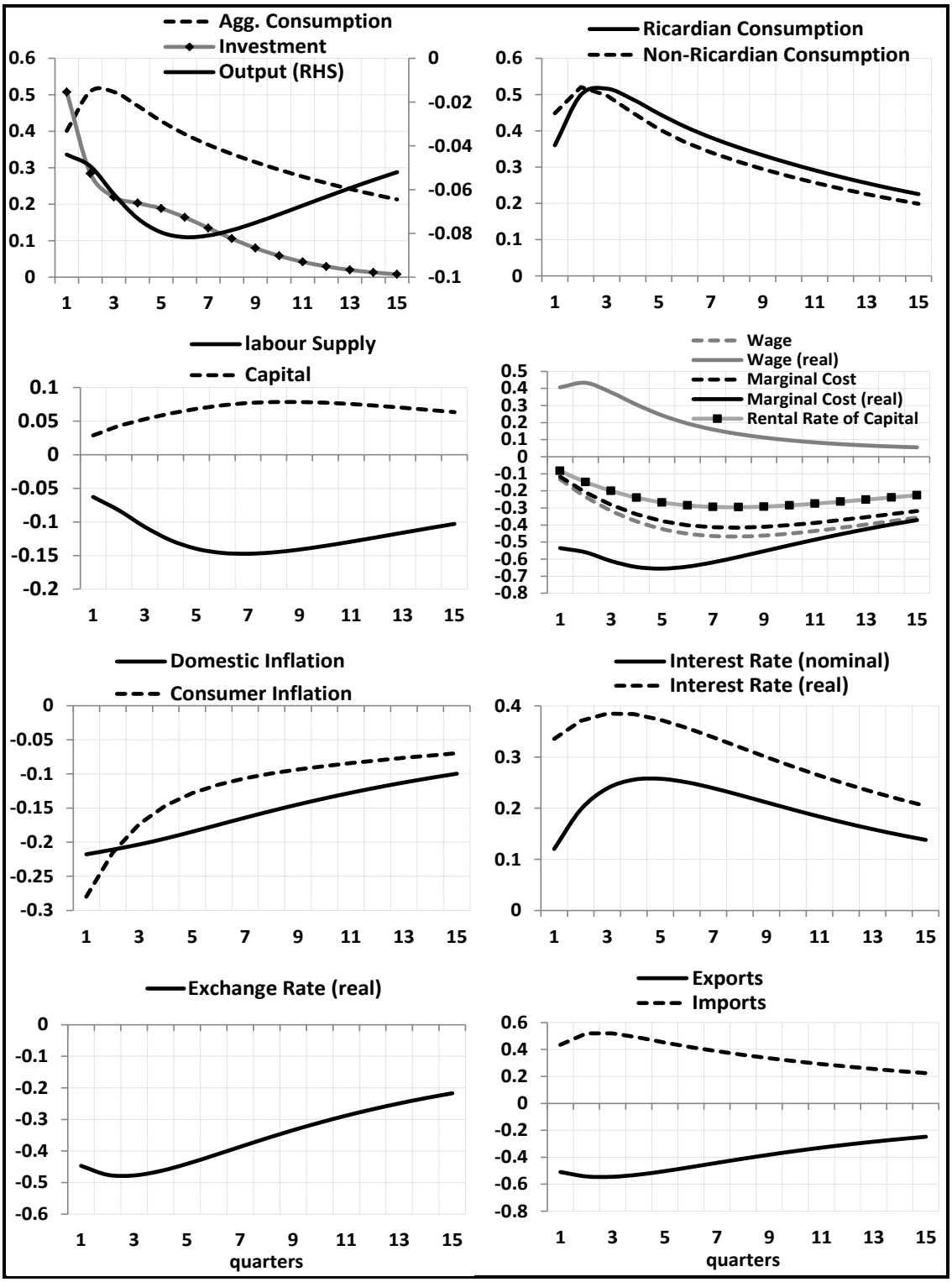


Figure 7.5: Sensitivity Analysis of monetary policy effect at different market rigidities

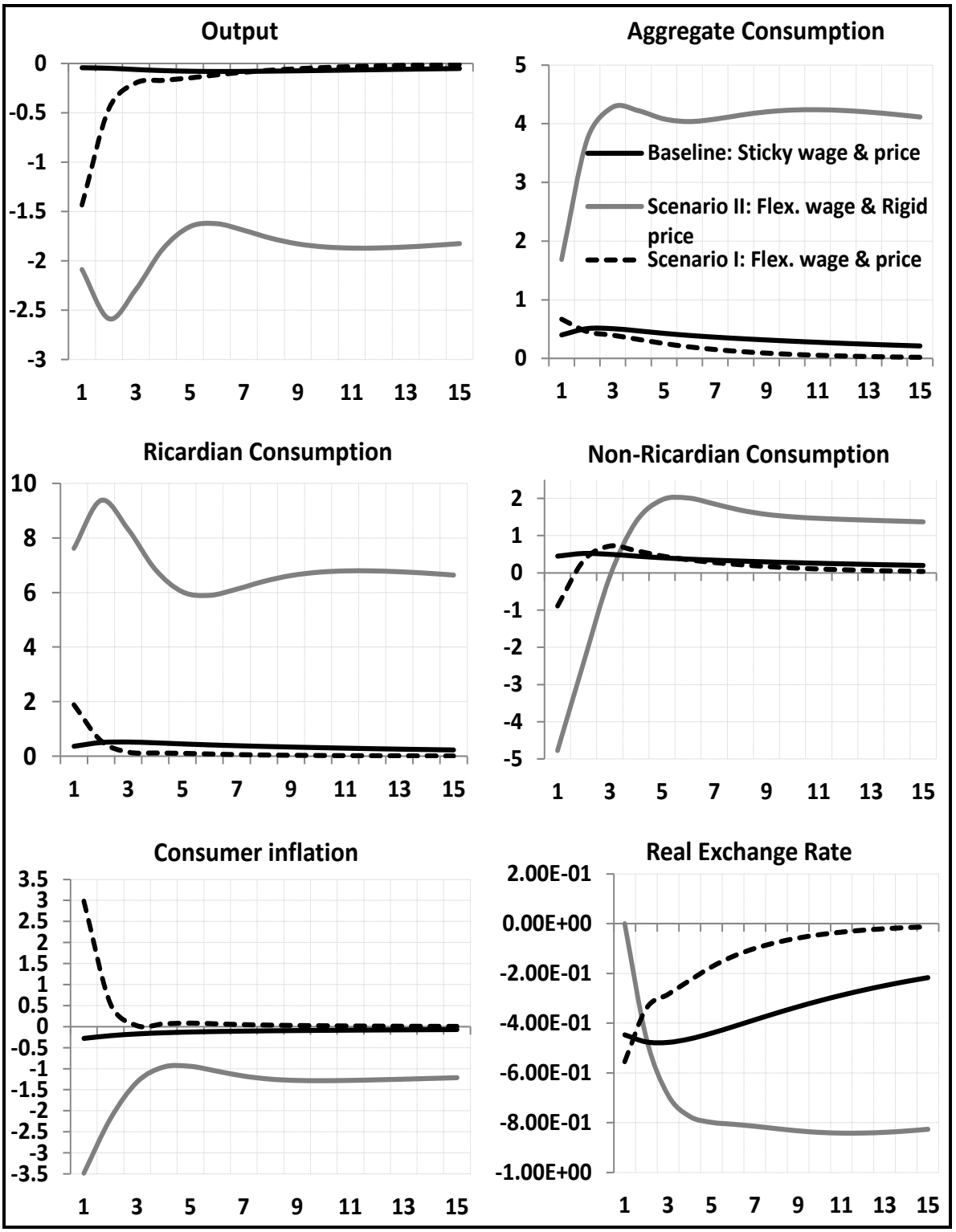


Figure 7.6: Sensitivity of monetary policy effect to the share of non-Ricardian consumers

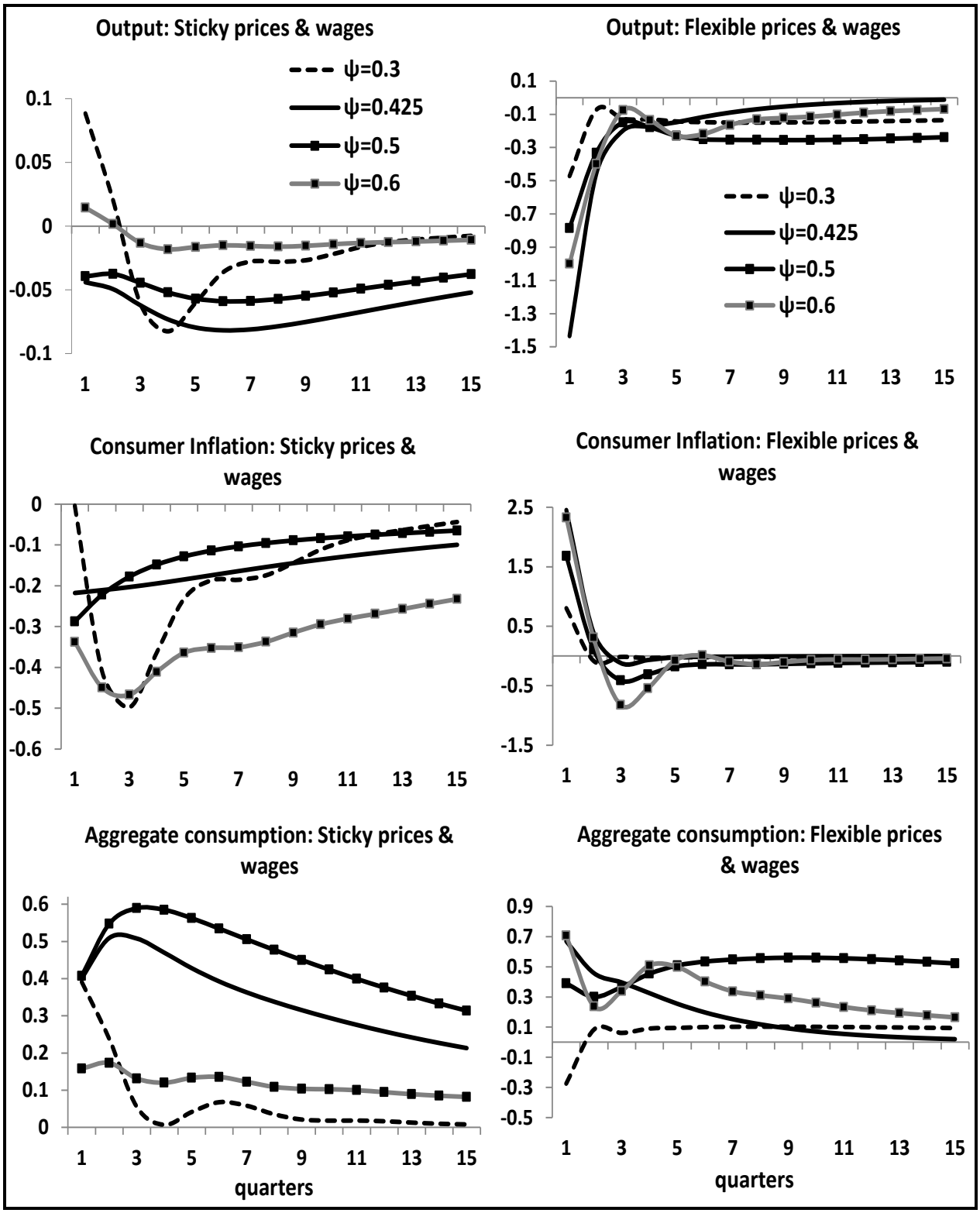
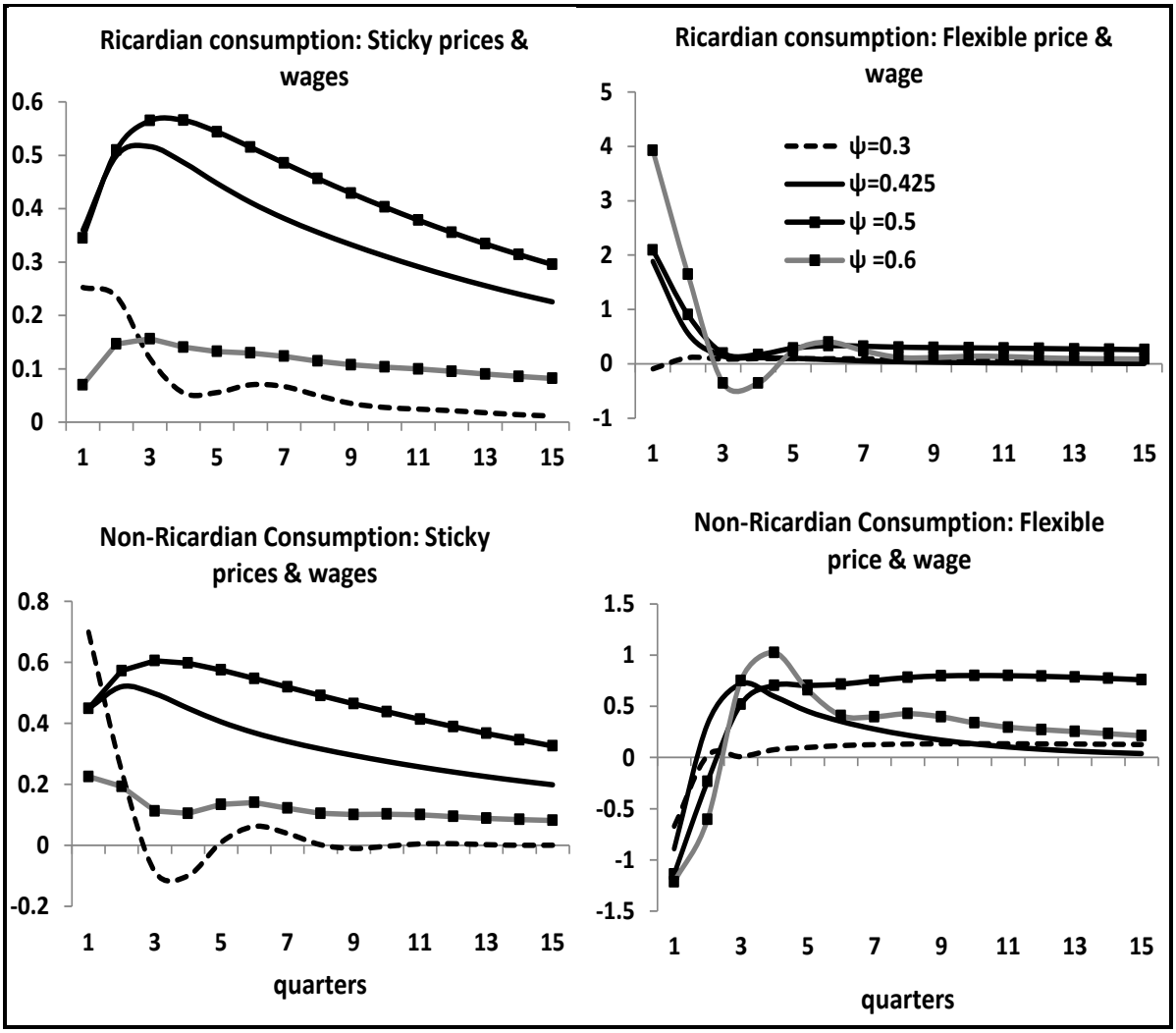


Figure 7.6: Conti…



7.4.6 Monetary policy responds to other domestic shocks

Appendix 7Av-xiii report the responses of monetary authority to other key structural impulses based on alternative levels of market rigidities. In particular, Appendix 7Av illustrates the macroeconomic implications of an increase in productivity. The figure reveals that output, consumption and investment rise while labour supply declines following a positive productivity shock. In all, aggregate and Ricardian and non-Ricardian consumptions increase contemporaneously, mainly driven by significant income effects. The decline is labour supply is due to a strong predominance of the income effect, leading a fall in wages. This is compensated by a higher demand for capital, amid a decline in cost of capital. Marginal cost falls on the back of both lower wages and rental rate of capital. Inflation (both domestic and consumer prices) initially fall on the back of the immediate fall in marginal cost along with an appreciated currency. Aggregate demand pressures in tandem with the subsequent slight real depreciation induce consumer inflation to rise moderately in the ensuing two quarters and eased thereafter. In response to inflation developments, monetary authority raises interest rate for the first

three quarters and gradually eases afterwards. The estimated reaction of monetary policy to a productivity increase is inconsistent with the findings of Smets and Wouters (2002) for Europe, Gali et al., (2003) and Ireland (1999) for the USA.

Regarding demand shock, Appendix 7Avi presents responses to positive preference shock. The qualitative implications of positive preference shock on aggregate consumption, investment, labour supply, capital, cost of factor inputs, marginal cost and nominal interest rates are very similar to those of positive productivity shock. The qualitative differences are that inflation (both domestic and consumer) rises, causing real wage to fall. It is this significant fall in real wage that induces a decline in consumption of non-Ricardian consumers while consumption of Ricardian household increases. The increase in nominal interest rate in response to higher inflation in turn stimulates real appreciation. Consistently, the gain in domestic currency deteriorates net exports and also represses output growth contemporaneously.

Then again, real exchange rate appreciation following favourable exchange rate risk premium shock (in Appendix 7Avii). Strengthening of the domestic currency deteriorates net export and hence crowds-out output with a subsequent decline in demand for both labour and capital. As a result, input costs decline which in turn yield an immediate drop in marginal cost and domestic inflation. In contrast, consumption increases immediately, driven by both the direct effect as real appreciation raise the financial balance sheet of households with foreign denominated bond and the indirect effect on non-Ricardian households. The increase in consumption conceivably reduces the marginal utility of working, leading to greater disinclination of household to work. The economic slowdown following favourable risk premium shock instigates a decline in interest rates. Intuitively, there is a hump-shape decline in interest rate following a favourable exchange rate risk premium shock.

Turning to the supply shocks, Appendix 7Aviii illustrates the macroeconomic implications of a positive labour supply shock. The qualitative responses to labour supply shock are broadly akin to that of productivity shock. In response to positive labour supply shock, capital declines to compensate for the increase in labour supply. Output also increases immediately, albeit moderately. Consumption of both Ricardian and non-Ricardian consumers increase due to income effect as labour income (both real and nominal wages) rises. Marginal cost rises on the back of wage increases which in turn fuels inflation. Monetary authority responds by raising interest rate which leads strengthen the domestic currency. In line with international macroeconomics, net export worsens at the back real appreciation

of the local currency. Consequently, the modest increase in output growth is driven by the rise in aggregate consumption which is moderated by a decline in investment and negative net export.

In contrast, Appendix 7Aix and 7Ax display adverse supply side shocks pertaining to the impact of negative price and wage mark-up shocks respectively. The qualitative illustration of Appendix 7Aix is that inflation (both domestic and overall consumer) immediately rises following adverse domestic price mark-up shock. In response to mounting inflationary pressures, monetary authority raises (nominal) interest rate instantly. The hike in policy interest rate causes the domestic currency to strengthen which successfully induces subsequent disinflation. The ensuing qualitative implications on output, aggregate consumption (also Ricardian and non-Ricardian), labour supply, cost of factor inputs, net exports and marginal cost at the back of adverse price markup shock is analogous to those of favourable risk premium shock. However, the adverse wage mark-up shock (Appendix 7Ax) yields slightly different qualitative ramifications when compared with those of price mark-up shock (in Appendix 7Aix) but qualitative akin to the positive labour supply shock. It is clear from the figure that wage increases following adverse wage mark-up shock which in turn boost consumption of both Ricardian and non-Ricardian consumers. The wage increase also raises marginal cost and the latter pushes inflation up. Interest rate increases in response to rising inflation, leading to real appreciation in the domestic currency. Net export worsens at the back of the local currency gains. Output increases contemporaneously as rise in aggregate consumption far outweighs the declines in both net exports and investment.

7.4.7 Foreign Spillovers to Domestic Economy

In Appendix 7Axi-xiii, we report the baseline responses of the domestic endogenous macro-variables to foreign output, inflation and interest rate shocks respectively.

As exhibited in Appendix 7Axi, exchange rate depreciates instantly following foreign policy shock and this is via the UIP channel. The loss in domestic currency stimulates exports relative to imports, leading to a positive net export and consequently, drives a hump-shaped but moderate increase in domestic output. The slowdown in imports implies lower imported inflation. Also, demand for labour inputs rises on the back of rising domestic output which in turn drives up both nominal wage and marginal cost. The rise marginal cost (both real and nominal) compels domestic inflation to rise via the New Keynesian Philips curve. However, the lower imported inflation due to negative imports induces overall consumer inflation to fall for the first three quarters. Real wage falls as the rise in domestic inflation outpace the pickup in nominal wage. Consumption of non-Ricardian consumers

consequently falls due to stronger negative income effect. Since policy target is overall consumer inflation, monetary authority accordingly cuts nominal interest rate instantly. Yet, real interest rate increases as the drop in consumer inflation outdoes the cut in nominal interest rate. However, negative income effect via negative real wage and adverse financial balance sheet effect via considerable exchange rate depreciation together cause Ricardian consumers to reduce consumption and investments immediately.

We can see that the qualitative responses foreign output shocks (in Appendix 7Axii) are broadly similar to that of foreign policy shock. The most striking qualitative dissimilarities are that both domestic inflation and real marginal cost decline while exchange rate marginally appreciated in response to foreign output shock. However, we can also see that the magnitudes of responses to foreign output shock are generally smaller than that to foreign interest rate shock. Consequently, foreign policy shock exerts relatively substantial influence in the domestic economy compare to the spillovers from foreign output shock which is in line with the variance decomposition analysis.

Appendix 7Axiii also presents spillovers from a temporary positive foreign inflation shock[103]. The figure reveals that spillovers from foreign inflation shock are qualitatively different from either foreign interest rate or output shocks. We can see that consumer inflation rises following foreign inflation shock (via imported inflation). But since the rise in consumer inflation is not one-for-one to the increase in foreign inflation, real exchange rate also appreciates to uphold the purchasing power parity (based on the perfect pass-through assumption). Domestic output declines on the back of real appreciation which in turn dampens demand for labour with a resultant fall in (nominal) wages and marginal cost. On one hand, domestic inflation falls as marginal cost (real) declines, while real wage rises. Aggregate consumption increases via income effect for non-Ricardian and both income and wealth effects for Ricardian consumers. Intuitively, wealth effect is via exchange rate implications on the financial balance sheets of those holding foreign denominated assets. Monetary authority raises nominal interest rate less than proportionately to induce an immediate negative real interest rate in the wake of rising consumer inflation and falling output. The passive monetary policy response is consistent with an appreciated domestic currency (in real terms). There is a hump-shaped increase in private investment by Ricardian consumers.

[103] We follow the extant literature (especially, Meloliana, 2015; Charnavoki and Dolado, 2014; Ferroni and Mojon, 2014; and Baumeister and Peersman, 2013) to define foreign inflation shock as a temporary shock that raises foreign inflation but dampens foreign output.

7.5 Conclusion

In this chapter, we develop DSGE model with non-Ricardian consumers to explore its suitability for macroeconomic policy analysis in small-open developing economies, like Ghana. The estimated HANK-DSGE model is specifically used to analyse monetary and fiscal policy as well as foreign spillover effects on the domestic real economy.

The empirical results provide relevant information for policy analysis and effective transmission of monetary policy implementation in Ghana and beyond. We find a considerable degree of price and wage stickiness in the Ghanaian macroeconomy. We have estimated the share of non-Ricardian consumers to be 0.425 for Ghana. Importantly, the posterior mean for the share of rule-of-thumb (or non-Ricardian) consumers is estimated to be 0.464 with a 95% confidence interval of [0.429 0.501]. The estimate is higher than the prior mean of 0.425 and indicated that approximately 46.4% of the households in Ghana are saddled with some forms of financial constraints and hence rely solely on their labour income. Our estimate for the share of rule-of-thumb household is clearly larger than the 0.4 value assumed in the empirical literature (including Dagher et al., 2010, 2012) for Ghana. We highlight that our estimated share for non-Ricardian consumers is robust and can further construe that studies that assume different values for the latter agents have the proclivity to generate less plausible estimates for policy inference.

More so, we find the most appropriate DSGE model for the Ghanaian macroeconomy to be a heterogeneous agent's (HANK) DSGE model with a 42.5% share of rule-of-thumb (non-Ricardian) households alongside nominal price and wage rigidities, and a forward-looking monetary policy rule. Here, forward-looking policy rule is the Taylor rule where authority reacts to one-period-ahead inflation deviation (from steady state) along with current output gap. We have also established that the DSGE models with heterogeneous agents (HANKs) outperform the models with representative agent (RANK) for Ghana, in terms of maximum likelihood estimators. This lends support to Mankiw's (2000) advocacy for heterogeneous consumers in economic models.

In terms of relevant of structural shocks, the chapter underscores the important influences of domestic monetary policy and government spending shocks on business cycle developments in Ghana. In the case of output, the dominant determinants are price mark-up shock, preference shock, domestic monetary policy shock and foreign inflation shock. Even though domestic monetary policy still matters for economic growth in the short-to-long time horizons, its influence is less robust when compared to the RANK model. The moderate effect of domestic monetary policy on output is conceivable as the former tends to impact only fraction of households in the HANK model. The contribution of

productivity shock to output is via marginal cost, while that of domestic monetary policy shock is via Ricardian consumption, nominal interest rate and inflation. We also find price mark-up shock, domestic monetary policy shock, preference shock and foreign inflation shock as the main determinants of inflation in Ghana across the forecast horizons. On the contrary, the dominant drivers of nominal interest rate are price mark-up shocks and domestic monetary policy, with some support from productivity shock, preference shock, labour supply shock and foreign CPI shock.

It is apparent that monetary policy effectively influences aggregate output and inflation in a way that is consistent with economic theory, and this is robust to the extent of market rigidities as well as the share of non-Ricardian consumers. In contrast to the RANK model in the preceding chapter, the heterogeneous agent's model is not prone to price puzzle. Consequently, our NK-DSGE model with heterogeneous consumers is more suitable for monetary policy analysis in Ghana. This observation clearly illustrates that models for developing economies like Ghana should ensure a cohabitation of hand-to-mouth and optimizing consumers. There is also conspicuous evidence that monetary policy shock crowds-in private consumption, driven by increases in both Ricardian and Non-Ricardian consumption. We also notice that the transmission of monetary policy is much stronger via the exchange rate channel. This is because the monetary policy shock on weighs heavily on the financial balance sheet of household and trade dynamics especially (consumption of imported goods) via its implications on exchange rate. Conceivably, a contractionary monetary policy shock appreciates the domestic currency which in turn propels higher imports for domestic consumption. In addition, the appreciation in the domestic currency also dampens imported inflation (and ultimately, overall consumer price inflation of the home economy) which in turn increases the purchasing power of households. Besides, the appreciation in the domestic currency improves the financial balance sheet of households especially those holding foreign currency denominated assets/liabilities and hence, stimulates their consumption.

Another important empirical finding is that public consumption spending shock still reduces private consumption in the sticky prices and wages model for a small-open developing economy like Ghana despite low or high fraction of rule-of-thumb households. Although this is against the conventional view of fiscal multiplier, the outcome seems plausible in this non-Ricardian setting given the decline in real wage. Intuitively, the response pattern of private consumption to increased government spending shock is highly dependent on the form of the fiscal policy rule and on how the real wage is determined in the labour market (see, Coenen and Straub, 2005). That is, the literature clearly articulates that the quantitative impact of a government spending shock (financed by taxes) on private consumption largely depends on the degree of debt financing and on whether the real wage increases

or decreases on impact. The baseline model shows a decline in real wage following increased government spending shock (as not all workers are able to adjust their wage each period), which is consistent with empirical evidence (see Coenen and Straub, 2005). The drop in real wage adversely affects the purchasing power of consumers, and hence decreasing the consumption of especially the ROT consumers. The decline in real wage together with the large negative wealth effect underpins the drop in private consumption following a fiscal expansion. However, the crowding-out effect is much stronger for the baseline (i.e. complex) model than for the simple (i.e. perfectly competitive) model, driven by a larger negative wealth effect in the former models. The moderate crowding-out effect on consumption in the simple (i.e. perfectly competitive) model, reinforces the offsetting role of ROT behaviour on the conventional negative wealth and intertemporal substitution effects triggered by the fiscal expansion (Gali et al., 2007). Consequently, our baseline model with 42.5% share of non-Ricardian consumers, forward-looking policy rule and nominal rigidities (in prices and wages) is able to solve one of the great problems of the standard DSGE models – the positive reaction of real wage to government spending shock that is inconsistent with empirical evidence.

CHAPTER EIGHT

SUMMARY AND CONCLUSION

8.0 Summary of the Thesis

Monetary policy framework provides nominal anchor to the economy. A nominal anchor is a variable policymakers use to tie down the level of prices. Underpinned by experience and strong empirical evidence, both academics and policymakers generally concur that high inflation and its associated high volatility distort the decision-making process of private agents regarding investment, consumption/savings, production and eventually result in sluggish economic growth (Croce and Khan, 2000; Purwanda and Rochana, 2017). Therefore, policymaking and macroeconomic stability remain an important research focus for central banks, particularly in developing economies. This is because these economies are often faced with relatively large and recurrent correlated shocks entirely different from their developed counterparts. In May 2007, Ghana became the 28th economy in the world but the second African economy after South Africa to officially opt for inflation targeting framework as a monetary policy strategy. Despite the well-formulated price stability objective and operational independence clearly preserved in the Bank of Ghana (BOG) Acts 2002 (Act 612) after the adoption of inflation targeting regime, inflationary pressures have lingered over the years in Ghana. Without question, Ghana's consumer price inflation has been among the highest in sub-Saharan African economies, and the inflationary developments are repeatedly connected to large internal and external aggregate demand and supply-side shocks. Against this background, this thesis thoroughly provides analysis of monetary policy making and macroeconomic stabilization in the leading African frontier market, Ghana. The thesis provides series of empirical and theoretical contribution to the literature and to monetary policy implementation not only in Ghana but also for other developing economies that have opted for inflation targeting.

In chapter two, the thesis examines the practical and institutional architecture of the current monetary policy framework using historical narratives and compare with the tenets of IT regime. More importantly, the chapter empirically further determines the degree of monetary policy transparency using both methodologies of Dincer-Eichengreen (DE, 2008) and Al-Mashat et al., (2018). Particularly, DE categorize transparency into the following five dimensions: (1) political transparency (openness about policy objectives); (2) economic transparency (openness about data, models, and forecasts); (3) procedural transparency (openness about the way decisions are made, achieved mainly through the release of minutes and votes); (4) policy transparency (openness about the policy implications, achieved through prompt announcement and explanation of decisions); and (5)

operational transparency (openness about the implementation of those decisions - in other words, about control errors and macroeconomic disturbances affecting their magnitude). Al-Mashat et al., (2018) however proposed new transparency index (henceforth, CBT-IT index) for inflation-forecast-targeting central banks which overcomes the shortcomings of DE index. Based on the theoretical underpinnings of IFT framework, the CBT-IT index focuses on three broad categories: (1) transparency about policy objectives, (2) transparency about the Forecasting and Policy Analysis System (FPAS), and (3) transparency about the policy process. The CBT-IT index offers more detailed scrutiny about the practice of central bank compare to the DE index. Furthermore, we follow Akosah et al (2017) to empirically construct an aggregate policy credibility index which is a weighted average of symmetric index (e.g. De Mendonça and de Guimarães e Souza, 2009) and asymmetric index (of Levieuge et al., 2018). The chapter identifies that the legal framework for the BOG operations is broadly consistent with the IT tenets, but there are some concerns with respect to policy transparency and credibility. Using the approaches of DE (2008, 2014) and Al-Mashat et al., (2018), the chapter finds a moderate level of policy transparency for Bank of Ghana (30.5% and 50% respectively). The relatively moderate score for BOG emanated largely from low level of policy transparency about its forecasting framework (FPAS model) and the procedural policy processes.

In chapter three, we provide detailed insights on whether the inflation targeting regime has imporved macroeconomic outcomes in Ghana, using monetary and real business cycle analyses as well as standard econometric techniques. The latter approach was utilized to determine the precise size and the direction of impact while accounting for other salient macroeconomic events and/or disasters that hit the Ghanaian economy. The basic empirical finding of the chapter is that the IT strategy has generally improved the macroeconomic management in Ghana by reducing average inflation rate, boosting average growth rate and dampening the cyclical oscillations in both output and inflation. Yet, the IT strategy seems to have recorded marginal gains with respect to inflation due to continuously high and protracted inflation inertia and the central bank's inability to effectively delink inflation expectation formation from actual inflation. The observed high inflation inertia and backward-looking inflation expectation formation are perhaps linked to the heightened volatility in exchange rate during the IT regime. Given the high passthrough of exchange rate to prices in Ghana (see Loloh, 2014), the latter observation therefore suggests that apposite monetary and fiscal policy measures are vital to ensure exchange rate stability in order to achieve the price stability objective while promoting a sustained level of economic growth in Ghana. Moreover, preemptive policies and reforms aim at bolstering the domestic financial sector is necessary to quicken financial and real sector responses to policy action and thus, shortening the policy transmission lags. Giving the recurring supply-side

shocks, it is pivotal for the central bank to increase its policy communication and transparency in order to shape expectation and hence, achieve low and more stable inflation.

In Chapter four, we explore volatility spillovers and the lead/lag relationships among the policy interest rate exchange rate and key policy targeted macro-variables (especially inflation and output gap) with the view to ascertaining the monetary policy transmission mechanism and its overall policy effectiveness in Ghana at both time- and frequency domains. Using battery of macroeconometric methods such as parametric and nonparametric Granger non-causality tests and the two generalized forecast error variance decomposition (GFEVD) approaches espoused by Diebold-Yilmaz (2012) and Barunik-Krehlik (2015) respectively, we specifically investigate (i) the signaling ability of the policy interest rate in the money market as well as the most influential money market interest rate(s) in Ghana; (ii) the interest rate-real sector nexus; and (iii) the extent to which the exchange rate impacts domestic interest rate settings and the overall monetary transmission mechanism. The chapter finds moderate levels of connectedness among money market interest rates in Ghana across time and multiscale, signifying modest signaling ability[104] of policy interest rate in the money markets. The rankings of directional and net spillovers clearly reveal that monetary policy rate and 91-day Treasury bill rate are net transmitters of shocks, while interbank, lending and saving rates are net receivers of shocks from the system. It is also apparent that Treasury bill emerges as the largest transmitter and the least recipient of shocks to and from the system respectively across analytical domains. The dominant influence of Treasury bill rate in the money market surmises a strong bearing of fiscal policy's debt management on domestic interest rate dynamics in Ghana. The chapter also detects a scale-dependent connectedness among the macro-variables as their linkages intensify at the longer time-scale. Consistent with the monetary policy transmission mechanism, both real policy rate and exchange rate are found to be net transmitters of shocks to the systems, while inflation and output gaps are net receivers of shocks from the system. Output gap is the largest receiver of shocks from the system, largely via real policy rate shock and this is consistent across forecast horizons. However, the dominance of net volatility spillovers (excluding own shock) is frequency-dependent as the real policy rate emerges as the largest transmitter of shocks at the shorter forecast horizon, while exchange rate becomes the largest shock transmitter to the system at the longer forecast horizon. This intuitively indicates the capacity of the monetary policy instrument to impact the real economic variables and equally underscores the important influence of real exchange rate in macro-dynamics of Ghana. Nevertheless, the magnitude of volatility spillovers from policy interest rate to and from the targeted macro-variables (particularly

[104] Signalling ability in this chapter means a leading variable or having strong influence on other variable(s).

output gap and inflation) appears to be moderate even in the long run, surmising less effective monetary policy transmission. The chapter articulates that a continuous maintenance of exchange rate stability is germane for the attainment of overall macroeconomic stability in the country. The chapter thus offers adequate knowledge of macroeconomic connectedness and policy transmission not only crucial for the effective use of policy instrument(s) but also for the understanding of the MPTM and entire macrostructure of Ghana.

In chapter five, we explore the actual monetary policy making in Ghana by appraising the policy rule followed by Central Bank of Ghana over the past one and half decades. This is to primarily ascertain whether monetary policy in Ghana can be more precisely described by either (i) the standard linear Taylor rule, or (ii) an augmented linear rule including exchange rate or (iii) a nonlinear augmented threshold rule. The chapter thus determines the relevance of the exchange rate in monetary policy rule in Ghana and whether monetary policy reactions to inflation and/or output gaps are symmetric and conforms to the Taylor principles. This is motivated by the persistently high inflationary environment amid recurrently large domestic and external shocks as well as the predominant volatility spillovers from exchange rate emphasized by the preceding chapter.

By employing macroeconometric techniques such as generalized methods of moment (which is able to avert potential endogeneity problems), Frequentist and Bayesian quantile regression methods and the standard threshold regression developed by Hansen (1999), the basic finding is that an asymmetric (nonlinear) monetary policy rule captures the behaviour of interest rate settings in Ghana better than a symmetric (linear) rule. There is strong evidence of monetary policy inertia in Ghana as the coefficient of lagged interest rate is close to unity. The estimated instant coefficient for inflation gap is positive and statistically significant, but the authority is rather more inclined to react strongly to above-target inflation (i.e. inflationary pressures) in the medium-to-long term than in the short-term. The Bank of Ghana however appears not to have followed a fixed rule as interest rate reaction to output, inflation and exchange rate differs depending on the prevailing conditions. In the normal policy environment (i.e. non-threshold rule), the central bank rather reacts strongly to the current (positive) inflation gap across historical time interval and time-frequency domain. Under such environment, a nonlinear non-augmented rule is appropriate as the inclusion of exchange rate increases the variances of both inflation and output gap, a contradiction to the findings of Ball (1999) and Debelle (1999). Yet, the relevance of exchange in the policy rule for Ghana is purely regime-specific. Notably, the exchange rate exerts an important influence on interest rate settings in the low inflation regime, supporting an augmented nonlinear (threshold) Taylor rule for Ghana in the latter regime. The greater policy reaction to the

exchange rate in the low inflation regime is underscored by the inclination for policy makers to chase other objectives when the inflation rate undershoots the target and rely also on the exchange rate channel for stabilizing the economy (Akdogan, 2015). Although there is still ample evidence of policy aversion to positive inflation gap in normal and/or low inflation regime, the Bank of Ghana does not methodically adhere to the Taylor principle as both the instant and cumulative policy reaction to inflation gap are below unity across quantile and timescales.

Chapter six develops a standard small-open economy New Keynesian (NK) general equilibrium model with representative optimizing consumers (RANK) for monetary policy analysis in Ghana. In terms of empirical analysis, the RANK DSGE model developed in this chapter shares the essential features of this class of standard New Keynesian models. The model has two economies (Home and Foreign) that interact in both goods and financial markets. The home economy is assumed to be insignificantly small in size relative to the foreign economy. Consequently, the foreign economy is assumed to be exogenous to developments in the domestic economy. Essentially, the model consists of forward-looking agents who are made up of households, firms and government. Households maximize their expected lifetime utility by consuming goods (domestically produced and foreign imports) and supplying labour and capital to firms. Households are able to smooth consumption via external habit formation in consumption. The firm, in turn, produces goods and set prices so as to maximize expected profit. Government comprises a fiscal authority that ensures a balanced budget at all times but undertakes only consumption spending (no public investment), and a monetary authority that sets the short-term interest rate based on the level of expected future inflation and current output gaps. In line with the literature, the model also introduces a relatively large number of additional frictions that are essential to mirror the empirical persistence and covariance in the main macroeconomic data of Ghana. In addition to habit formation in consumption, the model assumes that both price and wages are sticky a la Calvo. The model also incorporates a full set of structural shocks that are standard in recent New Keynesian DSGE models. We use six (6) macroeconomic variables over the period 2000Q1-2017Q4 while utilizing period 2000Q1-2007Q2 as training data. The variables are real GDP, private consumption, government consumption spending, private investment, consumer inflation and nominal interest rate for the home economy. The Euro Area is chosen as a representative foreign economy mainly due to their sizeable share (about 34.61%) of Ghana's external trade (see, Akosah et al., 2018).

Empirically, there is a conspicuous evidence that a forward-looking monetary policy rule - where authority reacts to one-period-ahead inflation deviation from target alongside current output gap - is the most appropriate one for Ghana. Therefore, adhoc inclusion of exchange rate in most empirical policy rules, especially for developing economies is inclined to generate less plausible estimates for

policy inference. Variations in output are mainly driven by price markup, labour supply, monetary policy and productivity shocks, indicating that monetary policy matters for output growth in Ghana, while changes in consumer inflation are largely compelled by exchange rate risk premium and price mark-up shocks, implying foreign spillovers via exchange rate channel. Changes in domestic interest rate, on the other hand, are primarily driven by price mark-up, domestic monetary policy and government spending shocks. The chapter identifies that shocks originating from the foreign economy have a broadly minimal direct impact on domestic macroeconomy, although potential indirect effects via the exchange rate channel (and by extension the trade channel) appear to be very important. We find that monetary policy response to macroeconomic shocks is broadly consistent with economic theory as authority adopts tightening (or easing) stance amid adverse (or favourable) shock. Yet, while contractionary monetary policy shock successfully depresses output, it is prone to price puzzle as consumer inflation increases instantly and only returns to the steady state after twenty quarters. Additionally, even though government spending shock boosts output growth and private investments but crowds-out private consumption, it does not allow many variables to return to their steady-state values. Consequently, the standard DSGE model with representative agent (RANK model) does not generate meaningful impulse response functions and hence not suitable for monetary policy investigation in Ghana. These deficiencies therefore call for a more suitable model that would capture some other notable features of developing economies (such as allowing for the cohabitation of optimizing and non-optimizing households) and be able to generate meaningful impulse response functions for monetary policy investigation in these economies.

As a consequent, the model in chapter six was extended further in chapter seven to account for heterogeneous consumer behaviour given the fact that there is large proportion of unbanked population in Ghana (see Kaplan et al., 2018, 2014; Dagher et al, 2012). Comparatively, therefore, chapter seven develops and assesses the suitability of a small-open economy DSGE model with heterogeneous agents (i.e. HANK) for macroeconomic policy investigations (i.e. monetary and fiscal policies as well as foreign spillover effects). In line with the empirical literature, this chapter develops a small-open economy DSGE model with heterogeneous agents (i.e. HANK) that has the same essential features and frictions in as the RANK-DSGE model except for the coexistence of both non-Ricardian and Ricardian consumers. The chapter also has the same objectives as in chapter six since it is just an extension of the latter.

Following the empirical literature, we initially estimate possible range of shares of non-Ricardian consumers based on the theoretical Euler consumption equation that is augmented with output

(income) using two stage least squares technique (particularly, the Generalized Method of Moments, GMM). The estimated possible range of shares for non-Ricardian consumers are then used as prior means in our HANK DSGE model along with alternative specifications of monetary policy rules and different prior distributions for the Calvo parameters. In the third stage, the preferred HANK-DSGE model along with alternative scenarios (based on different market structure or rigidities) is used to address the following policy questions: Does the model generate meaningful impulse response functions? That is, are monetary policy responses to macroeconomic shocks consistent with economic theory? Or, are macroeconomic responses to monetary policy shock consistent with economic theory? What are the main driven forces of output and inflation in the Ghanaian economy? Giving the crucial role of the public sector in employment and consumption in most developing economies, does government consumption spending crowd-out private consumption in Ghana as alluded to by the relevant economic theory? Are there significant spillovers effects from the foreign economy to the Ghanaian economy?

The empirical analysis of the HANK-DSGE model yields the most appropriate prior mean for the share of non-Ricardian consumer to be 0.425 for Ghana which in turn produces a corresponding posterior mean of 0.464 with a 95% confidence interval of [0.429 0.501]. This suggests that about 46.4% of consumers are classified as non-Ricardian, given the Ghanaian macro-dataset. Consistent with the empirical literature, we identify that the out-of-sample forecasting performance of our estimated baseline HANK-DSGE model outshines the RANK-DSGE model. Similar to the RANK-DSGE model, we identify the most appropriate monetary policy rule for Ghana to be a forward-looking policy rule - where the monetary authority responds to one-quarter-ahead inflation deviation from target together with contemporary output gap. Monetary and fiscal policies are found to exert significant impacts on business cycle developments in Ghana and this is particularly robust to the extent of market rigidities. Contrary to the RANK model, the chapter finds that monetary policy to influence aggregate output and inflation in a way that is consistent with economic theory and hence, not prone to price puzzle. This is however contingent on a continuous strict adherence to the Taylor principles by monetary authority, given the extent of market rigidities and the share of non-Ricardian consumers. Akin to the RANK-DSGE estimates, there is ample evidence of crowding-out effect of positive government spending shock on aggregate private consumption in the baseline HANK-DSGE model with Calvo price and wage rigidities, despite low or high fraction of non-Ricardian consumers. In addition, baseline HANK-DSGE model is able to solve one of the great problems of the standard DSGE models - the positive reaction of real wage to increased government spending shock which is

empirically inconsistent. Also consistent with RANK model, the exchange rate remains an important channel through which both domestic and foreign spillovers affect the Ghanaian macroeconomy.

8.1 Conclusion and Policy Implications

Collectively, several key policy arguments and conclusions are deduced from the thesis. First and foremost, the thesis classifies Ghana as an Inflation-Forecast-Targeter (IFT). Clearly, the West African nation has not yet reach the status of a fully-fledged IFT economy as it was found not have satisfied certain key transparency requirements for an fully-fledged IFT economy. To advance to a fully-fledged IFT status, the Bank of Ghana (BOG) therefore has to follow the best practices of major central banks to, among others, disclose the conditional numerical forecast path of the endogenous policy interest rate within its core quarterly projection model. This facilitates the understanding of how the monetary authority in Ghana has been addressing the short-run output-inflation trade-offs. Importantly, it is evidently clear that the existing legal framework (in terms of clarity in policy objectives and central bank independence, etc.) for BOG's operations is consistent with the IT tenet. In addition, the estimated score reinforces the findings by Dincer and Eichengreen (2014) and Naszodi et al., (2016) that the Bank of Ghana is less transparent which contributes to the entrenched inflation inertia. By extension, the moderate score is also an indication that the central bank may be perceived to be incredible by private agents. This implies further that economic agents' formation of inflation expectation would be continue to be backward-looking, as alluded to by Kovanen (2011), which does not bode well for realizing the core policy objective of price stability in Ghana. More importantly, the relatively low-to-moderate score for BOG emanated largely from low level of policy transparency about its forecasting framework (FPAS model) and the procedural policy processes. And to boost monetary policy transparency, the thesis identifies the following salient areas that require critical attention from the central bank of Ghana: (1) the documentation and publication of the core quarterly projection model (FPAS) with key equations (especially the loss function); (2) the provision of more information about how the Bank is dealing with the short-run sacrifice ratio (i.e. tradeoffs between output and inflation); (3) public access to the minutes from the MPC meetings with or without detailed contributions by MPC members; (4) evaluating and publishing how each decision on policy instrument or target are attained; (5) in addition to regular publication of fan chart for inflation in the monetary policy report, the Bank should also consider publishing other core macroeconomic variables that are included in their baseline forecasts with confidence bands, risk assessments, and decomposition of forecast revisions; (6) the underlying methodology for the construction of forecast confidence bands should also be clearly explained; (7) there is the need for regular review of forecasting performance of the central bank and this should be made accessible to the public; (8) Continuous external evaluation

of the policy framework and the FPAS at least every 5 years even when not under IMF program, and publishing the findings.

Second, despite the fact that the IT strategy has generally enhanced macroeconomic management in Ghana, there is still higher degree of inflation persistence and backward-looking inflation expectation formation by economic agents. The latter empirical findings can be attributed to weak monetary policy pass-through to the real economy due to protracted policy transmission lags, unremitting high levels of government debt and frequent supply-side shocks (e.g. exchange rate depreciation at the back of unfavourable growth of traditional export market) which create new sources of economic pressures that the central bank finds it difficult to ignore.

Third, both real policy rate and exchange rate are net transmitters of shocks, while inflation and output gaps are net receivers of shocks. Yet, exchange rate exerts a predominant influence on the Ghanaian macroeconomic outcomes, indicating the former as the leading channel of monetary policy transmission in Ghana. Accordingly, the thesis emboldens the Bank of Ghana to continuously uphold stability in the domestic currency in order to successfully accomplish its price stability objective.

Fourth, there is clear indication that asymmetric monetary policy rule in Ghana. Yet, the monetary authority has, over the years, not responded to inflation shocks in a manner recommended by the Taylor principle, given its external and domestic constraints. This observation further surmises that the monetary authority in Ghana has broadly been very accommodative to inflationary pressures as other policy interventions have not yielded the intended purpose of successfully taming inflation. The passive response to inflationary pressures is primarily underpinned by weak institutions (Bleaney et al. 2020) as well as inefficient transmission of monetary policy to the money market and the real sector (Kovanen 2011). However, the monetary authority becomes more forward-looking in the high inflation regime as its cumulative reaction to expected inflation exceeds unity. On a whole, the Bank of Ghana is more aggressive toward inflation than output growth. There is thus an apparent policy pursuit of a precautionary demand for price stability in a quest to building policy credibility, consistent with the findings of Bleaney et al (2020), Dolado et al (2005), Chevapatrakul and Paez-Farrell (2014). The weak policy response to output gap could either mean an increased output uncertainty as the authority is unable to accurately gauge the true state of the Ghanaian business cycle at the time of decision making or the authority does not react to the real economy independently from its concerns about inflation. The weak evidence of heterogeneous policy preferences in different political regimes also implies that BOG duly exercises its operational independence (as enshrined in BOG Act 612) in using its policy instruments in Ghana irrespective of the political administration.

Fifth, the thesis reinforces clear contribution to the literature regarding empirical evidence of non-Ricardian consumers (with 95% confidence interval of 42.9%-50.1%) who are not able to smooth consumption intertemporarily in Ghana and hence, not directly influenced by monetary policy shock via interest rate. We can also conclude that HANK models that allows for the coexistence of non-Ricardian and Ricardian consumers deliver consistent and meaningful impulse response functions and hence, most suitable for monetary policy analysis in Ghana. Therefore, the monetary framework for forecasting and policy analysis (FPAS) should consider including a share of consumers who are non-Ricardian in order to adequately reflect the actual dynamics of the Ghanaian macroeconomy and other countries with similar characteristics. On the other hand, a collective observation from both general equilibrium models is that monetary and fiscal policies exert significant impacts on business cycle developments in Ghana. It is also evident that fiscal policy plays a crucial role in monetary policy stabilization efforts in Ghana. Consequently, continuous fiscal prudence remains fundamental for the attainment of broad macroeconomic stability objectives in Ghana.

Last but not the least, the thesis concludes that a forward-looking monetary policy rule – where authority react to one-period-ahead inflation deviation from steady state along with current output gap - is the most appropriate monetary policy rule for Ghana. By implication, adhoc inclusion of exchange rate in monetary policy rules for Ghana (as often observed in most empirical studies) is likely to yield less plausible estimates for accurate policy inference especially when using non-threshold models.

In term of relevance, the thesis covers a broad range of topics on monetary policy transmission and its effectiveness that are of practical importance to policymakers, practitioners, businesses and academics alike, especially in developing and frontier economies that are saddled with acute structural challenges. This together with the rich theoretical, conceptual and empirical background drawn from a wide scope of literature reasonably make the thesis standout in the extant literature on the monetary policy conducts of central banks in the developing and frontier economies. Conspicuously, the thesis thus makes novel and important contribution to the literature from both empirical and methodological perspectives. For instance, the extant literature so far offers no perspective on monetary policy dynamics within time-frequency (multiscale) domain despite the fact that the relevance of time-frequency analysis is highly articulated in the extant literature. In terms of methodological contribution, the application of time-frequency techniques shows that this thesis has substantially extended the analysis of monetary policy conducts in an area not yet explored in the current literature. This implies that the thesis is among the few studies, if not the first, to investigate the conduct of monetary authority within multiscale domain along with Bayesian quantile inference, which is a novel

contribution. Empirically, the findings of the thesis also provide new and unique perspectives that extend current understanding of the monetary policy framework and its inter-connectedness with the real sector within a frontier or developing economy saddled with underdeveloped financial markets as well as heterogeneous economic agents. In sum, the analyses and discussions in this thesis significantly add to the body of knowledge which will be applicable not only to Ghana but also to other developing countries.

8.2 Limitations of the Thesis

Like most studies, this thesis is not without limitations. The key limitation to the thesis and its findings is the lack of large datasets which is mostly prevalent in developing economies. Although significant effort is made to ensure more robust estimates by using Bayesian estimation techniques due to the small sample size, the thesis would have considerably benefited from the availability of large dataset. It is unclear whether the replication techniques adopted in the Bayesian estimation methods as well as the application of wavelet techniques helped avert potential small sample bias in the thesis. Consequently, the empirical findings of this thesis can serve as benchmarks or reference points for future studies that will benefit from the availability of large data sample.

8.3 Areas of Further Research

The thesis empirically examines monetary policy making in Ghana using various econometric techniques, culminating in the development of a New Keynesian DSGE model with heterogeneous consumers. Particularly, the thesis has investigated the implications of non-Ricardian households on the transmission of monetary and fiscal policies by utilizing most of the standard features of a medium-size DSGE model. It has a small open economy framework which fits the Ghanaian economy much better than the closed economy design; it contains price and wage rigidities, habit formation, labour unions, a forward-looking monetary policy rule and a simple fiscal rule (where lump-sum taxes increase in response to a rise in public debt and/or government spending). In addition, we use impulse response of eleven additional shocks. Nevertheless, the fiscal policy analysis concentrates exclusively on government consumption spending shock along with a simple fiscal rule. Consequently, one possible extension is to incorporate other fiscal policy tools in a HANK-DSGE framework to examine the effects of structural shocks to (a) public investment spending, (b) transfers and (c) discretionary taxes. Besides, it will be curious to extend the HANK-DSGE framework in this chapter to incorporate adjustment costs on investment and under-utilization cost of installed capacity in the context of Ghana and other developing economies with similar characteristics. Our model also assumed separable consumer utility function in consumption and labour. But it would be interesting to further consider

adopting intratemporal nonseperability between consumption and labour, as this would play a significant role in the response of consumption to various shocks.

9.0 References

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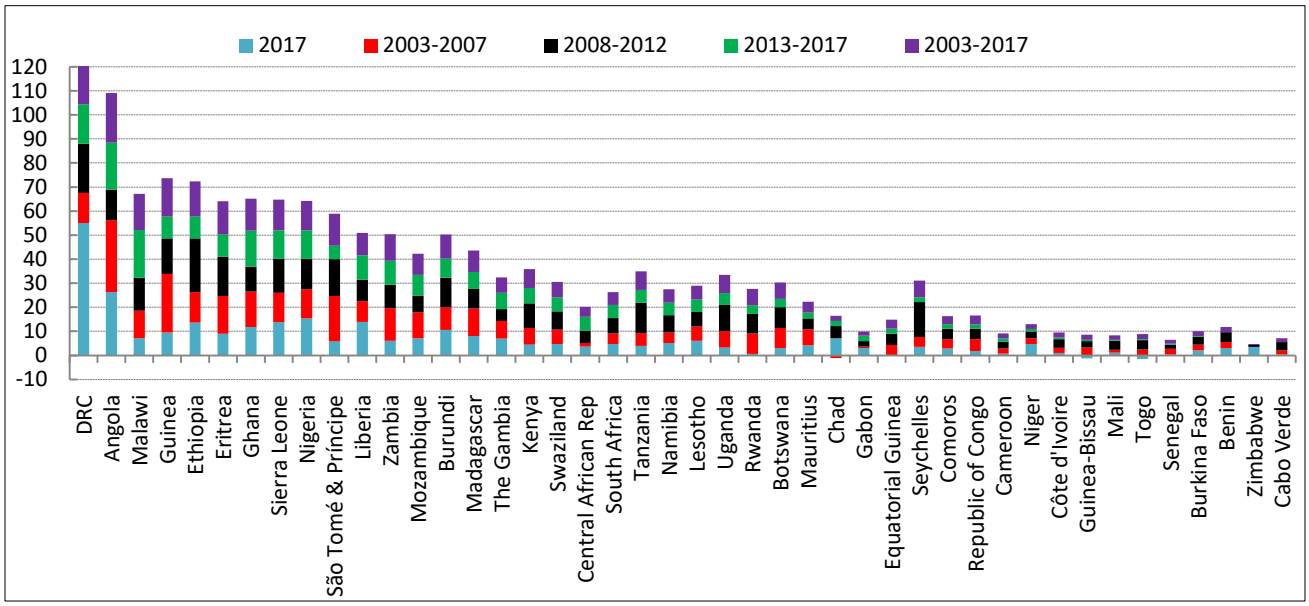
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10. Appendix

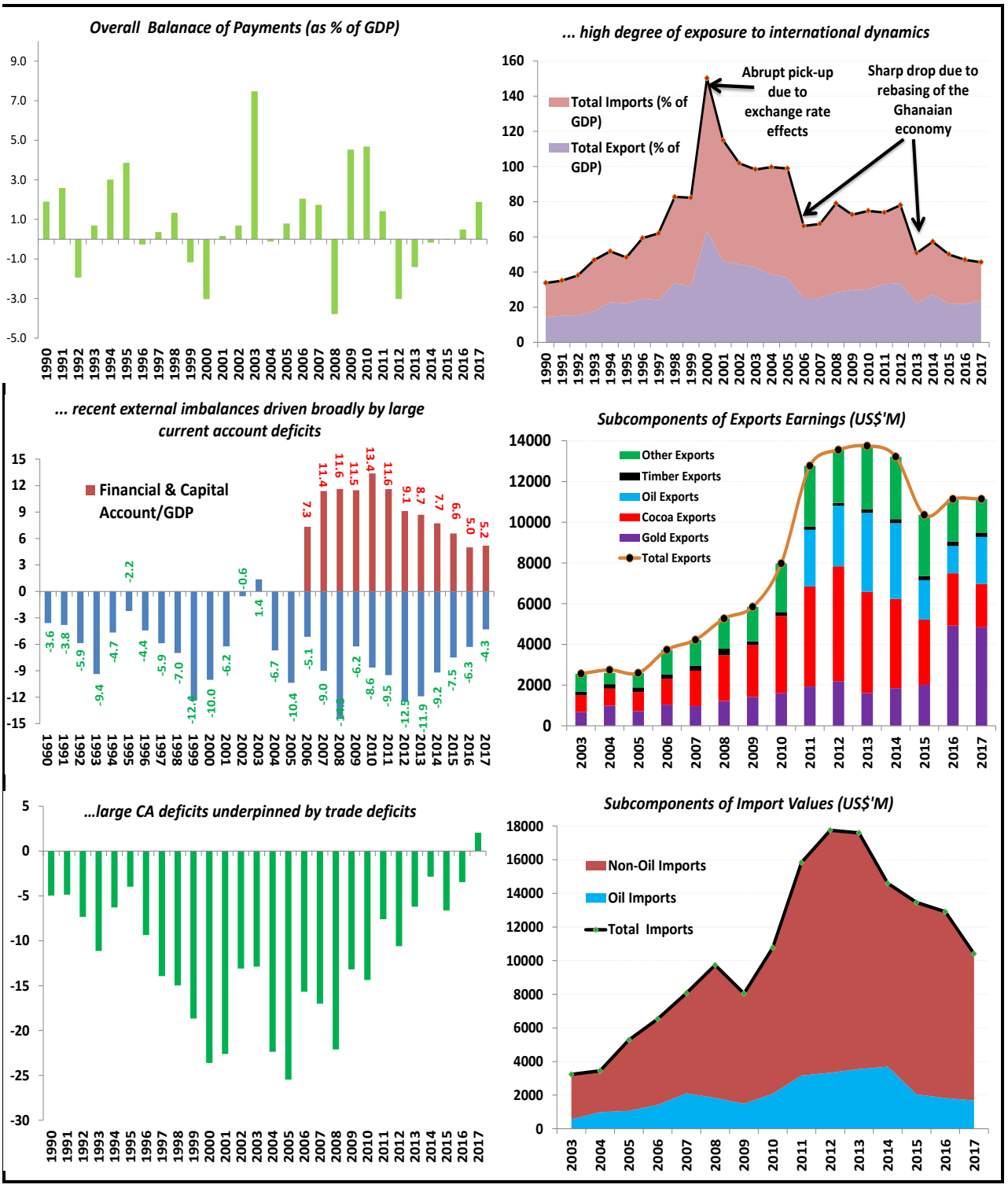
Appendix 1A

i: Headline CPI Inflation for sub-Saharan African (SSA) Economies (End of Period, %)



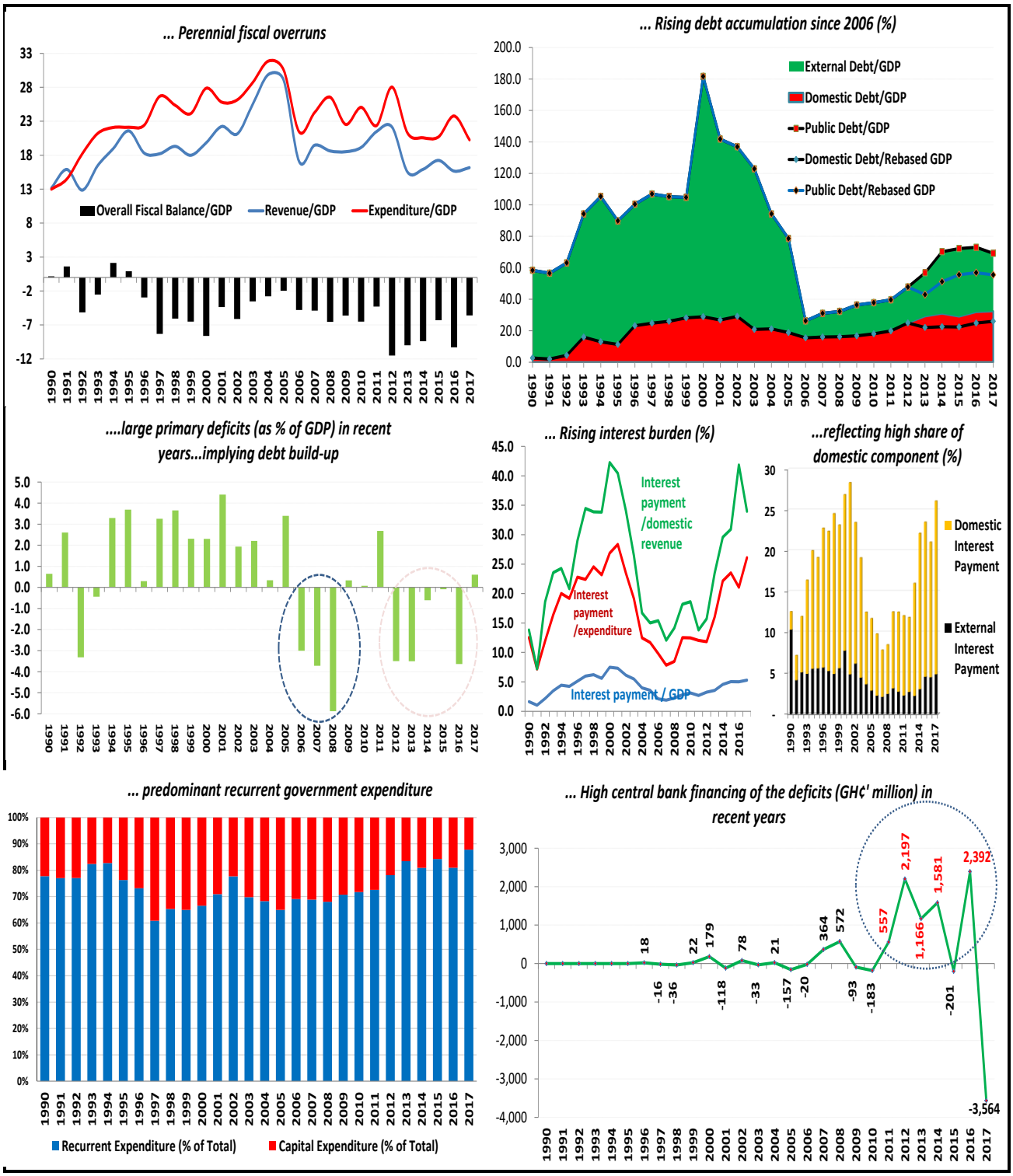
Source: Authors' construct based on data from IMF's Regional Economic Outlook (April 2018)

ii: External Sector Performance Indicators for Ghana



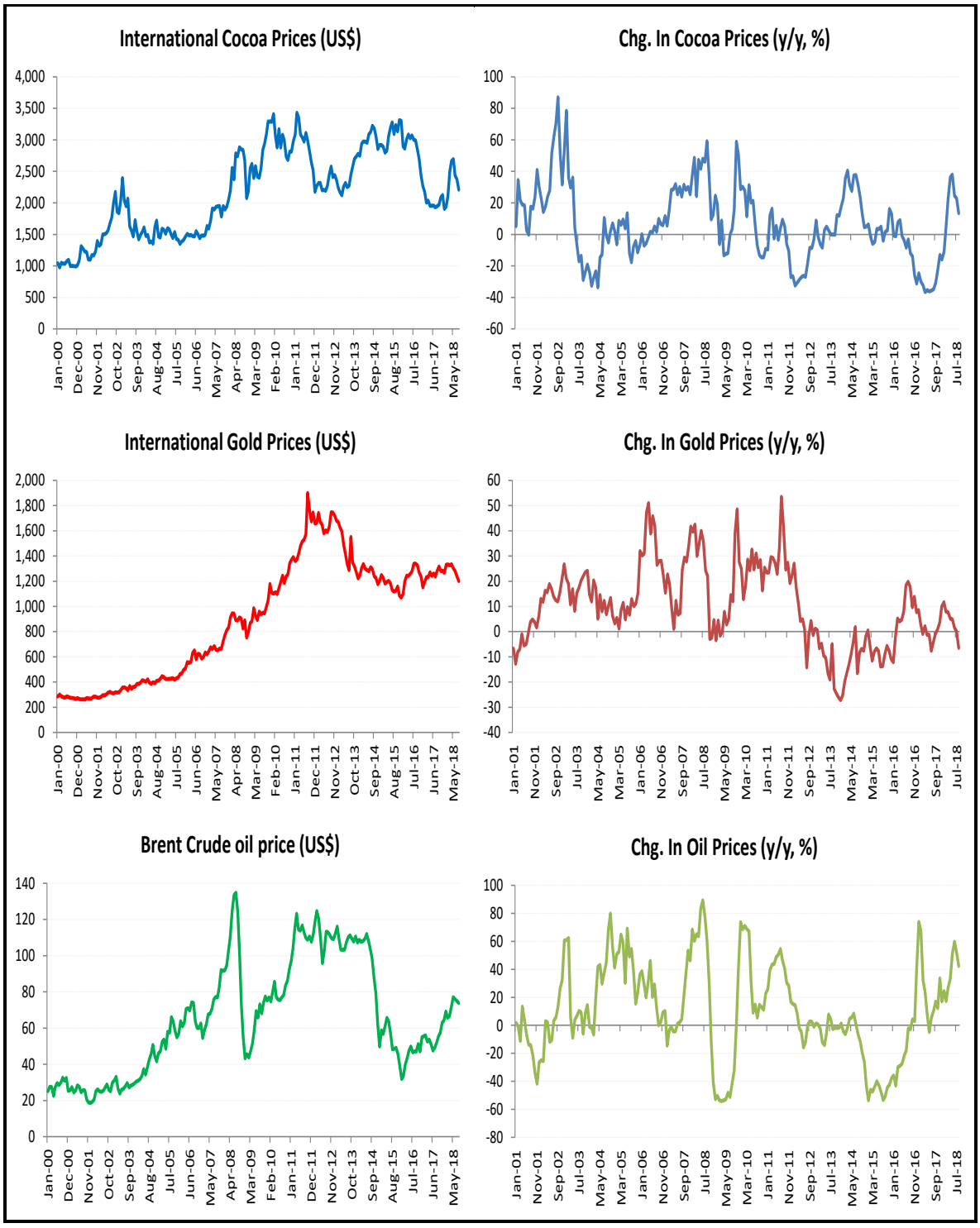
Source: Authors' construction based on data from BOG and GSS

iii: Ghana's Fiscal Profile



Note: the figure employs the rebased GDP numbers for 2010 and 2018 that used 2006 and 2013 as base-year respectively. Source: Own construct based on data from BOG, MOFEP and GSS.

iv: Dynamics of International Commodity Prices



Source: Authors' construction based on data from BOG

Appendix 2A

Application of Dincer-Eichengreen (DE) Central Bank Transparency Questions and Scores for Bank of Ghana

i. Political Transparency

	Questions	D-E Score	BOG Score
(a)	Is there a formal statement of the objective(s) of monetary policy, with an explicit prioritization in case of multiple objectives?		
i.	No formal objective(s)	0	
ii.	Multiple objectives without prioritization.	1/2	
iii.	One primary objective, or multiple objectives with explicit priority.	1	1
(b)	Is there a quantification of the primary objective(s)?		
i.	No	0	
ii.	Yes	1	1
(c)	Are there explicit contacts or other similar institutional arrangements between the monetary authorities and the government?		
i.	No central bank contracts or other institutional arrangements	0	
ii.	Central bank without explicit instrument independence or contract	1/2	
iii.	Central bank with explicit instrument independence or central bank contract although possibly subject to an explicit override procedure	1	1

Author: There is clear policy objective and target at the bank's website

ii. Policy Transparency

	Questions	DE Score	BOG Score
(a)	Are decisions about adjustments to the main operating instrument or target announced promptly?		
i.	No or only after the day of implementation	0	
ii.	Yes, on the day of implementation	1	1
(b)	Does the central bank provide an explanation when it announces policy decisions?		
i.	No	0	
ii.	Yes, when policy decisions change, or only superficially	1/2	
iii.	Yes, always and including forwarding-looking assessments	1	1
(c)	Does the central bank disclose an explicit policy inclination after every policy meeting or an explicit indication of likely future policy actions (at least quarterly)?		
i.	No	0	
ii.	Yes	1	1

Authors: The press release and monetary policy report provide reasons underpinning policy decisions at the time.

iii. Economic Transparency

	Questions	D-E Score	BOG Score
(a)	Is the basic economic data relevant for the conduct of monetary policy publicly available? (The focus is on the following five variables: money supply, inflation, GDP, unemployment rate and capacity utilization.)		
i.	Quarterly time series for at most two out of the five variables	0	
ii.	Quarterly time series for three or four out of the five variables	1/2	1/2
iii.	Quarterly time series for all five variables	1	
(b)	Does the central bank disclose the macroeconomic model(s) it uses for policy analysis?		
i.	No	0	0
ii.	Yes	1	
(c)	Does the central bank regularly publish its own macroeconomic forecasts?		
i.	No numerical central bank forecasts for inflation and output	0	
ii.	Numerical central bank forecasts for inflation and/or output published at less than quarterly frequency	1/2	1/2
iii.	Quarterly numerical central bank forecasts for inflation and output for the medium term (one to two years ahead), specifying the assumptions about the policy instrument (conditional or unconditional forecasts)	1	

Author: The FPAS model is not published but summary of economic and financial statistics are published after policy meetings. Fan chart for inflation is published in quarterly frequency since 2003 while annual projections of real GDP (output) growth (up to 2years) are published since 2017.

iv. Operational Transparency

	Questions	DE Score	BOG Score
(a)	Does the central bank regularly evaluate to what extent its main policy operating targets (if any) have been achieved?		
i.	No or not very often (at less than annual frequency)	0	
ii.	Yes but without providing explanations for significant deviations	1/2	1/2
iii.	Yes, accounting for significant deviations from target (if any); or, (nearly) perfect control over main operating instrument/target	1	
(b)	Does the central bank regularly provide information on (unanticipated) macroeconomic disturbances that affect the policy transmission process?		
i.	No or not very often.	0	
ii.	Yes but only through short-term forecasts or analysis of current macroeconomic developments (at least quarterly)	1/2	0
iii.	Yes, including a discussion of past forecast errors (at least annually)	1	
(c)	Does the central bank regularly provide an evaluation of the policy outcome in light of its macroeconomic objectives?		
i.	No or not very often (at less than annual frequency)	0	0
ii.	Yes but superficially	1/2	

iii.	Yes, with an explicit account of the contribution of monetary policy in meeting the objectives	1	

Author: The press releases and monetary policy reports provide reasons for deviation as well as the looming risks to inflation and output. However, external policy evaluation is done by IMF but not very often. Yet, there is no policy evaluation document on the bank's website.

v. Procedural Transparency

	Questions	DE Score	BOG Score
(a)	Does the central bank provide an explicit policy rule or strategy that describes its monetary policy framework?		
i.	No	0	0
ii.	Yes	1	
(b)	Does the central bank give a comprehensive account of policy deliberations (or explanations in case of a single central banker) within a reasonable amount of time?		
i.	No or only after a substantial lag (more than eight weeks)	0	0
ii.	Yes, comprehensive minutes (although not necessarily verbatim or attributed) or explanations (in case of a single central banker), including a discussion of backward- and forward-looking arguments.	1	
(c)	Does the central bank disclose how each decision on the level of its main operating instrument or target was reached?		
i.	No or only after a substantial lag (more than eight weeks).	0	0
ii.	Yes, comprehensive minutes (although not necessarily verbatim or attributed) or explanations (in case of a single central banker), including a discussion of backward- and forward-looking arguments.	1	

Author**:** Minutes from policy deliberations are not published by BOG

Appendix 2B

Application and Determination of CBT-IT Transparency question and score for Bank of Ghana

Category A: Transparency about Objectives

A1. Is there a formal statement of the objectives of monetary policy emphasizing the dual mandate (or multiple objectives), and that inflation is the primary objective? Is it easily accessible on the central bank's website?	
Single inflation objective or multiple policy objectives without prioritization	**0.0**
Inflation as the primary objective such that any other objective (output, etc.) cannot be inconsistent with the primary objective of anchoring inflation and inflation expectations.	**1.0**

BOG score: 1/1

A2. Is the inflation target defined clearly?	
No medium-term numerical target over a horizon of 2-3 years or more (hereafter *medium term*).	*0.0*
Inflation target defined as a "*tolerance*" or "*control range*" target. Inflation target defined as a medium-term target, however, the meaning of the range or the band is not clear.	*0.5*
Inflation target defined as a well-defined *point* target. If a band is used, it is clearly communicated.	*1.0*

BOG score: 1/1

A3. Might financial stability objectives override the primacy of the inflation (price stability) objective? If the central bank does not have a financial stability responsibility, it should be explicit that it uses the policy interest rate tool to affect financial conditions to the extent that it affects the output gap and hence achieving the inflation target.	
(i) Another institution is responsible for financial stability.	
Central bank cares about financial stability to the extent that it affects stabilization objectives (output and unemployment), but it is unclear that inflation is the primary objective.	*0.0*
Central bank cares about financial stability to the extent that it affects stabilization objectives (output and unemployment), and makes it clear that inflation is the primary objective.	*1.0*
(ii) Central bank is at least partly responsible for financial stability.	
The borderlines between the monetary policy and financial stability tools are unclear. This creates confusion about the primary objective of price stability.	*0.0*
The central bank has both monetary policy and macro-prudential tools and it is clear how the central bank adjusts its tools to achieve its monetary policy and financial stability objectives.	*1.0*

BOG score: 1/1; Bank of Ghana (amendment) Act 2016 indicates clear financial stability mandate of BOG aside the prime objective of price stability.

A4. Does the central bank use a loss function evaluation to show how well it has been doing in managing the short-run output-inflation tradeoff?

No.	0.0
Yes.	1.0
Perfect score requires: the central bank should publish the values of the loss function and represent them in a chart.	

BOG score: 0/1

BOG's Total Score for Category A =3/4

Category B: Transparency about the FPAS

B1. Are the basic economic data relevant for the conduct of monetary policy publicly available in a downloadable format from the central bank's website (could also include links to other statistical agencies)? For example, data reported in the monetary policy reports should be made available on the website.	
No database is publicly available	0.0
A minimal set of series is publicly available, output gap or other ways of measuring capacity utilization, inflation, inflation expectations, wages, unemployment, and GDP.	0.5
All series used in producing the MPR are published in a downloadable format, such as an Excel spreadsheet. These series include at least the seven series above (capacity utilization (preferably the output gap), inflation, inflation expectations, wages, unemployment, and GDP).	1.0

BOG score: 0.2 /1 *as only inflation and GDP are available.*

B2. Is the core quarterly projection model (model used for policy-making) publicly available and documentation updated within the last 5 years?	
No	0.00
Yes, in a "working paper" format only, i.e., irreproducible	0.25
Yes, in a working paper and with code.	0.50
Yes, in a working paper, with code, and web-based front-end to modify forecast assumptions.	1.00

BOG score: 0/1

B3. How transparent is the central bank about the reaction functions (or loss functions) that are used to compute the interest rate paths (or paths for other instruments when the policy rate is constrained by the ELB) in their regular projection exercises? Do the monetary policy reports include a reference to the core model documentation that has the reaction function or the loss function?	
The central bank does not publish either the reaction function or the loss function.	0.0
The central bank publishes the reaction function and/or loss function (with the coefficients) in an easily accessible place on the central bank's website.	1.0

BOG score: 0/1

B4. For what variables does the central bank publish a consistent endogenous-instrument (e.g., policy rate) quarterly macroeconomic projection over a horizon of at least two years?

None.	0.0
Inflation.	0.2
Inflation and GDP growth.	0.4
Inflation, GDP growth, and the endogenous interest rate path.	0.6
Inflation, GDP growth, the endogenous interest rate path, and the output gap.	0.8
Inflation, GDP growth, the endogenous interest rate path, the output gap, and the exchange rate.	1.0

BOG score: 0/1. No quarterly forecast time series are published in the monetary policy (MP) report since 2008.

B5. Does the central bank regularly publish forecast densities (fan charts) to communicate forecast uncertainty?	
No fan charts.	0.0
Fan chart for inflation.	0.2
Fan charts for inflation and GDP growth.	0.4
Fan charts for inflation, GDP growth, and the endogenous interest rate path.	0.6
Fan charts for inflation, GDP growth, the endogenous interest rate path, and the output gap.	0.8
Fan charts for inflation, GDP growth, the endogenous interest rate path, the output gap, and the exchange rate.	1.0

BOG score: 0.2/1. Only Fan chart for inflation is published since 2010

B6. Is the underlying methodology constructing the forecast densities (fan charts) clear and easily accessible? *For example, do the regularly published forecast densities (fan charts) reflect (i) monetary policy reaction to shocks (model-based stochastic simulations); (ii) historic experience (past forecast errors); (iii) judgment (e.g., magnitude of structural shocks versus measurement errors); and (iv) other constraints (e.g., effective lower bound)?*	
No fan chart or the fan chart methodology is not explained.	0.0
Fan charts published in all monetary policy reports and the methodology is clearly explained and/or links to a technical paper is provided.	1.0

BOG Score: 0/1. Fan chart for inflation is provided but without underlying methodology

B7. Does the central bank regularly publish an assessment of forecast revisions (decomposition of forecast changes vis-à-vis the previous forecast)?	
No	0.0
For inflation only with a discussion of the underlying causes.	0.2
For inflation and GDP growth with a discussion of the underlying causes.	0.4
For inflation, GDP growth, and the endogenous interest rate path with a discussion of the underlying causes.	0.6
For inflation, GDP growth, the endogenous interest rate path, and the output gap with a discussion the underlying causes.	0.8
For inflation, GDP growth, the endogenous interest rate path, the output gap, and the exchange rate with a discussion the underlying causes.	1.0

BOG score: 0/1

B8. Does the central bank publish alternative scenarios in their monetary policy reports to illustrate key risk(s) in the baseline forecast?

No alternative scenario.	0.0
The major risk(s) is communicated in an alternative scenario(s).	1.0

BOG score: 0/1; Currently, no alternative scenario is reported in the monetary policy report.

B9. Do the monetary policy reports include historical data and forecasts for financial variables? Financial variables include long-term government bond yields, consumer lending rates, mortgage rates, equity prices, property prices, credit aggregates, corporate risky spreads (e.g., BAA-AAA bond yields), and credit standards (e.g., loan officer surveys). All data should be available in downloadable format.	
No data or forecast of financial variables is available.	0.0
Historical data on less than 5 of the above variables are available, and forecasts for less than 5 of the above variables are available.	0.1-0.9*
Historical data on 5 or more of the above variables are available, and forecasts for 5 or more of the above variables are available.	1.0

* For historical series, the central bank would be awarded 0.1 for each type of financial variables up to a maximum of 0.5. For forecast series, the central bank would be awarded 0.1 for each type of financial variables up to a maximum of 0.5.

BOG score: 0.2/1; As only historical data for some of the variables are published.

BOG's total score for Category B: 0.6/9

Category C: Transparency about Policy Process

C1. Does the central bank publish a press statement immediately following the policy decisions?	
The central bank does not publish a press statement immediately after the policy decisions.	0.0
The central bank publishes press statements in the native language only.	0.5
The central bank publishes press statements in English.	1.0

BOG score: 1/1

C2. Is the policy decision explained at a press conference immediately after it is announced? Are the presentations available in English?	
No	0.0
Yes, after all policy meetings, at pre-announced dates and times. The press conference with the Q&A session is webcasted and the recording is then made available on the website. The presentations are available in downloadable form only in the native language.	0.5
Yes, after all policy meetings, at pre-announced dates and times. The press conference with the Q&A session is webcasted and the recording is then made available on the website. The presentations are available in downloadable form in English	1.0

BOG score: 1/1

C3. Does the central bank present its regular forecast updates with the Q&A session to journalists, analysts, and market participants? Are the presentations available in English?	
No.	0.0

Yes. The presentation and Q&A are available only in the native language.	0.5
Yes. The presentation and Q&A are available in English.	1.0

BOG score: 0/1

C4. Is there a public account of the policy deliberations ("minutes") published in less than one month after the meeting?	
(i) when policy decisions are made by a monetary policy committee	
No.	0.00
Yes, but condensed, non-attributed, and without voting results.	0.50
Yes, detailed and with voting results on the main policy instrument. Contributions by individual MPC members and votes are not attributed.	0.75
Yes, detailed and with voting results on the main policy instrument. Contributions by individual MPC members and votes are attributed.	1.00

BOG score: 0/1

(ii) when policy decisions are made by a single policymaker	
No.	0.0
Yes, with arguments/explanations.	1.0

BOG score: 0/1

C5. Is the role of staff and policymakers in the baseline forecast process communicated clearly?	
No. It is not clear how the forecast is constructed and is used in the decision-making process.	0.0
Yes. The ownership of the forecast and its role in the decision-making process is defined clearly.	1.0

BOG Score: 0/1; No, the roles are not officially communicated by the Bank to the public although an IMF's staff report provides some information regarding that in 2009. Source: IMF country Report No. 09/256.

C6. Is the forecasting performance of the central bank reviewed at least once a year in the monetary policy reports or in a separate document?	
No	0.0
Yes	1.0

BOG Score: 0/1

C7. When was the last time the central bank or the government held or invited an external evaluation of the policy framework and the FPAS, and made the results publicly available?	
No evaluation in last 5 years	0.0
Either policy framework or FPAS evaluation in the last 5 years.	0.5
Both policy framework and FPAS evaluation in the last 5 years.	1.0

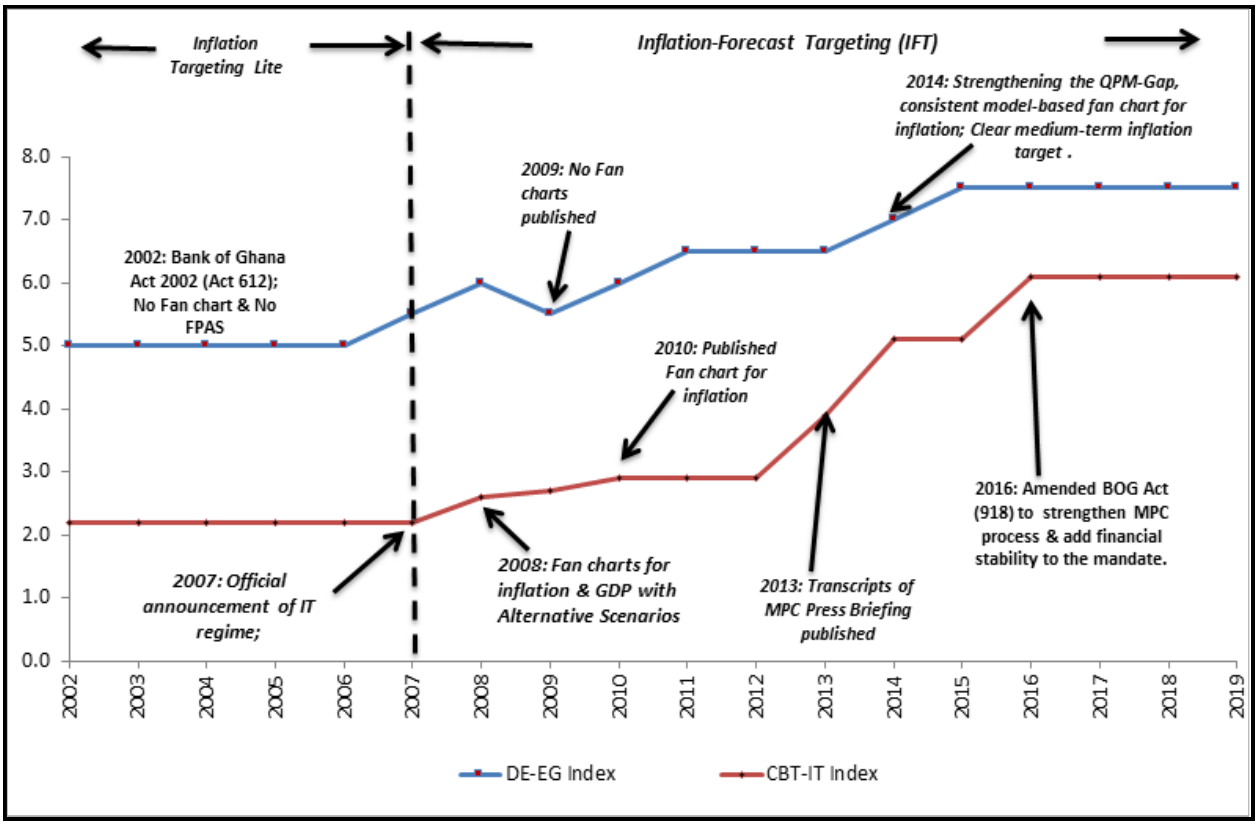
BOG Score: 0.5/1

BOG's Total Score for Category C: 2.5/7

Overall BOG's Transparency Score is: 6.1/20 == 30.5%

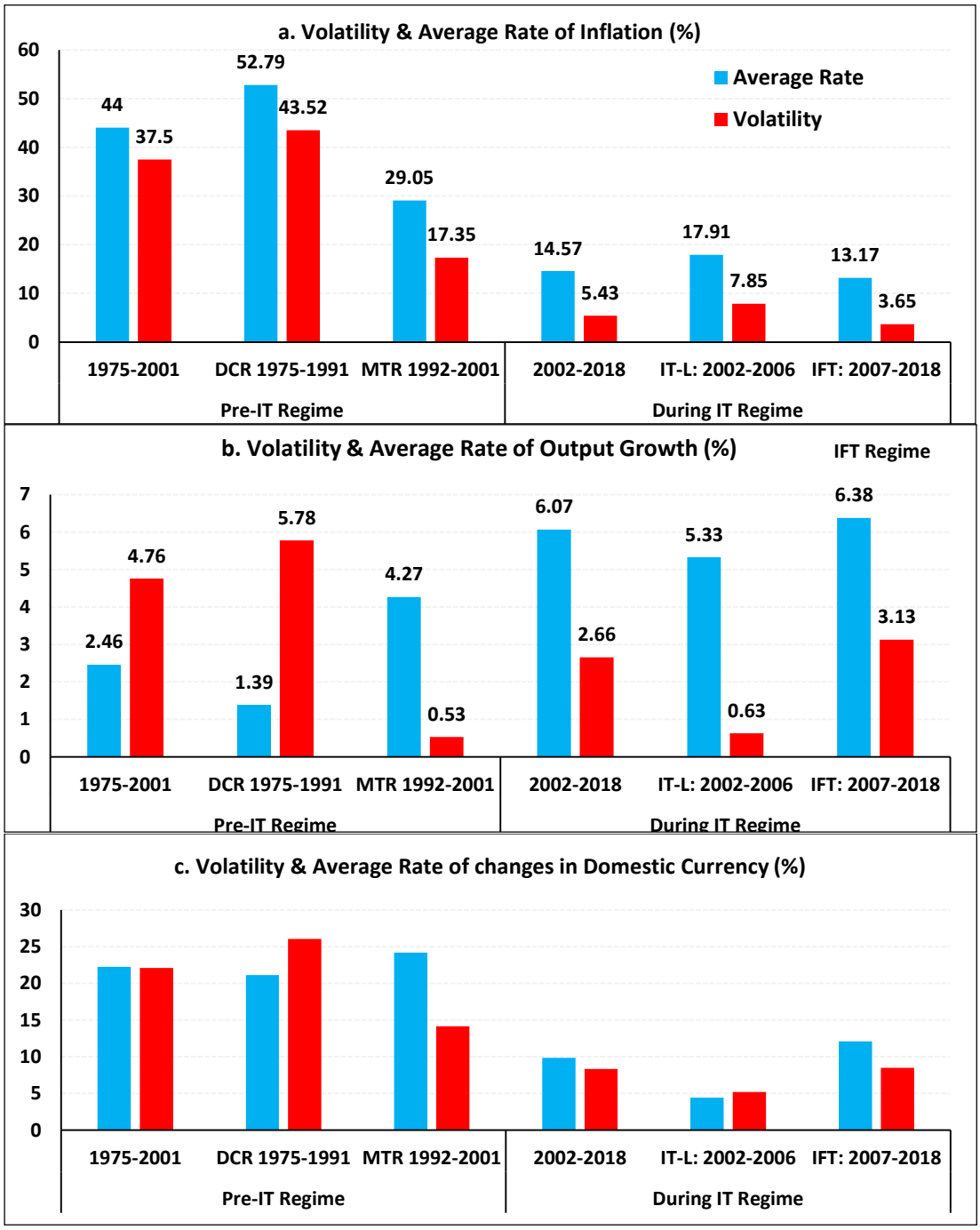
Appendix 2C

i. Historical Trends of Policy Transparency Score: DE-EG & CBT-IT Approaches



Appendix 3A

i: Relative Regime-Specific Macroeconomic Outcomes - Summary Statistics



ii: Result of Unit Root Test

	ADF Test				KPSS Test		
	Ho: Series is non-stationary				*Ho: Series is stationary*		
	None	Constant	Constant & Trend	First Difference	Constant	Constant & Trend	First Difference
MPR_t	[0.30]	[0.24]	[0.58]	[0.00]*	{0.23}	{0.22}*	{0.24}
$Tbill_t$	[0.22]	[0.06]	[0.18]	[0.00]*	{0.11}	{0.11}	{0.06}
$lcpi_t$	[0.99]	[0.78]	[0.06]	[0.01]**	{1.13}*	{0.22}**	{0.48}
ly_t	[0.99]	[0.95]	[0.29]	[0.01]**	{1.13}*	{0.13}	{0.15}
$ygap_t$	[0.00]*	[0.02]**	[0.09]	[0.00]*	{0.06}	{0.06}	{0.06}
$lxrate_t$	[0.96]	[0.99]	[0.33]	[0.00]*	{1.08}*	{0.22}**	{0.11}

Note: {} and [] denote test statistics and p-values respectively; * & ** denote 1% and 5% alpha levels respectively. MPR_t, denotes monetary policy rate; $lcpi_t$, denotes log of consumer price index; ly_t denotes log of real GDP; $Y_{gap,t}$, is output gap; $Xdep_t$ is nominal exchange rate; and $lxrate_t$ denotes log of nominal bilateral exchange rate. ADF represent Augmented Dickey-Fuller**;** KPSS denotes Kwiatkowski-Philips-Schmidt-Shin.

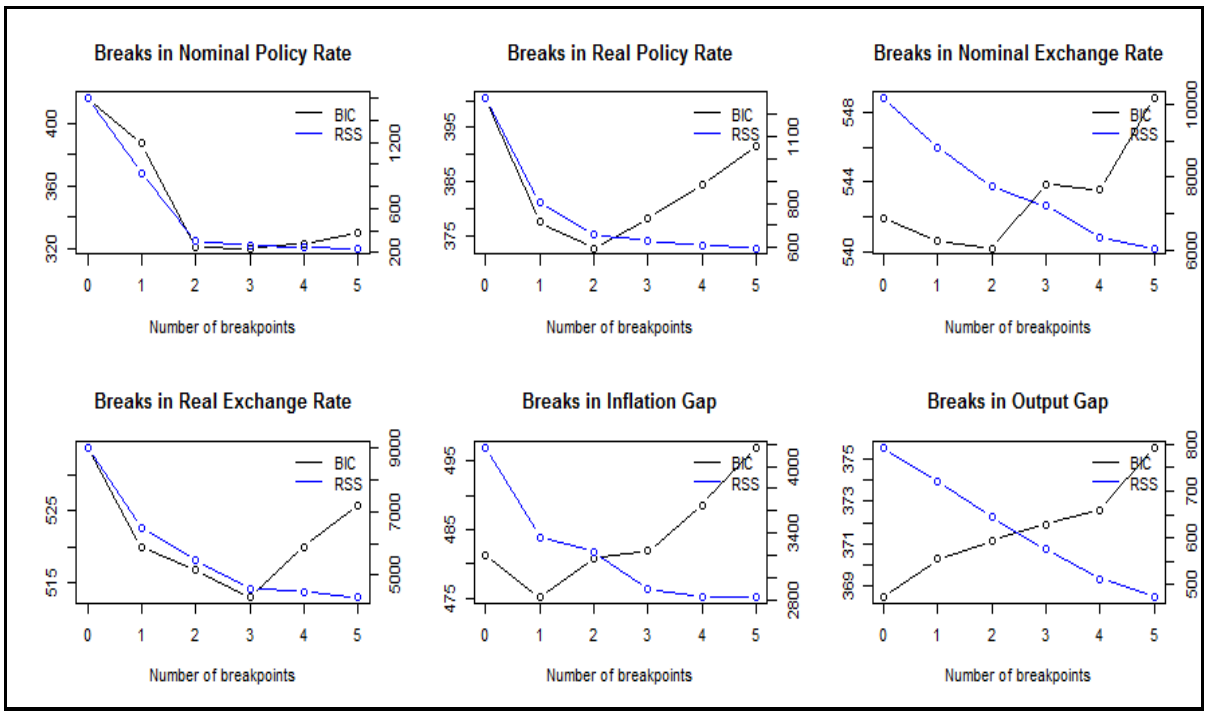
Appendix 5A

i: Unit Root Test

	ADF Test				PP Test				KPSS Test		
	Ho: Series is non-stationary				*Ho: Series is non-stationary*				*Ho: Series is stationary*		
	None	Constant	Constant & Trend	First Diff.	None	Constant	Constant & Trend	First Diff.	Constant	Constant & Trend	First Diff.ence
MPR_t	[0.30]	[0.24]	[0.58]	[0.00]*	[0.30]	[0.33]	[0.73]	[0.00]*	{0.23}	{0.22}*	{0.24}
$INF_{gap,t}$	[0.00]*	[0.01]**	[0.00]*	[0.00]*	[0.00]*	[0.00]*	[0.00]*	[0.00]*	{0.45}	{0.06}	{0.02}
$Y_{gap,t}$	[0.00]*	[0.02]**	[0.09]	[0.00]*	[0.00]*	[0.00]*	[0.00]*	[0.00]*	{0.08}	{0.06}	{0.64}**
$Xdep_t$	[0.06]***	[0.09]***	[0.14]	[0.00]*	[0.00]*	[0.00]*	[0.00]*	[0.00]*	{0.21}	{0.08}	{0.13}
RER_t	[0.02]**	[0.20]	[0.16]	[0.00]*	[0.01]**	[0.109]	[0.15]	[0.00]*	{0.49}**	{0.08}	{0.03}
INF_t	[0.00]*	[0.00]*	[0.00]*	[0.00]*	[0.00]*	[0.00]*	[0.00]*	[0.00]*	{0.51}	{0.14}	{0.17}

Note: {} and [] denote test statistics and p-values respectively; *, ** & *** denote 1%, 5% & 10% alpha levels respectively. MPR_t, denotes monetary policy rate; $INF_{gap,t}$, denotes deviation of inflation from target; $Y_{gap,t}$, is output gap; $Xdep_t$ is nominal exchange rate; and RER_t denotes real exchange rate; INF_t is actual inflation; PP is Philips-Perron; ADF represent Augmented Dickey-Fuller; KPSS denotes Kwiatkowski-Philips-Schmidt-Shin.

ii. Unknown Multiple Structural Breaks Test



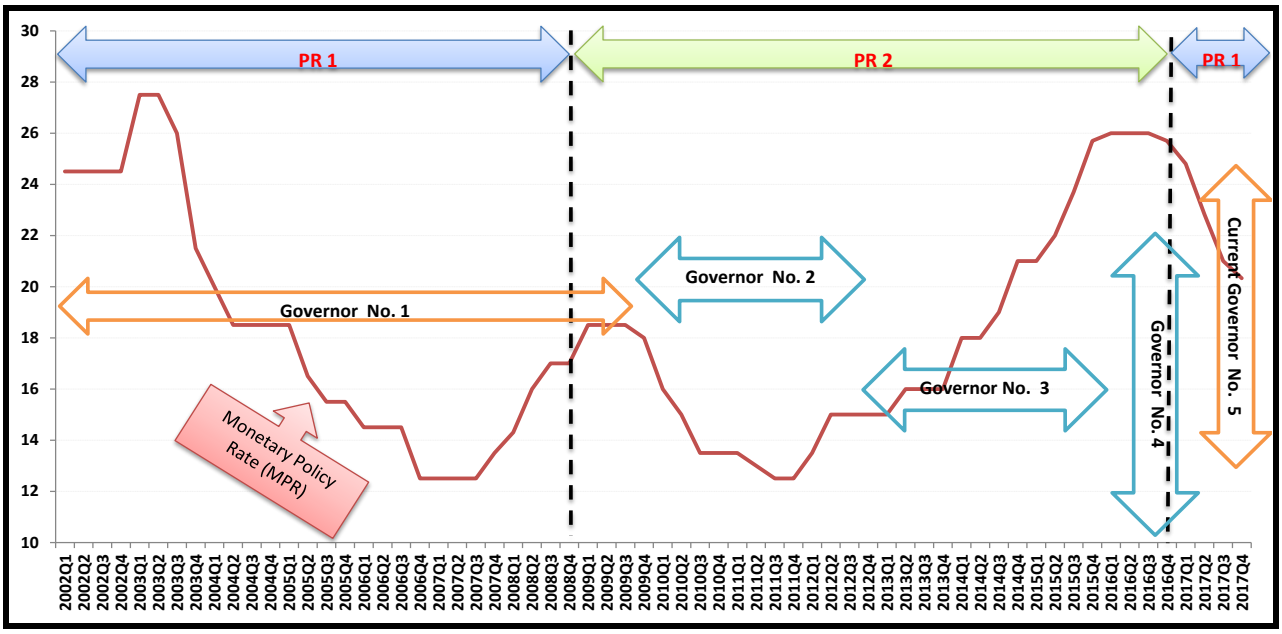
Note: the figure displays the results for unknown multiple structural breaks by Zeileis et al. (2003).

iii: Bai-Perron Test of Multiple Break points

	Bai-Perron tests of L+1 vs. L sequentially determined breaks	***Compare information criteria for 0 to M globally determined breaks***	
	Sequential F-statistic determined breaks:	*Schwarz criterion selected breaks:*	*LWZ criterion selected breaks:*
MPR	0	0	0
INF_{GAP}	0	0	0
Y_{GAP}	1	1	1
Xdep	1	0	0
RER	0	0	0
INF	0	0	0

Note: the detected break-date for both Y_{gap} is 2005Q1, while the break-date for Xdep is 2007Q4. INF_{GAP} is inflation gap; INF is inflation rate; RER is real exchange rate; Xdep is nominal exchange rate; MPR is policy interest rate; Y_{gap} is output gap; Due to the small sample size, we followed the literature to apply a trimming (e) of 25% and the corresponding maximum of two breakpoints (M=2)

iv. Historical Trends in MPR (%), Tenure of Central Bank Governors and Political Regime (PR)



Note: The chart covers the initial preparation and full adoption of IT regime in Ghana (thus from 2002).

Appendix 5B

i: Political regime effects on actual inflation in Ghana using *ARMA (p, q)* model

	Dependent Variable: Δlcpi			
	1	**2**	**3**	**4**
C	0.033	0.033	0.033	0.032
	[8.54]^{A}	[8.57]^{A}	[8.50]^{A}	[9.57]^{A}
DUMPR	0.001	0.001	0.001	0.004
	[0.19]	[0.21]	[0.20]	[0.64]
AR(1)	0.588	0.599	0.581	1.147
	[7.24]^{A}	[6.78]^{A}	[5.40]^{A}	[3.05]^{A}
AR(2)		-0.020		-0.403
		[-0.37]		[-1.62]
MA(1)			0.010	-0.531
			[0.11]	[-1.32]
	Model Diagnostics			
Adjusted R^2	*0.34*	*0.32*	*0.32*	*0.33*
SSR	*0.01*	*0.01*	*0.01*	*0.01*
DW- Stat	*1.96*	*1.99*	*1.97*	*2.09*
F-statistic	*{16.89}^{A}*	*{11.09}^{A}*	*{11.08}^{A}*	*{8.73}^{A}*

Note: DUMPR denote dummy variable which takes a value of one (1) for political regime 1 and a zero (0) for periods of political regime 2; ***Δlcpi*** is log changes in consumer price index (year-on-year); The superscript A denotes 1% significant level.

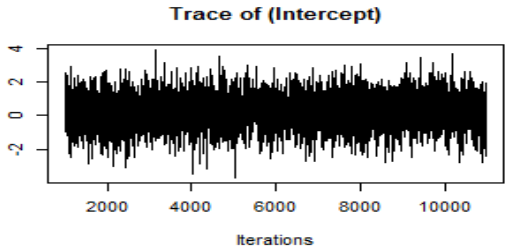
ii: Model Selection for Two Stage FQR Estimates

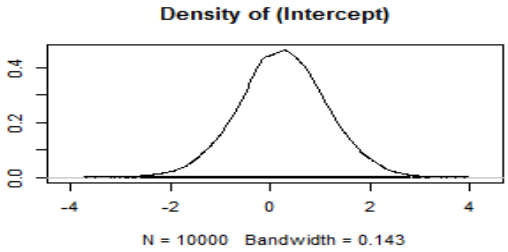
	25th		**50th**		**75th**		**90th**	
C	13.280	0.366	14.796	0.626	16.755	1.194	18.522	-1.593
	[25.39]*	[0.57]	[28.02]*	[0.92]	[23.29]*	[1.43]	[19.72]*	[-1.64]
INF_{gap_hat}	0.678	0.071	0.701	0.126	0.793	0.150	0.852	-0.012
	[6.62]*	[1.64]	[6.65]*	[2.77]*	[5.64]*	[2.70]*	[4.49]*	[-0.19]
Y_{gap_hat}	-0.934	0.073	-0.904	0.013	-1.391	0.060	-1.158	0.340
	[-5.34]*	[0.99]	[-5.05]*	[0.16]	[-5.79]*	[0.61]	[-3.59]*	[3.00]*
MPR_{t-1}		0.943		0.942		0.940		1.180
		[22.49]*		[21.43]*		[17.40]*		[18.99]*
Model Diagnostics								
Adj. R-squared	0.278	0.732	0.343	0.774	0.386	0.802	0.328	0.792
Prob(Quasi-LR stat)	{0.000}*	{0.000}*	{0.000}*	{0.000}*	{0.000}*	{0.000}*	{0.000}*	{0.000}*
S.E. of regression	3.726	1.217	3.110	1.117	3.690	1.255	4.961	1.974
Normality	{0.002}*	{0.000}*	{0.001}*	{0.001}*	{0.032}**	{0.003}*	{0.003}*	{0.000}*
Stability	{0.103}	{0.481}	{0.486}	{0.715}	{0.028}**	{0.519}	{0.251}	{0.526}
Correlogram of Residuals	Reject	Accept	Reject	Accept	Reject	Accept	Reject	Accept
Squared Residuals	Reject	Reject (lag 3)	Reject	Accept	Accept	Accept	Reject	Accept

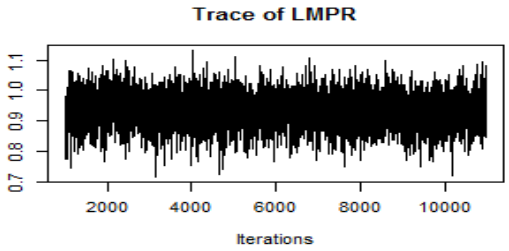
Appendix 5C

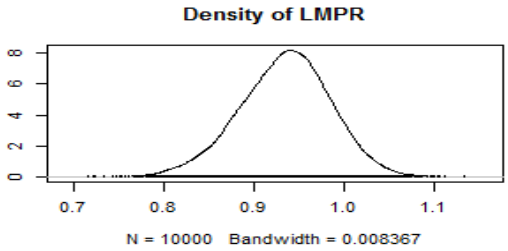
i: Trace and Density Plot for Symmetric Bayesian Quantile Regression

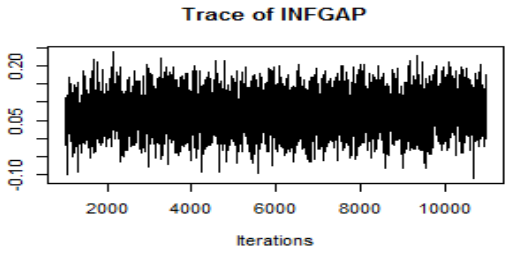
1.2 30th decile for MPR regressed on macro-variables

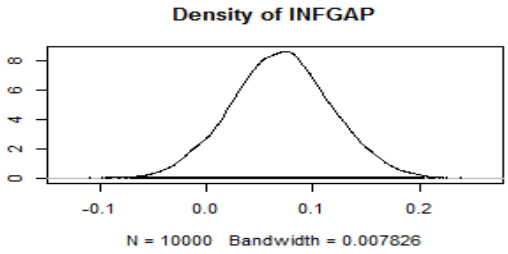


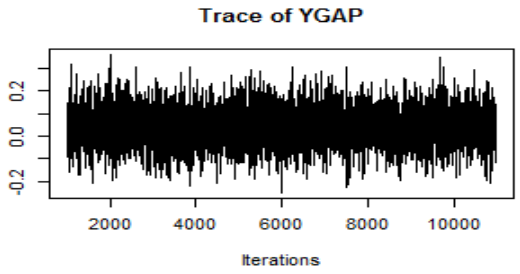


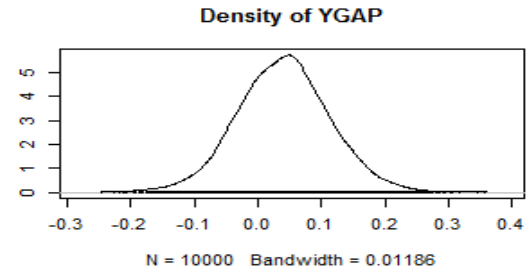


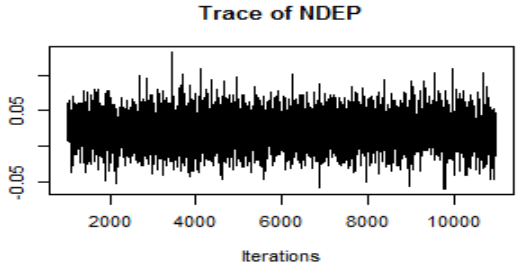


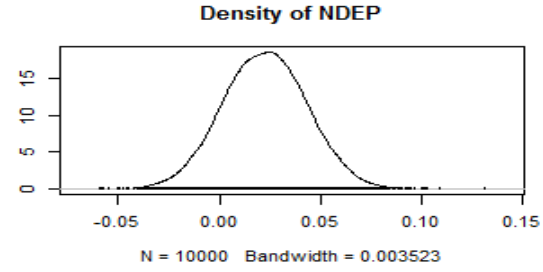




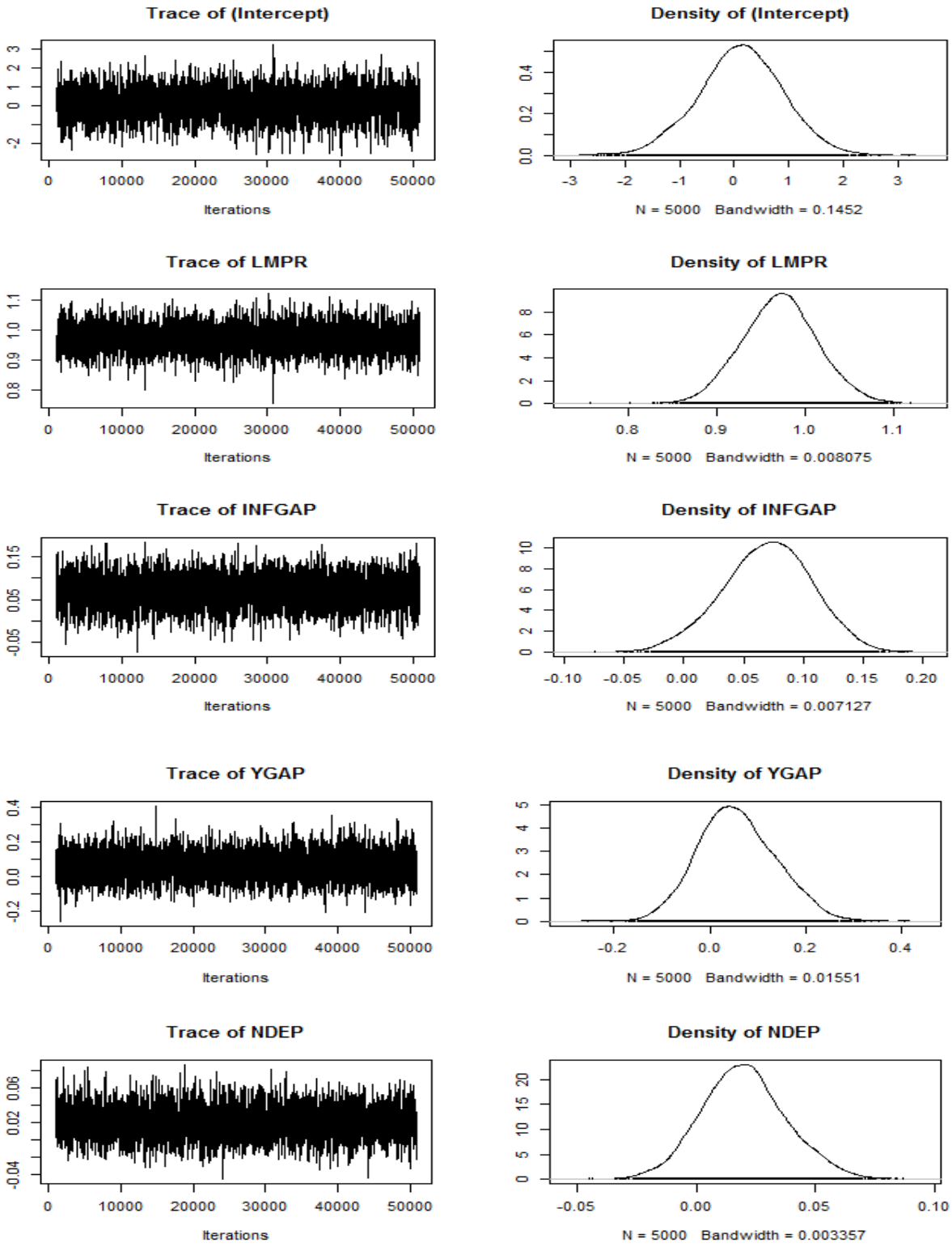




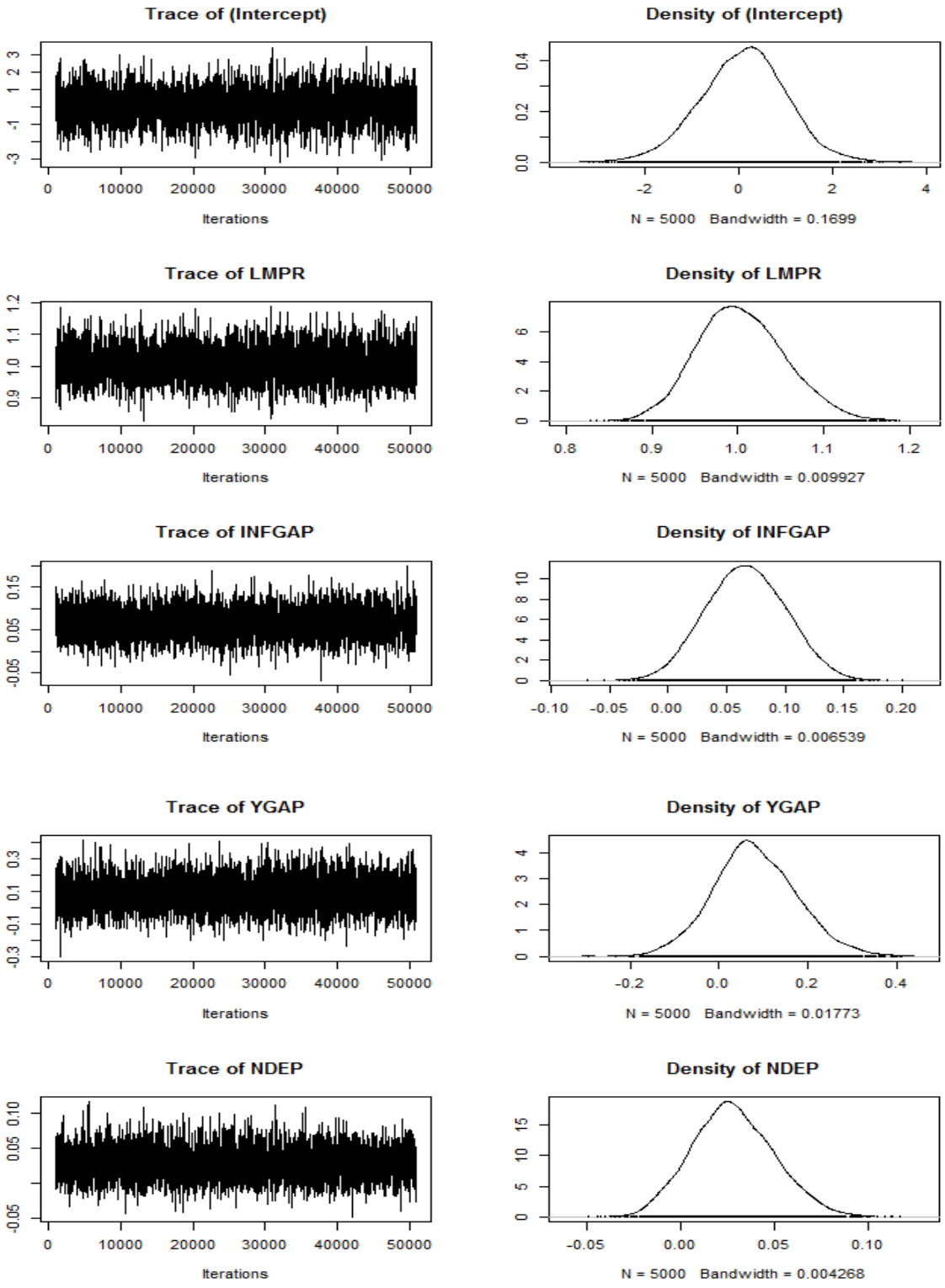




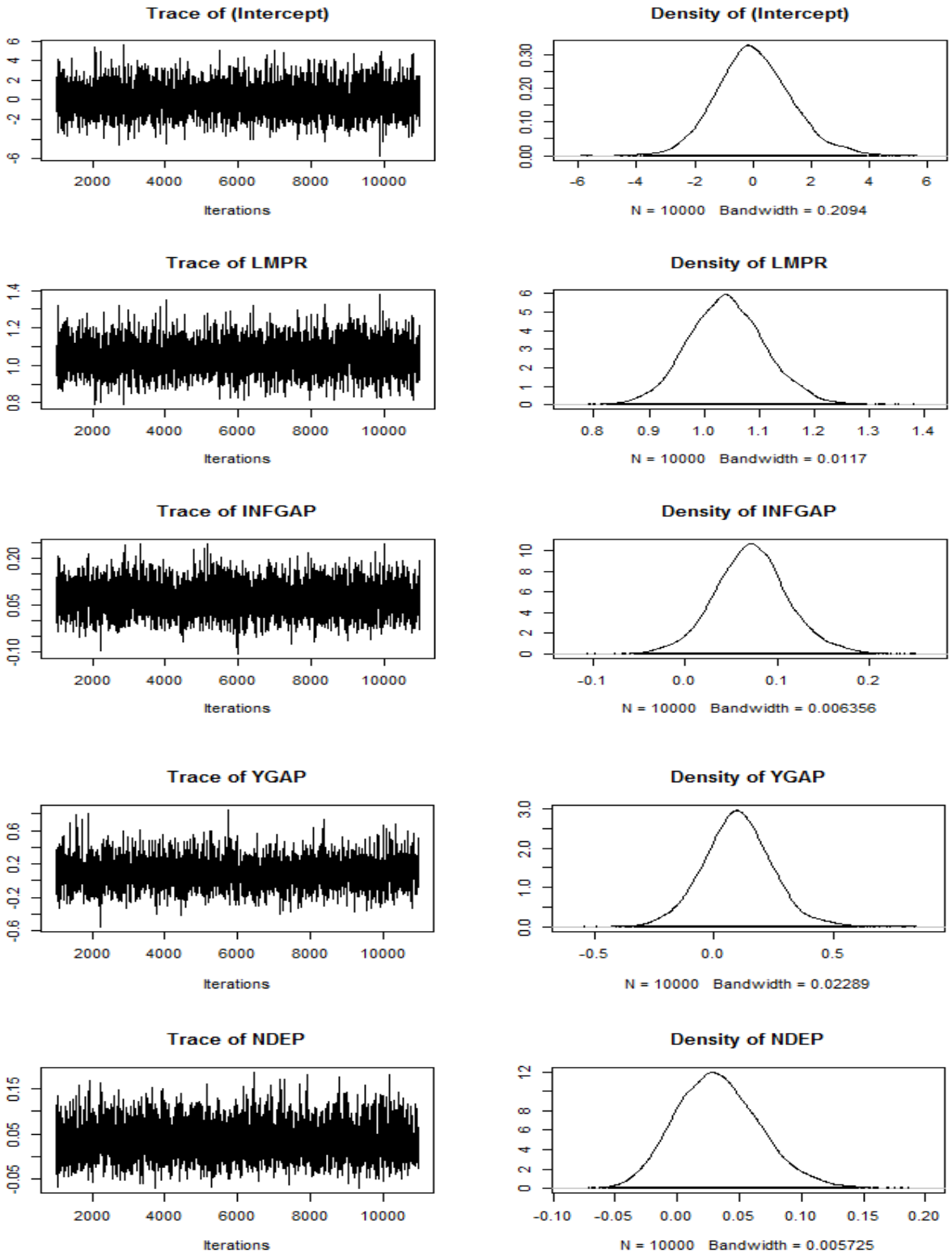
1.3 50th quantile for MPR regressed on Macro-data



1.4 75th quantile for MPR regressed on Macro-data

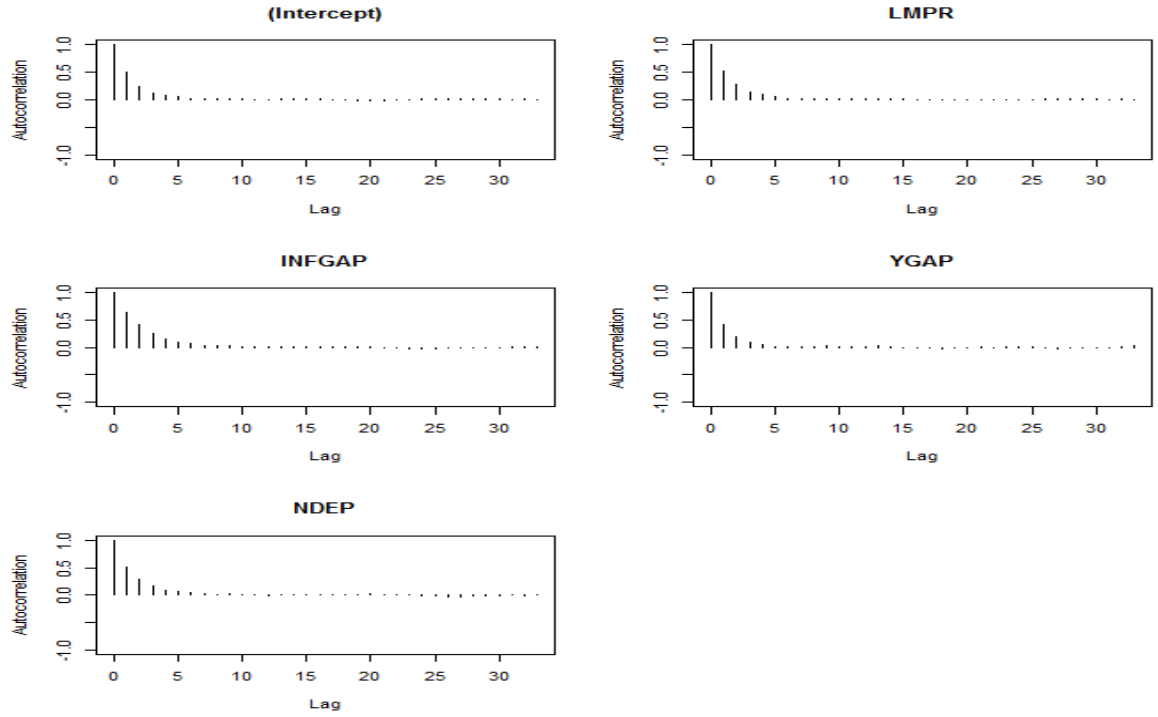


1.5 90th decile for MPR on against macro-variables

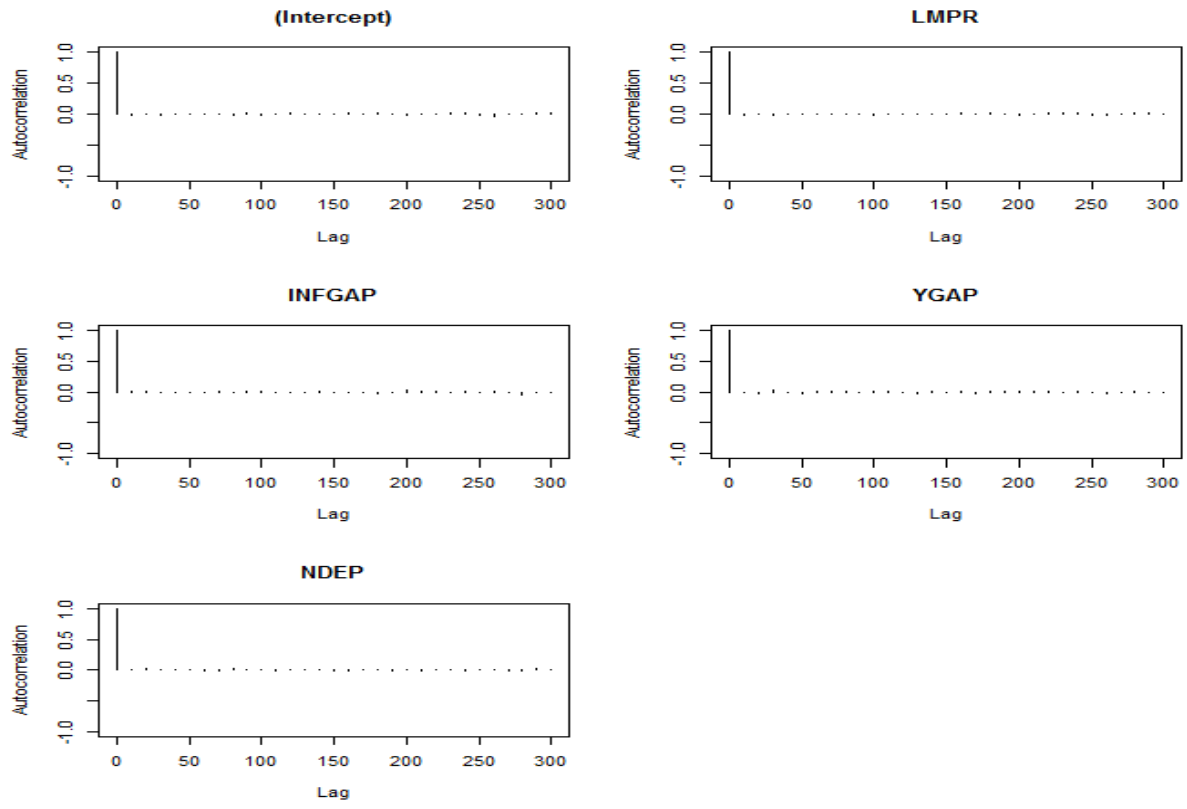


ii: Residual ACF of Fitted Symmetric Bayesian Quantile Regressions for MPR

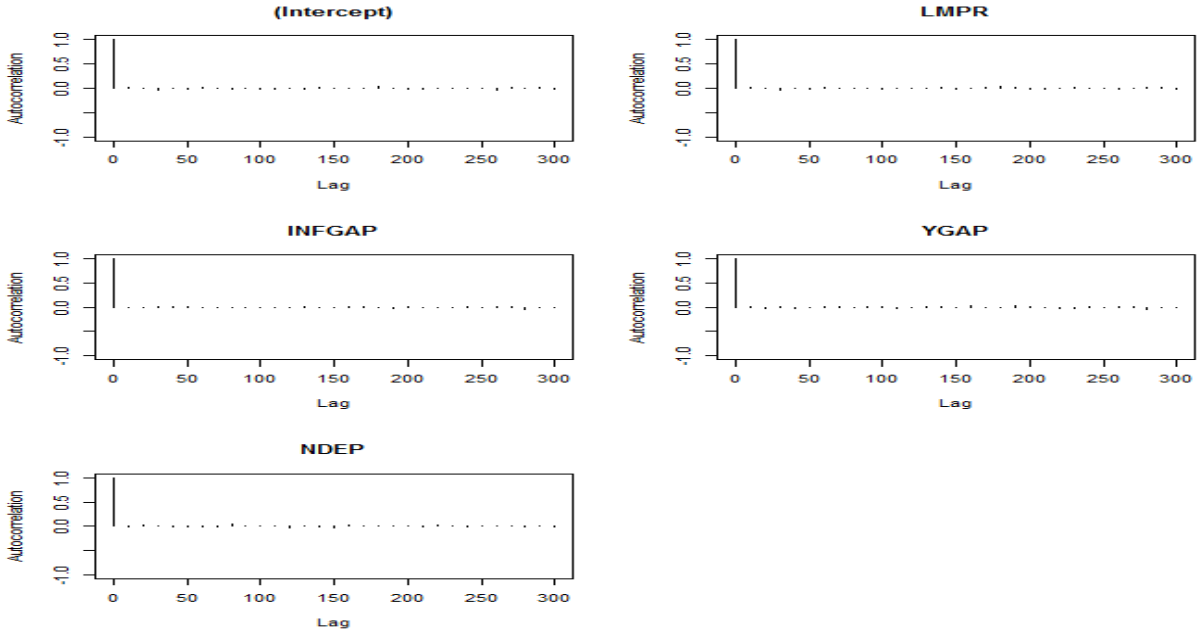
1.6 Residual ACF of fitted regression for MPR at the 30th Decile



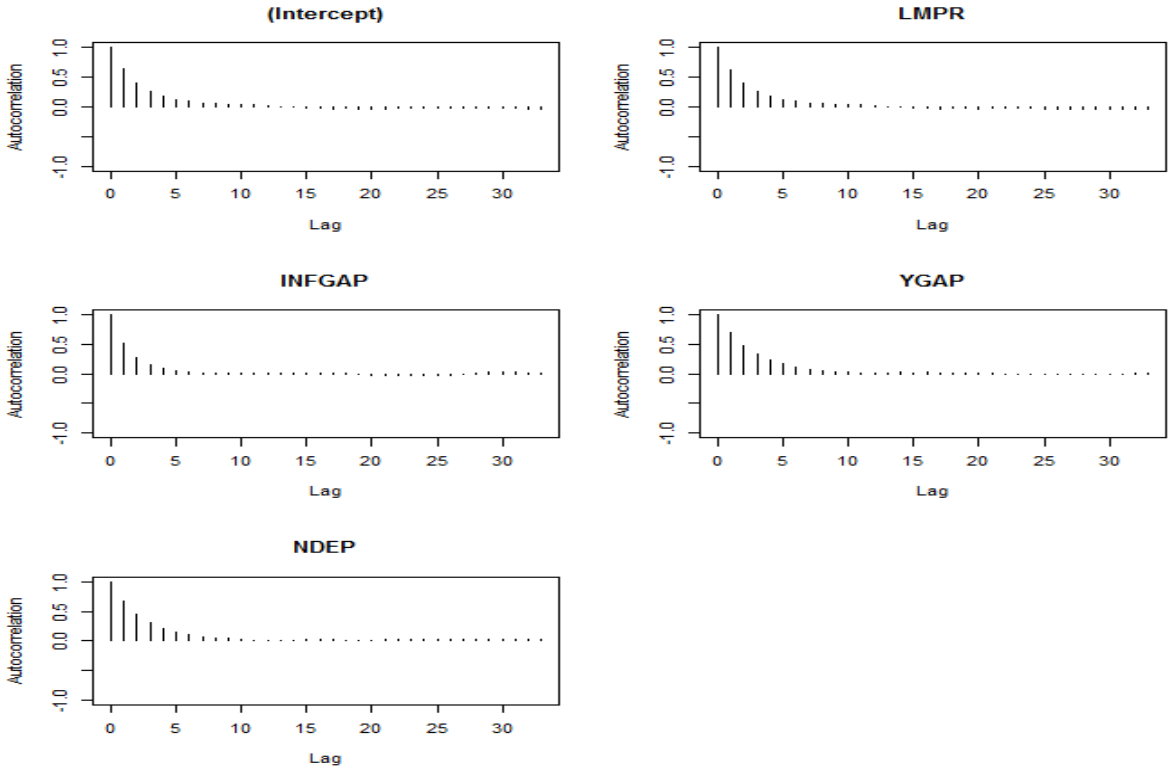
1.7 Residual ACF of fitted regression for MPR at the 50th quartile



1.8 Residual ACF of fitted regression for MPR at the 75th quartile

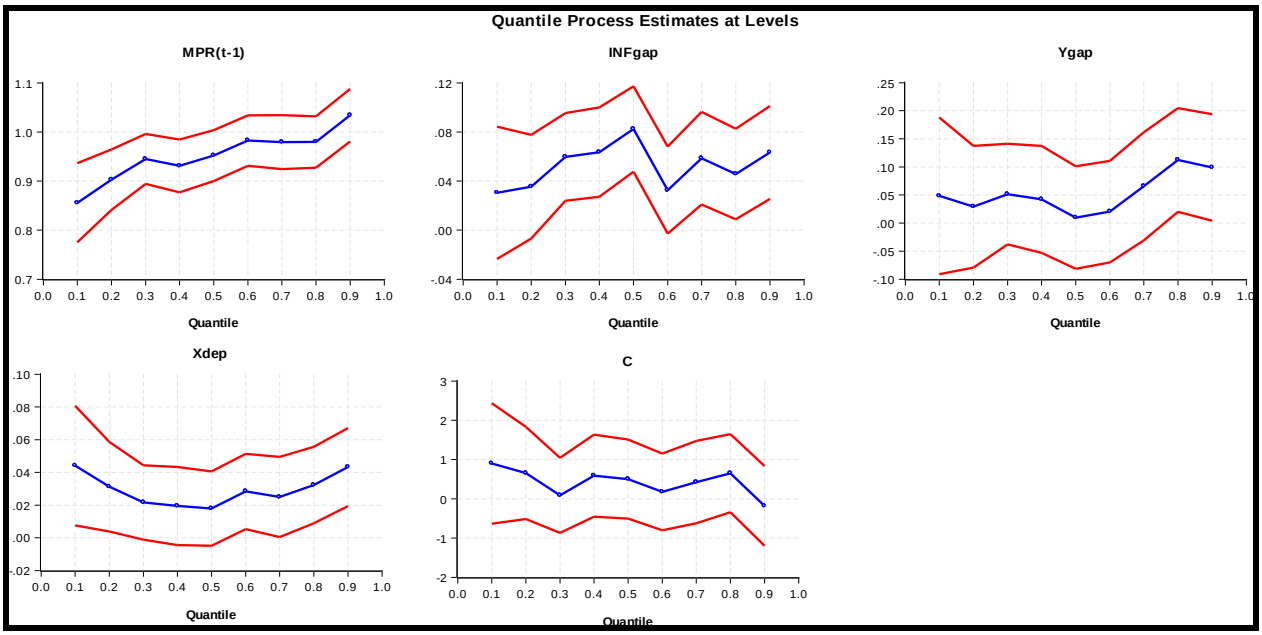


1.9 Residual ACF of fitted regression for MPR at the 90th Decile



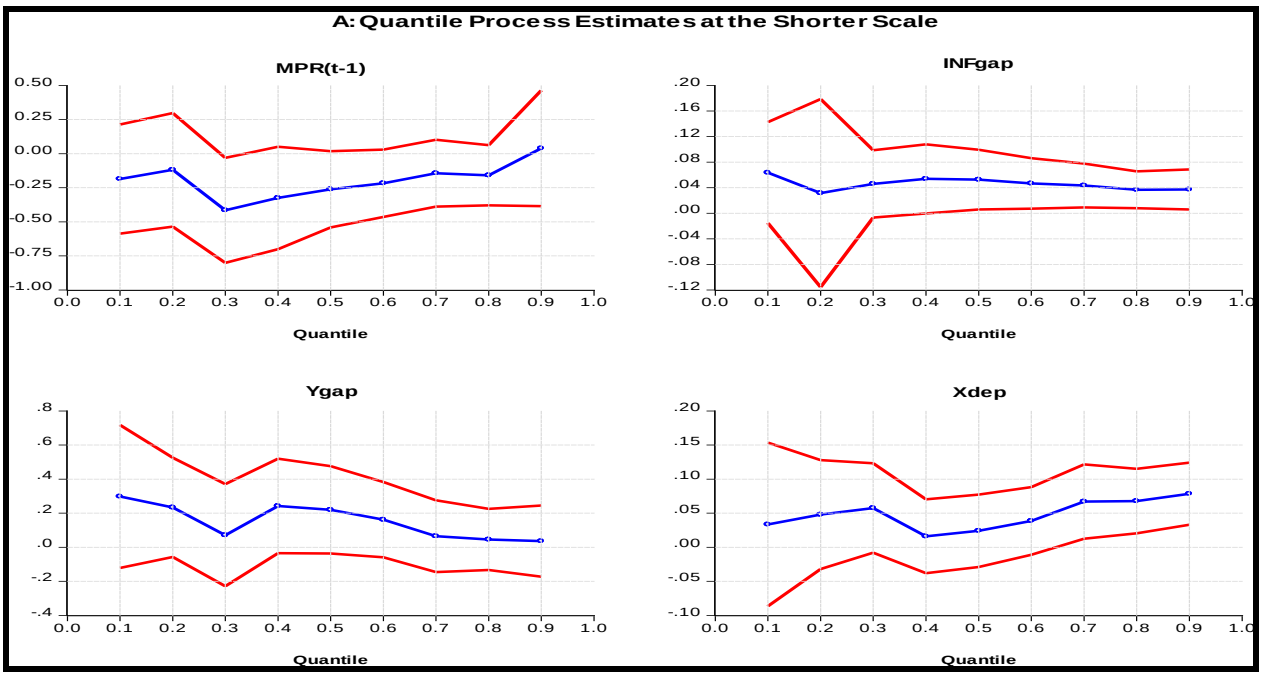
Appendix 5D

i: Frequentist quantile process estimates for linear Taylor rule at time-domain



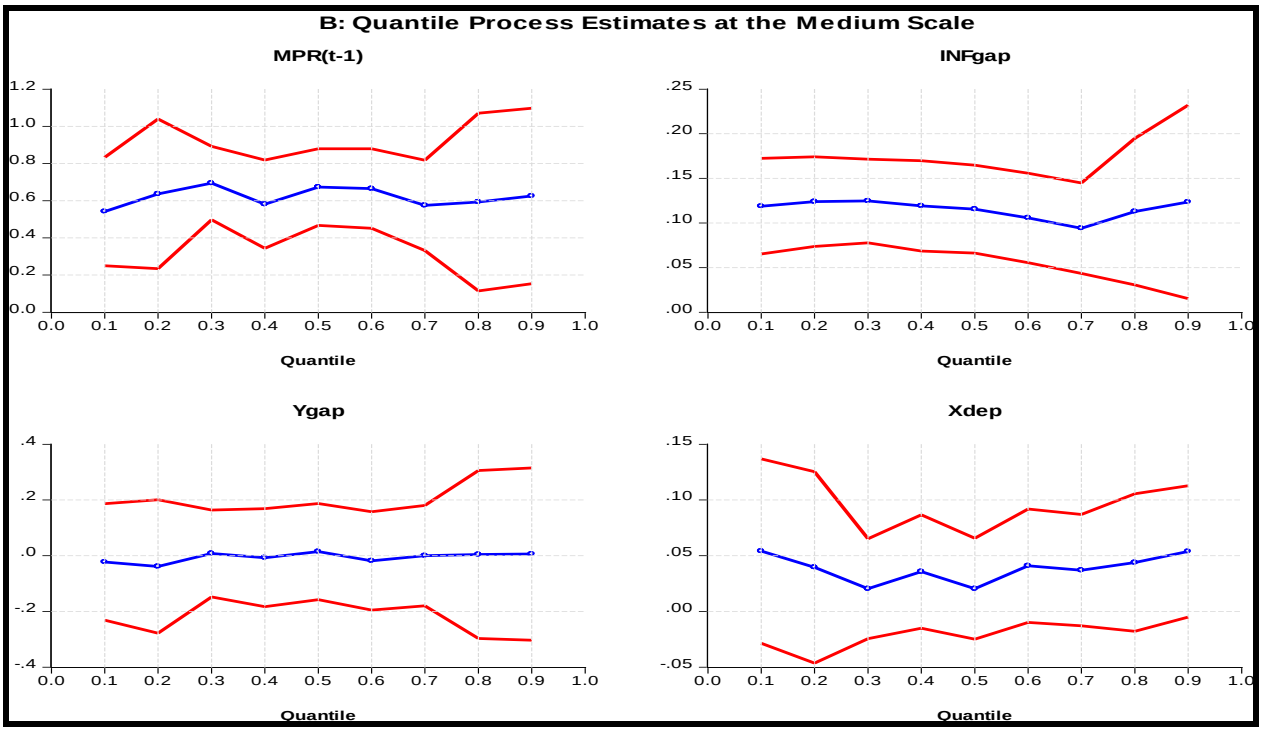
Note: Model satisfies stability and normality assumptions with respective p-values of 0.5093 and 0.4027. INFGAP is inflation gap; YGAP is output gap and Xdep denote changes in log nominal exchange (+ = depreciation; - = appreciation).

ii: Frequentist Quantile Process Estimates for Linear Taylor Rule at the Shorter Time-Run



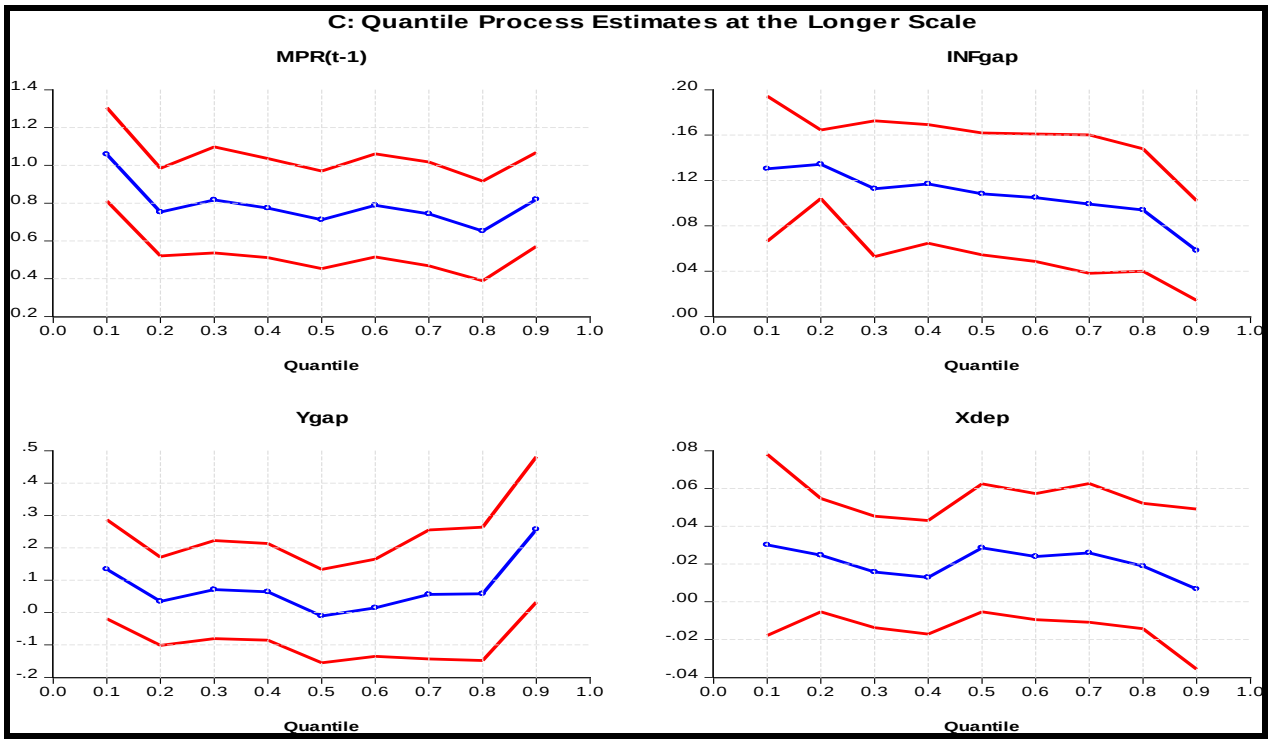
Note: Model satisfies stability and normality assumptions with respective p-values of 0.2855 and 0.5324.

iii: Frequentist Quantile Process Estimates for Linear Taylor Rule at the Medium Time-Scale



Note: Model satisfies stability and normality assumptions with respective p-values of 0.2403 and 0.1741.

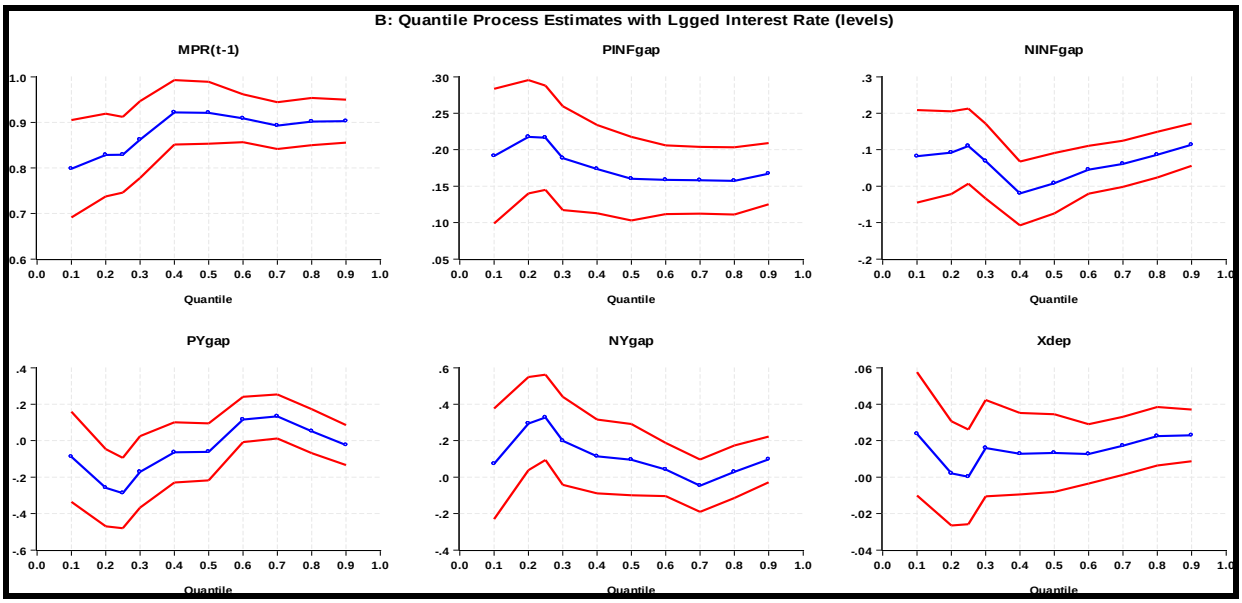
iv: Frequentist Quantile Process Estimates for Linear Taylor Rule at the Longer Time-Scale



Note: Model satisfies stability and normality assumptions with respective p-values of 0.1640 and 0.5458. This is based on aggregated dataset; INFGAP is inflation gap; YGAP is output gap; Xdep denote changes in log nominal exchange (+ = depreciation; - = appreciation)

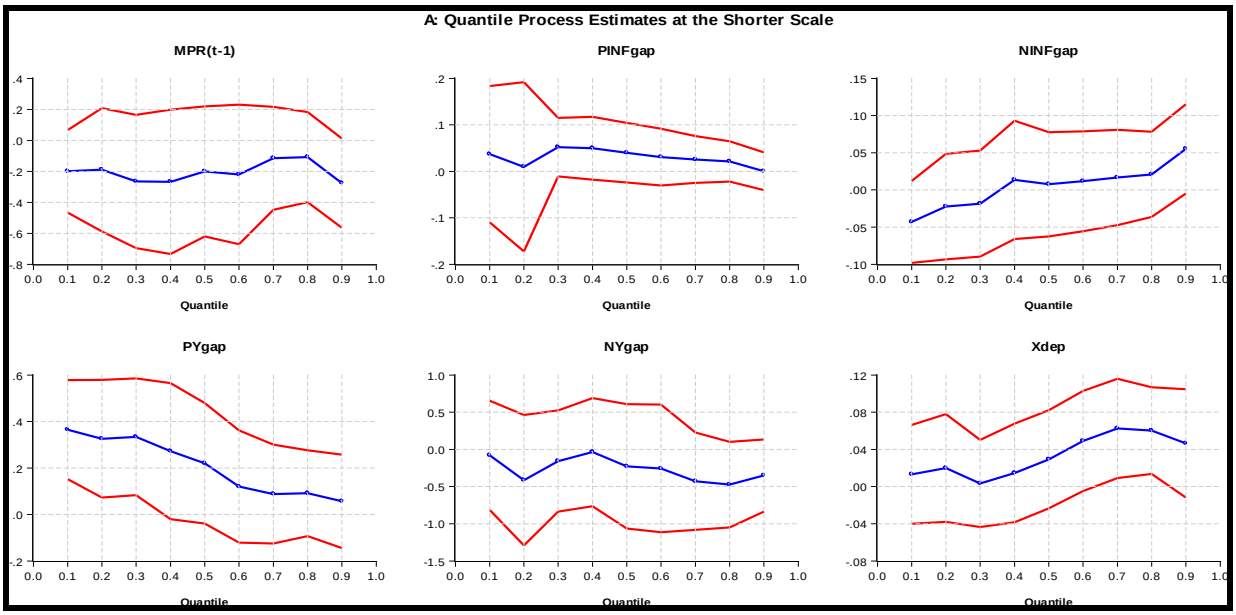
Appendix 5E

i: FQ Estimates for Nonlinear Taylor rule at Time-Domain



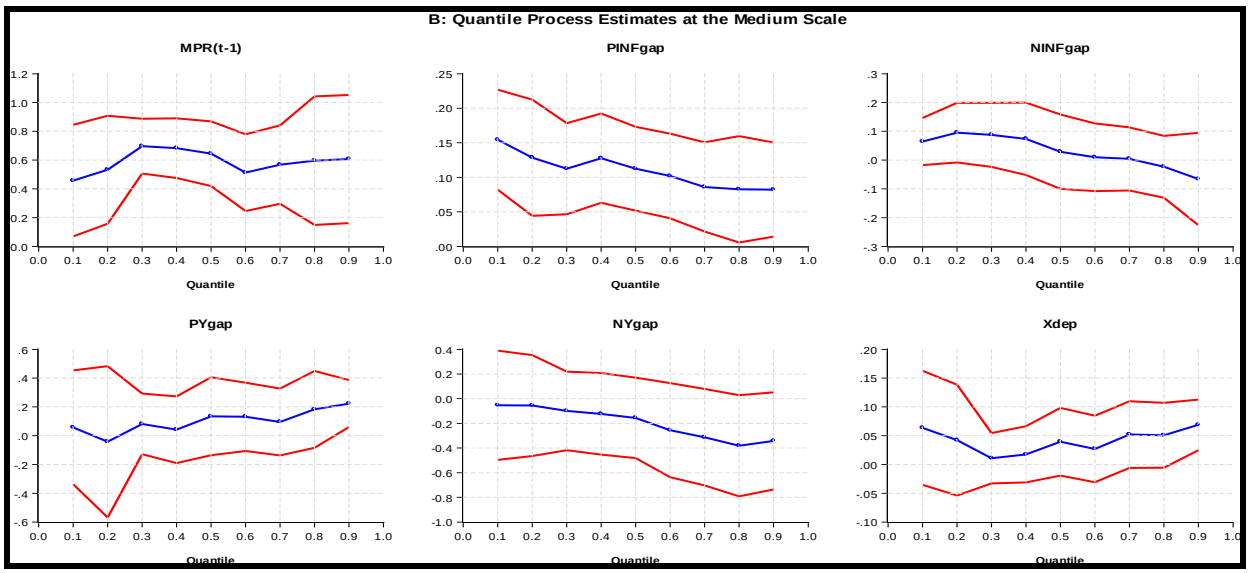
Note: This model includes lagged policy interest rate. It satisfies stability and normality assumptions with respective p-values of 0.4213 and 0.1418 and the Q-statistics for both Correlogram of Residuals and Squared Residuals could not reject the null of no serial correlation up to lag 28. PINFGAP is positive inflation gap; NINFGAP is negative inflation gap; PYGAP is positive output gap; NYGAP is negative output gap and Xdep denote changes in log nominal exchange (+ = depreciation; - = appreciation).

ii: FQ Estimates for Nonlinear Taylor rule at Shorter Time-Scale



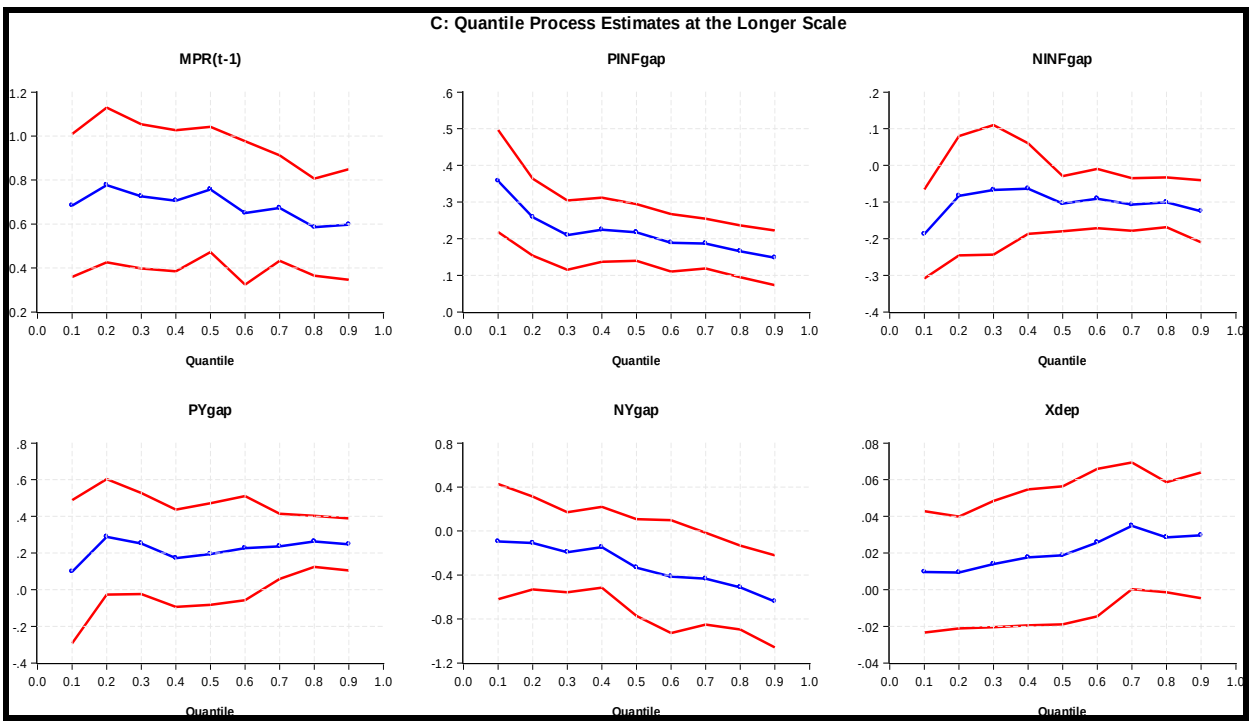
Note: Model satisfies stability and normality assumptions with respective p-values of 0.8598 and 0.7324. PINFGAP is positive inflation gap; NINFGAP is negative inflation gap; PYGAP is positive output gap; NYGAP is negative output gap and Xdep denote changes in log nominal exchange (+ = depreciation; - = appreciation)

iii: FQ Estimates for Nonlinear Taylor rule at the Medium Time-Scale



Note: Model satisfies stability and normality assumptions with respective p-values of 0.3047 and 0.1648. PINFGAP is positive inflation gap; NINFGAP is negative inflation gap; PYGAP is positive output gap; NYGAP is negative output gap and Xdep denote changes in log nominal exchange (+ = depreciation; - = appreciation)

iv: FQ Estimates for Nonlinear Taylor rule at the Longer Time-Scale



Note: Model satisfies stability and normality assumptions with respective p-values of 0.9621 and 0.1325. PINFGAP is positive inflation gap; NINFGAP is negative inflation gap; PYGAP is positive output gap; NYGAP is negative output gap and Xdep denote changes in log nominal exchange (+ = depreciation; - = appreciation)

Appendix 5F

i. Two-Stage Symmetric Bayesian Quantile Estimates of MPRF at Time-Domain

	30th	40th	50th	60th	75th	80th	90th
Panel A: Linear Estimate							
c	0.600	0.573	0.620	0.691	0.491	0.216	-0.509
	[1.289]	[1.178]	[1.126]	[1.204]	[1.587]	[1.786]	[2.227]
i_{t-1}	0.923*	0.939*	0.949*	0.958*	0.997*	1.028*	1.121*
	[0.085]	[0.078]	[0.075]	[0.082]	[0.110]	[0.123]	[0.147]
$\hat{\pi}_t$	0.089	0.083	0.087	0.099	0.105	0.089	0.025
	[0.077]	[0.074]	[0.079]	[0.091]	[0.113]	[0.119]	[0.133]
$\hat{y}_t$	0.076	0.067	0.063	0.069	0.115	0.154	0.244
	[0.131]	[0.128]	[0.131]	[0.143]	[0.174]	[0.189]	[0.238]
Panel B: Nonlinear Estimate							
c	1.716	1.316	1.216	1.311	1.628	1.780	1.972
	[1.651]	[1.502]	[1.440]	[1.496]	[1.734]	[1.956]	[2.751]
i_{t-1}	0.844*	0.882*	0.901*	0.907*	0.906*	0.903*	0.911*
	[0.098]	[0.088]	[0.084]	[0.084]	[0.095]	[0.107]	[0.152]
$\hat{\pi}_t^+$	0.218**	0.207**	0.203**	0.208**	0.232**	0.246**	0.274**
	[0.068]	[0.070]	[0.072]	[0.076]	[0.087]	[0.096]	[0.131]
$\hat{\pi}_t^-$	-0.042	-0.034	-0.041	-0.047	-0.061	-0.068	-0.096
	[0.087]	[0.080]	[0.075]	[0.076]	[0.084]	[0.095]	[0.144]
$\hat{y}_t^+$	-0.199	-0.138	-0.121	-0.131	-0.156	-0.153	-0.099
	[0.299]	[0.274]	[0.263]	[0.278]	[0.326]	[0.362]	[0.516]
$\hat{y}_t^-$	0.198	0.184	0.156	0.117	0.055	0.031	-0.040
	[0.200]	[0.198]	[0.215]	[0.233]	[0.295]	[0.322]	[0.468]

Note: *& ** denote 1% & 5% significant level respectively; i_{t-1} denotes lagged changes in monetary policy rate; $\hat{\pi}_t^+$ is positive deviation of inflation from target. $\hat{\pi}_t^-$ denotes negative deviation of inflation from target; $\hat{y}_t^+$ is the fitted positive output gap (period of economic boom); $\hat{y}_t^-$, is negative output gap (period of economic downturn); a hatted "^" variable indicates a fitted value generated from the first stage GMM approach.

ii. Alternative Bayesian Quantile Estimates of MPRF at Time-Domain: Monthly Data

	30th	50th	75th	30th	50th	75th	30th	50th	75th	30th	50th	75th
Panel A: 2001M1 - 2017M12												
$\boldsymbol{c}$	0.068	0.034	0.060	0.056	0.025	0.062	0.037	0.019	0.044	0.036	0.018	0.066
	[0.208]	[0.149]	[0.211]	[0.243]	[0.163]	[0.235]	[0.244]	[0.167]	[0.247]	[0.261]	[0.182]	[0.257]
$\boldsymbol{i_{t-1}}$	0.992*	0.997*	1.001*	0.992*	0.997*	0.999*	0.993*	0.998*	0.999*	0.992*	0.997*	0.998*
	[0.012]	[0.008]	[0.011]	[0.014]	[0.008]	[0.012]	[0.013]	[0.009]	[0.013]	[0.014]	[0.009]	[0.013]
$\widetilde{\boldsymbol{\pi}}_{\boldsymbol{t}}$	0.005	0.002	0.002	0.005	0.001	0.002	0.004	0.001	0.001	0.004	0.001	0.002
	[0.013]	[0.009]	[0.012]	[0.014]	[0.010]	[0.014]	[0.015]	[0.010]	[0.015]	[0.016]	[0.011]	[0.015]
$\widetilde{\boldsymbol{\pi}}_{\boldsymbol{t+3}}$							0.002	0.003	0.015	0.002	0.003	0.012
							[0.006]	[0.005]	[0.013]	[0.009]	[0.008]	[0.015]
$\widetilde{\boldsymbol{y}}_{\boldsymbol{t}}^{\boldsymbol{rciea}}$	0.000	0.000	0.002	0.000	0.001	0.003	-0.001	0.001	0.003	0.000	0.001	0.003
	[0.008]	[0.006]	[0.009]	[0.009]	[0.007]	[0.011]	[0.009]	[0.007]	[0.011]	[0.010]	[0.007]	[0.012]
$\Delta \boldsymbol{e_{t-1}}$				0.001	0.002	0.009				0.000	0.001	0.007
				[0.006]	[0.005]	[0.011]				[0.009]	[0.007]	[0.013]
Panel B: IFT Regime (2007M1 - 2017M12)												
$\boldsymbol{c}$	0.591	0.313	0.822	0.667	0.361	0.963	0.616	0.327	0.639	0.674	0.371	0.746
	[0.638]	[0.454]	[0.794]	[0.734]	[0.540]	[0.924]	[0.923]	[0.719]	[1.174]	[1.004]	[0.801]	[1.299]
$\boldsymbol{i_{t-1}}$	0.954*	0.979*	0.956*	0.948*	0.976*	0.949*	0.951*	0.977*	0.960*	0.946*	0.973*	0.955*
	[0.043]	[0.029]	[0.048]	[0.048]	[0.033]	[0.053]	[0.052]	[0.037]	[0.059]	[0.056]	[0.042]	[0.063]
$\widetilde{\boldsymbol{\pi}}_{\boldsymbol{t}}$	0.047	0.025	0.069	0.055	0.030	0.080	0.051	0.026	0.048	0.056	0.030	0.057
	[0.046]	[0.034]	[0.064]	[0.058]	[0.043]	[0.074]	[0.077]	[0.062]	[0.105]	[0.087]	[0.070]	[0.115]
$\widetilde{\boldsymbol{\pi}}_{\boldsymbol{t+3}}^{\boldsymbol{survey}}$							-0.001	0.005	0.036	0.003	0.006	0.032
							[0.051]	[0.045]	[0.079]	[0.055]	[0.048]	[0.084]
$\widetilde{\boldsymbol{y}}_{\boldsymbol{t}}^{\boldsymbol{rciea}}$	0.000	0.002	0.008	0.001	0.002	0.009	0.001	0.002	0.010	0.001	0.002	0.011
	[0.012]	[0.010]	[0.019]	[0.013]	[0.011]	[0.021]	[0.014]	[0.011]	[0.021]	[0.015]	[0.012]	[0.022]
$\Delta \boldsymbol{e_{t-1}}$				-0.001	0.000	0.002				-0.002	0.000	0.003
				[0.011]	[0.009]	[0.016]				[0.012]	[0.010]	[0.017]

Note: $\boldsymbol{i_{t-1}}$ denotes lagged changes in monetary policy rate; $\widetilde{\boldsymbol{\pi}}_{\boldsymbol{t}} > 0$, denotes positive deviation of inflation from target (i.e. inflationary periods). $\widetilde{\boldsymbol{\pi}}_{\boldsymbol{t}}$ denotes negative deviation of actual inflation from target (i.e. disinflationary period); Δe_{t-1} denoted lagged nominal exchange rate depreciation.

$\tilde{\pi}_{t+3}^{survey}$ denotes 3-month agents' expected inflation deviation from target. $\tilde{y}_t^{rciea}$ denotes output gap using the composite index of economic activities developed by the central bank to gauge economic activities in Ghana;

iii. Generated MPIP values from One-Stage Bayesian Quartile estimation method

	Panel A: Contemporaneous Rule						Panel B: Forward-Looking Rule					
	30th	**50th**	**60th**	**75th**	**80th**	**90th**	**30th**	**50th**	**60th**	**75th**	**80th**	**90th**
i_{t-1}	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**
$\tilde{\pi}_t$	0.441	0.144	0.167	0.475	**0.557**	0.349	0.379	0.131	0.119	0.347	0.429	0.269
$\tilde{\pi}_{t+1}$							0.083	0.032	0.038	0.097	0.117	0.119
$\tilde{y}_t$	0.091	0.044	0.061	0.163	0.190	0.174	0.074	0.038	0.038	0.104	0.133	0.127
Δe_{t-1}	0.055	0.023	0.026	0.080	0.094	0.078	0.045	0.017	0.020	0.061	0.072	0.055
c	0.342	0.222	0.236	0.390	0.437	0.414	0.297	0.188	0.188	0.316	0.363	0.345

Panel C: Nonlinear Taylor Rule						
	30th	**50th**	**60th**	**75th**	**80th**	**90th**
i_{t-1}	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**
$\tilde{\pi}_t > 0$	**0.809**	**0.662**	**0.666**	**0.928**	**0.943**	**0.732**
$\tilde{\pi}_t < 0$	0.071	0.070	0.081	0.088	0.101	0.102
$\tilde{y}_t > 0$	0.103	0.084	0.081	0.123	0.138	0.181
$\tilde{y}_t < 0$	0.186	0.141	0.137	0.163	0.170	0.203
Δe_{t-1}	0.047	0.029	0.031	0.044	0.057	0.069
c	0.324	0.277	0.262	0.338	0.353	0.378

Note: i_{t-1} denotes lagged interest rate; $\tilde{\pi}_t$ denotes deviation of inflation from target; $\tilde{y}_t$ is output gap; Δe_{t-1} denotes lagged nominal exchange rate depreciation.

Appendix 6A

i. Derivation of Key Equations

1.10 The Firm

Taking the prices of factors of production (W_t, R_t^K) as given, intermediate firm seeks to minimize the following total cost of production;

$$\min_{N_{i,t},K_{i,t}} W_t N_{i,t} + R_t^K K_{i,t} \quad (A1)$$

subject to the production technology constraint

$$Y_{i,t} = \mho_t K_{i,t}^{\lambda} N_{i,t}^{1-\lambda} \quad (A2)$$

where $\mho_t$ is the total factor productivity (or technological progress) which follows an AR(1) process as:

$$\log(\mho_t) = (1 - p_{\mho})\log(\mho_{ss}) + p_{\mho}\log(\mho_{t-1}) + \varepsilon_t^u \quad (A3)$$

$p_{\mho}$ is the autoregressive parameter of productivity with $|p_{\mho}| < 1$ while $\varepsilon_t^u \sim (0, \sigma_{\mho})$ signifies productivity shock. K_t denotes rented physical capital; N_t represents amount of differentiated labour hired by the $i-th$ firm.

The FOCs for the preceding problem yield

$$\frac{\partial L}{\partial N_t}: \quad W_t = \mathrm{F}_t(1-\lambda)(\upsilon_t K_t^{\lambda} N_t^{-\lambda}) \tag{A4}$$

$$\frac{\partial L}{\partial K_t}: \quad R_t^{\kappa} = \mathrm{F}_t\lambda(\upsilon_t K_t^{\lambda-1} N_t^{1-\lambda}) \tag{A5}$$

$$\frac{\partial L}{\partial \mathrm{F}_t}: \quad Y_t = \upsilon_t K_t^{\lambda} N_t^{1-\lambda} \tag{A6}$$

where $\mathrm{F}_{i,t} = MC_{i,t}$ where $MC_{i,t}$ is marginal cost. Since (A2) can be written as $\frac{Y_{i,t}}{N_{i,t}} = \upsilon_t K_{i,t}^{\lambda} N_{i,t}^{-\lambda}$, and $\frac{Y_{i,t}}{K_{i,t}} = \upsilon_t K_{i,t}^{\lambda-1} N_{i,t}^{1-\lambda}$, then (A4) and (A5) can also be rearranged to obtain the labour and capital demand for an intermediate firm, i, as follows;

$$N_{i,t} = (1-\lambda) MC_{i,t}\left(\frac{Y_{i,t}}{W_t}\right) \tag{A7}$$

$$K_{i,t} = \lambda MC_{i,t}\left(\frac{Y_{i,t}}{R_t^{\kappa}}\right) \tag{A8}$$

Combining equations (A7) and (A8) yields the expression;

$$\frac{W_t}{R_t^{\kappa}} = \frac{(1-\lambda)}{\lambda}\frac{K_{i,t}}{N_{i,t}} \tag{A9}$$

The RHS of (A9) is the marginal rate of technical substitution (MRTS) which measures the rate at which labour can be replaced with capital while maintaining a constant level of technology. The LHS of (A9) is the economic rate of substitution (ERS), gauging the extent to which labour can be replaced by capital while maintaining the same cost.

Solving for $N_{i,t}$ in equation (A9) result in

$$N_{i,t} = \frac{(1-\lambda)}{\lambda}\frac{R_t^{\kappa}}{W_t} K_{i,t} \tag{A10}$$

Substituting equation (A10) back into production function (A2) results in

$$K_{i,t} = \frac{Y_{i,t}}{\upsilon_t}\left[\frac{(1-\lambda)}{\lambda}\frac{R_t^{\kappa}}{W_t}\right]^{-(1-\lambda)} \Leftrightarrow \quad K_{i,t} = \frac{Y_{i,t}}{\upsilon_t}\left[\frac{\lambda}{(1-\lambda)}\frac{W_t}{R_t^{\kappa}}\right]^{1-\lambda} \tag{A11}$$

We further substitute equation (A11) into (A10) yields

$$N_{i,t} = \frac{Y_{i,t}}{\upsilon_t}\left[\frac{(1-\lambda)}{\lambda}\frac{R_t^{\kappa}}{W_t}\right]\left[\frac{\lambda}{(1-\lambda)}\frac{W_t}{R_t^{\kappa}}\right]^{1-\lambda} \Leftrightarrow N_{i,t} = \frac{Y_{i,t}}{\upsilon_t}\left[\frac{\lambda}{(1-\lambda)}\frac{W_t}{R_t^{\kappa}}\right]^{-\lambda} \tag{A12}$$

Given equations (A11) and (A12), the total cost function, $TC_{i,t} = W_t N_{i,j,t} + R_t^{\kappa} K_{i,j,t}$, can be expressed as;

$$TC_{i,t} = W_t \frac{Y_{i,t}}{\upsilon_t}\left[\frac{\lambda}{(1-\lambda)}\frac{W_t}{R_t^{\kappa}}\right]^{-\lambda} + R_t^{\kappa}\frac{Y_{i,t}}{\upsilon_t}\left[\frac{\lambda}{(1-\lambda)}\frac{W_t}{R_t^{\kappa}}\right]^{1-\lambda} \tag{A13}$$

Following Costas (2016), we multiply $\frac{1}{(1-ג)}$ and $\frac{1}{ג}$ to the first and second terms on RHS of equation (A13) to obtain:

$$TC_{i,t} = W_t \frac{Y_{i,t}}{\mho_t}\left[\frac{ג}{(1-ג)}\frac{W_t}{R_t^{\kappa}}\right]^{-ג}\frac{1}{(1-ג)} + R_t^{\kappa}\frac{Y_{i,t}}{\mho_t}\left[\frac{ג}{(1-ג)}\frac{W_t}{R_t^{\kappa}}\right]^{1-ג}\frac{1}{ג}$$

$$\Leftrightarrow TC_{i,t} = \frac{Y_{i,t}}{\mho_t}\left[\frac{W_t}{1-ג}\right]^{1-ג}\left(\frac{R_t^{\kappa}}{ג}\right)^{ג} \quad (A14)$$

The nominal marginal cost is identical for all intermediate firm ($MC_t = MC_{i,t} = \frac{\partial TC_{i,t}}{\partial Y_{i,t}}$) and is derived as

$$MC_t = \frac{1}{\mho_t}\left[\frac{W_t}{1-ג}\right]^{1-ג}\left(\frac{R_t^{\kappa}}{ג}\right)^{ג} \quad (A15)$$

1.11 Lagrange multipliers for households

We first log-linearized the Lagrange multiplier expression for households in (24) by utilizing the following supplementary variable:

$$A: \qquad CC_t = C_t - hC_{t-1}$$

We begin by determining the steady state expressions of the supplementary equation. The two auxiliary equation yields the same steady state expression as follows

$$CC_{ss} = C_{ss}(1-h) \quad (B1)$$

Given equation (2.25), the steady state expression for equation (24) is

$$\wedge_{ss} P_{ss} = \hat{\zeta}_{ss}^{z}(C_{ss} - hC_{ss})^{-\sigma_c}$$

$$\Leftrightarrow \wedge_{ss} P_{ss} = \hat{\zeta}_{ss}^{c} C_{ss}^{-\sigma_c}(1-h)^{-\sigma_c} \quad (B2)$$

We then log-linearizing the supplementary equation A as

$$CC_{ss}(1+cc_t) = C_{ss}(1+\hat{c}_t) - hC_{ss}(1+\hat{c}_{R,t-1})$$

Replacing the first term on the LHS by its steady state in (2.25), we obtain

$C_{ss}(1-h)(1+\widehat{cc}_t) = C_{ss}(1+\hat{c}_t) - hC_{ss}(1+\hat{c}_{t-1})$

After expanding the preceding expression and simplifying, we obtain

$$\widehat{cc}_t = \frac{1}{(1-h)}[\hat{c}_t - h\hat{c}_{t-1}] \quad (B3)$$

The next stage is to rewrite the Lagrange equation for Ricardian household using the auxiliary variables as follows:

$$\wedge_t P_t = \hat{\zeta}_t^{c} CC_{R,t}^{-\sigma_c} \quad (B4)$$

Log linearizing (2.29) yields

$$\widehat{\Lambda}_t = \frac{\sigma_c}{(1-h)}\left([\hat{c}_t - h\hat{c}_{t-1}]\right) - \hat{p}_t + \hat{\zeta}_t^c \qquad (B5)$$

1.12 The Wage Rate for Households

We follow the same procedure above to derive NKPC for gross wage in the home economy. We thus log-linearized both equations (1.54) and (1.56) to obtain:

$$\widetilde{w}_t^{\tau} = (1-\beta\vartheta_w)E_t\sum_{i=0}^{\infty}(\beta\vartheta_w)^i\{\zeta_{t+i}^n + \vartheta_l\hat{n}_{t+i} - \widehat{\Lambda}_{t+i}\} \qquad (C1)$$

$$\widehat{w}_t = \vartheta_w\widehat{w}_{t-1} + (1-\vartheta_w)\widehat{w}_t^{\tau} \qquad (C2)$$

Similar substitution of (C1 into (C2) yields

$$\widehat{w}_t = \vartheta_w\widehat{w}_{t-1} + (1-\vartheta_w)(1-\beta\vartheta_w)E_t\sum_{i=0}^{\infty}(\beta\vartheta_w)^i\{\vartheta_l\hat{n}_{t+i} - \widehat{\Lambda}_{t+i} + \zeta_{t+i}^n\} \qquad (C3)$$

Equation (C3) can also be written as

$$\widehat{w}_t - \vartheta_w\widehat{w}_{t-1} = (1-\vartheta_w)(1-\beta\vartheta_w)E_t\sum_{i=0}^{\infty}(\beta\vartheta_w)^i\{\vartheta_l\hat{n}_{t+i} - \widehat{\Lambda}_{t+i} + \zeta_{t+i}^n\} \qquad (C4)$$

To eliminate the summation term in the RHS of equation (C4), we apply $i = 0$ and $i = 1\ to\ \infty$

$$\widehat{w}_t = \vartheta_w\widehat{w}_{t-1} + (1-\vartheta_w)(1-\beta\vartheta_w)\{\vartheta_l\hat{n}_t - \widehat{\Lambda}_t + \zeta_t^n\}$$
$$+ (1-\vartheta_w)(1-\beta\vartheta_w)E_t\sum_{i=0}^{\infty}(\beta\vartheta_w)^i\{\vartheta_l\hat{n}_{t+i} - \widehat{\Lambda}_{t+i} + \zeta_{t+i}^n\} \qquad (C5)$$

Given equation (C4), we can rewrite (C5) as

$$\widehat{w}_t = \vartheta_w\widehat{w}_{t-1} + (1-\vartheta_w)(1-\beta\vartheta_w)\{\vartheta_l\hat{n}_t - \widehat{\Lambda}_t + \zeta_t^n\} + \beta\vartheta_w(E_t\widehat{w}_{t+1} - \vartheta_w\widehat{w}_t)$$
$$\Leftrightarrow \widehat{w}_t = \vartheta_w\widehat{w}_{t-1} + (1-\vartheta_w)(1-\beta\vartheta_w)\{\vartheta_l\hat{n}_t - \widehat{\Lambda}_t + \zeta_t^n\} + \beta\vartheta_w E_t\widehat{w}_{t+1} - \beta\vartheta_w\vartheta_w\widehat{w}_t \qquad (C6)$$

After subtracting $\widehat{w}_t$ from the term $(\hat{n}_{t+i} - \widehat{\Lambda}_{t+i} + \zeta_{t+i}^n)$ in equation (C6) and simplifying yields a generic Philips curve equation for households' gross wage inflation as

$$(\widehat{w}_t - \widehat{w}_{t-1}) = \beta(E_t\widehat{w}_{t+1} - \widehat{w}_t) + \frac{(1-\vartheta_w)(1-\beta\vartheta_w)}{\vartheta_w}\{\vartheta_l\hat{n}_t - \widehat{\Lambda}_t - \widehat{w}_t + \zeta_t^n\} \qquad (C7)$$

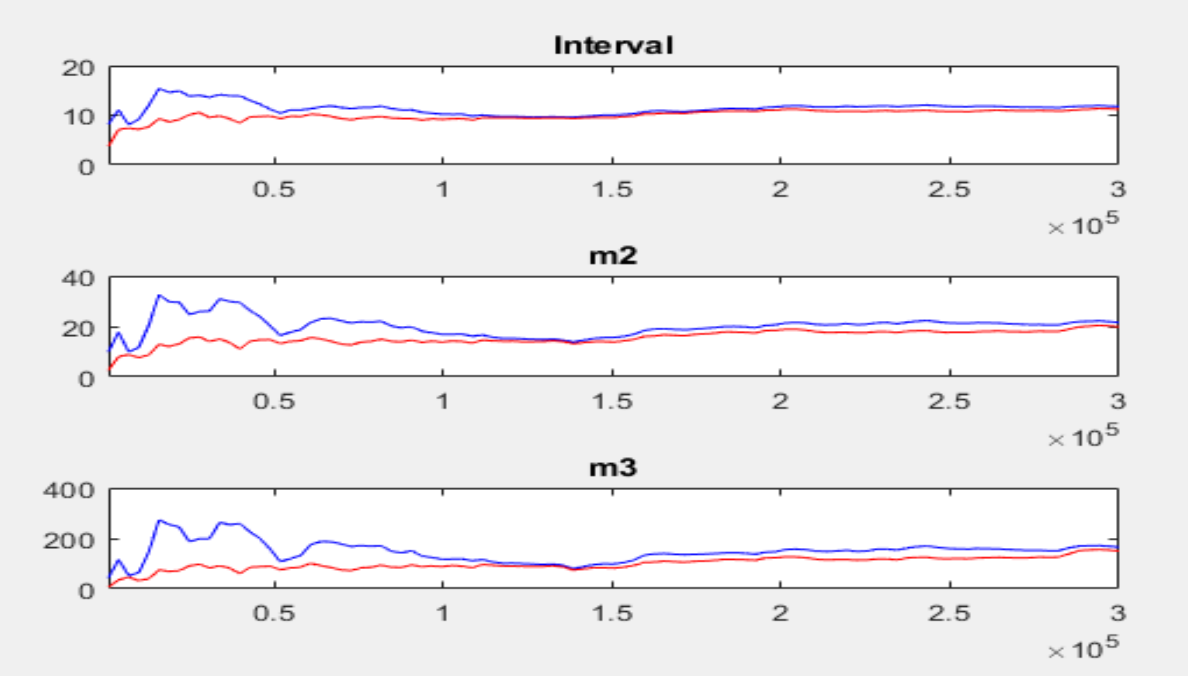
This is further written as;

$$\hat{\pi}_t^w = \beta E_t\hat{\pi}_{t+1}^w + \frac{(1-\vartheta_w)(1-\beta\vartheta_w)}{\vartheta_w}\{\hat{n}_t - \widehat{\Lambda}_t - \widehat{w}_t + \zeta_t^n\} + \zeta_t^w \qquad (C8)$$

where $\hat{\pi}_t^w = \widehat{w}_t - \widehat{w}_{t-1}$; and ζ_t^w denotes wage mark-up shock which is assumed to IID.

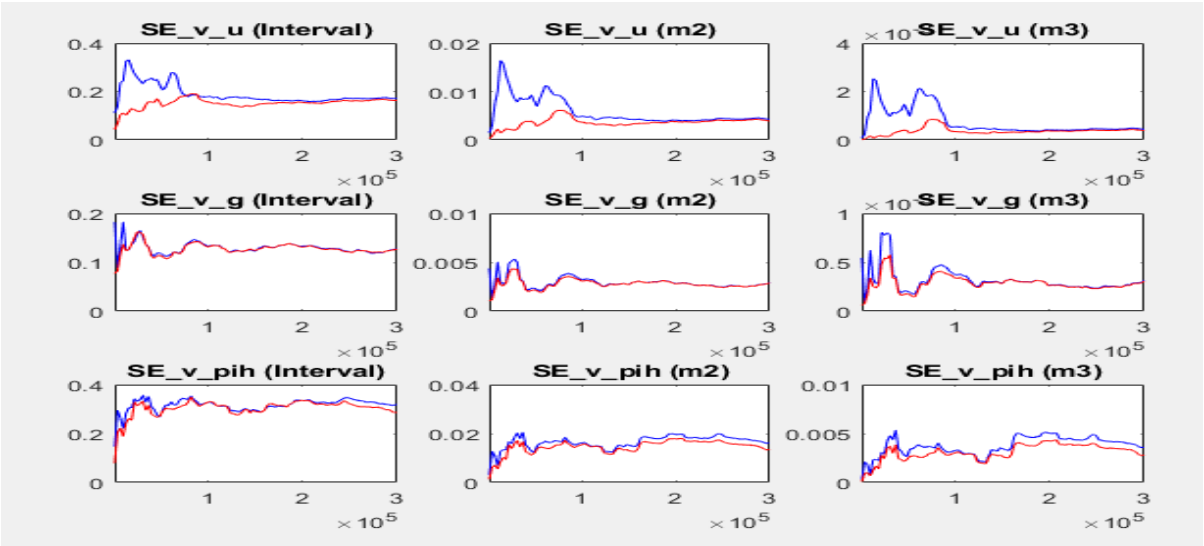
Appendix 6B

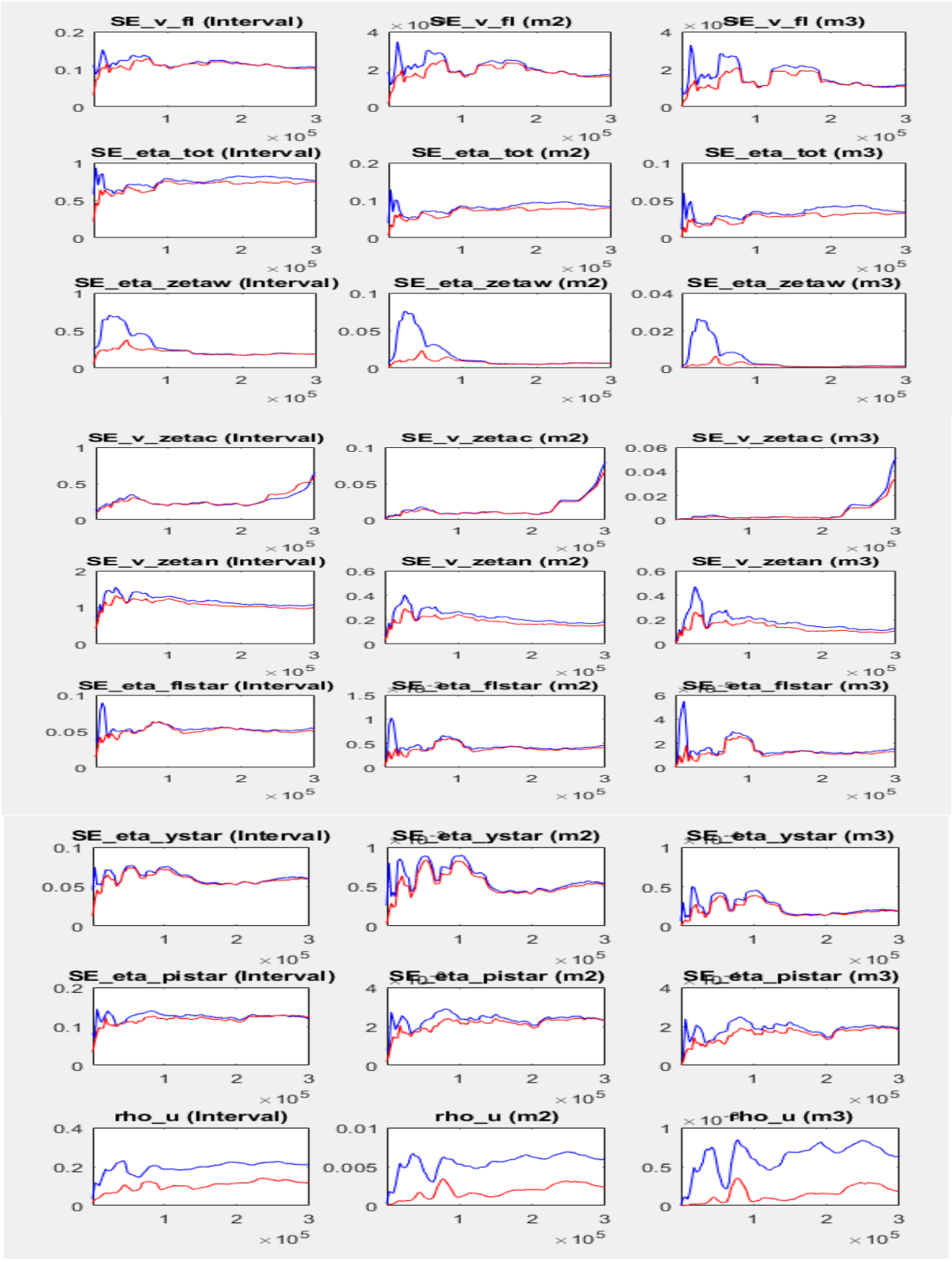
i. Multivariate Convergence Diagnostics of the Baseline Model

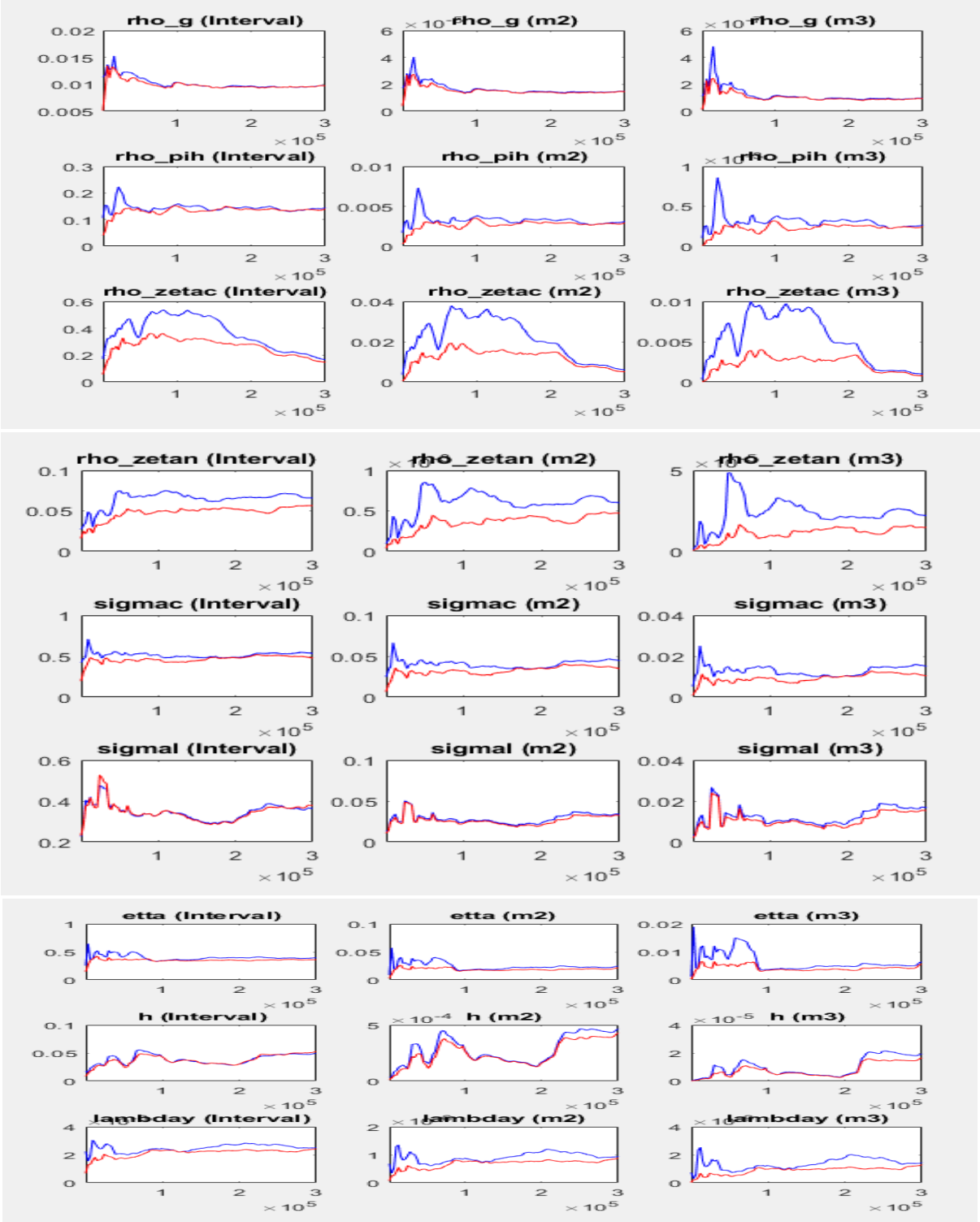


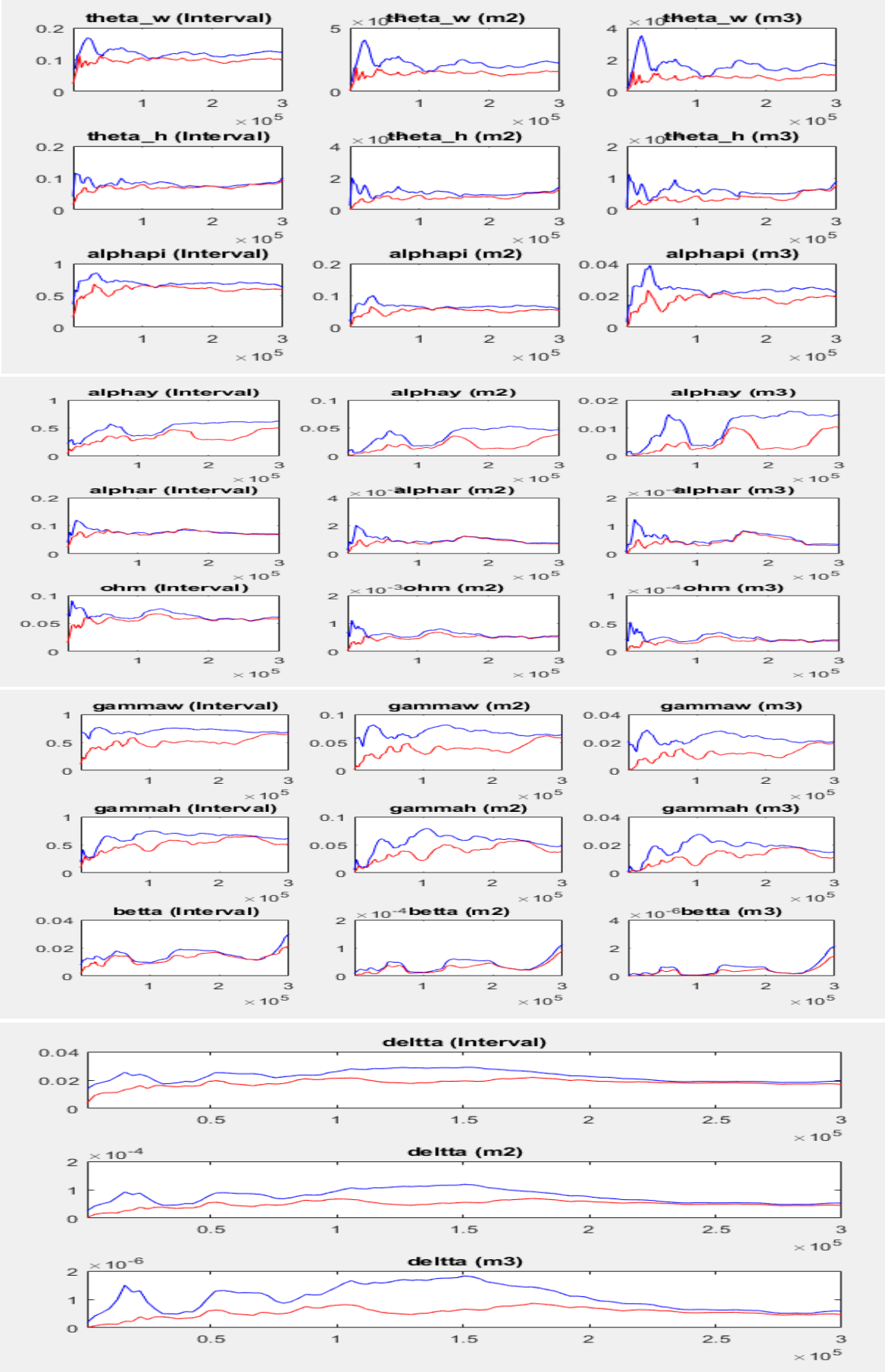
Note: The information is summarized in three graphs, with each graph representing specific convergence measures and having two distinct lines that represent the results within and between chains. Those measures are related to the analysis of the parameters mean (interval), variance (m2) and third moment (m3). The red line denotes the within-chain while the blue line represents the between-chain covariance. Convergence requires that both lines, for each of the three measures, become relatively constant and converge to each other.

ii. Univariate Convergence Diagnostics of the Baseline Model



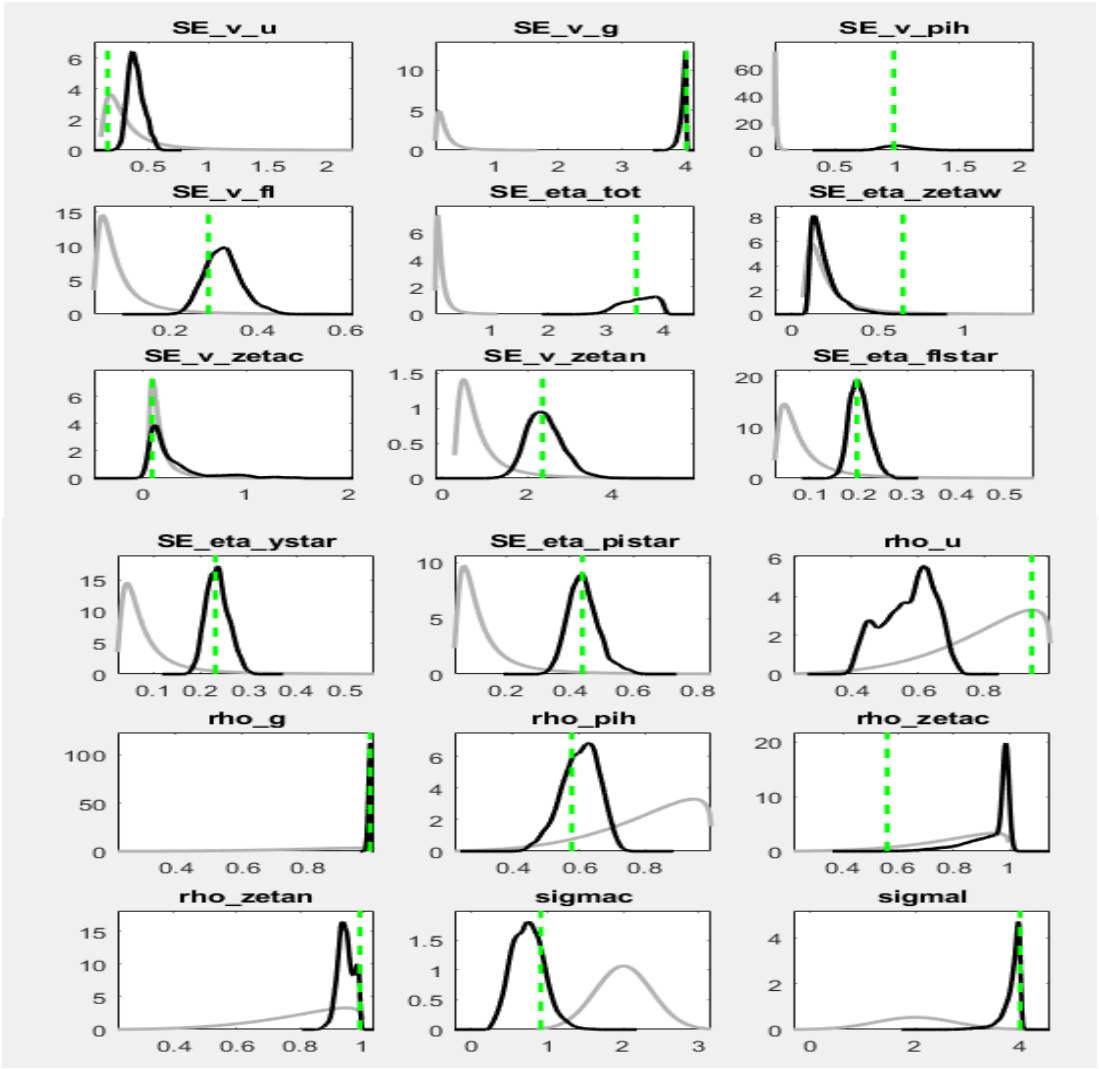

SE_v_fl (Interval)
SE_v_fl (m2)
SE_v_fl (m3)
SE_eta_tot (Interval)
SE_eta_tot (m2)
SE_eta_tot (m3)
SE_eta_zetaw (Interval)
SE_eta_zetaw (m2)
SE_eta_zetaw (m3)
SE_v_zetac (Interval)
SE_v_zetac (m2)
SE_v_zetac (m3)
SE_v_zetan (Interval)
SE_v_zetan (m2)
SE_v_zetan (m3)
SE_eta_fistar (Interval)
SE_eta_fistar (m2)
SE_eta_fistar (m3)
SE_eta_ystar (Interval)
SE_eta_ystar (m2)
SE_eta_ystar (m3)
SE_eta_pistar (Interval)
SE_eta_pistar (m2)
SE_eta_pistar (m3)
rho_u (Interval)
rho_u (m2)
rho_u (m3)

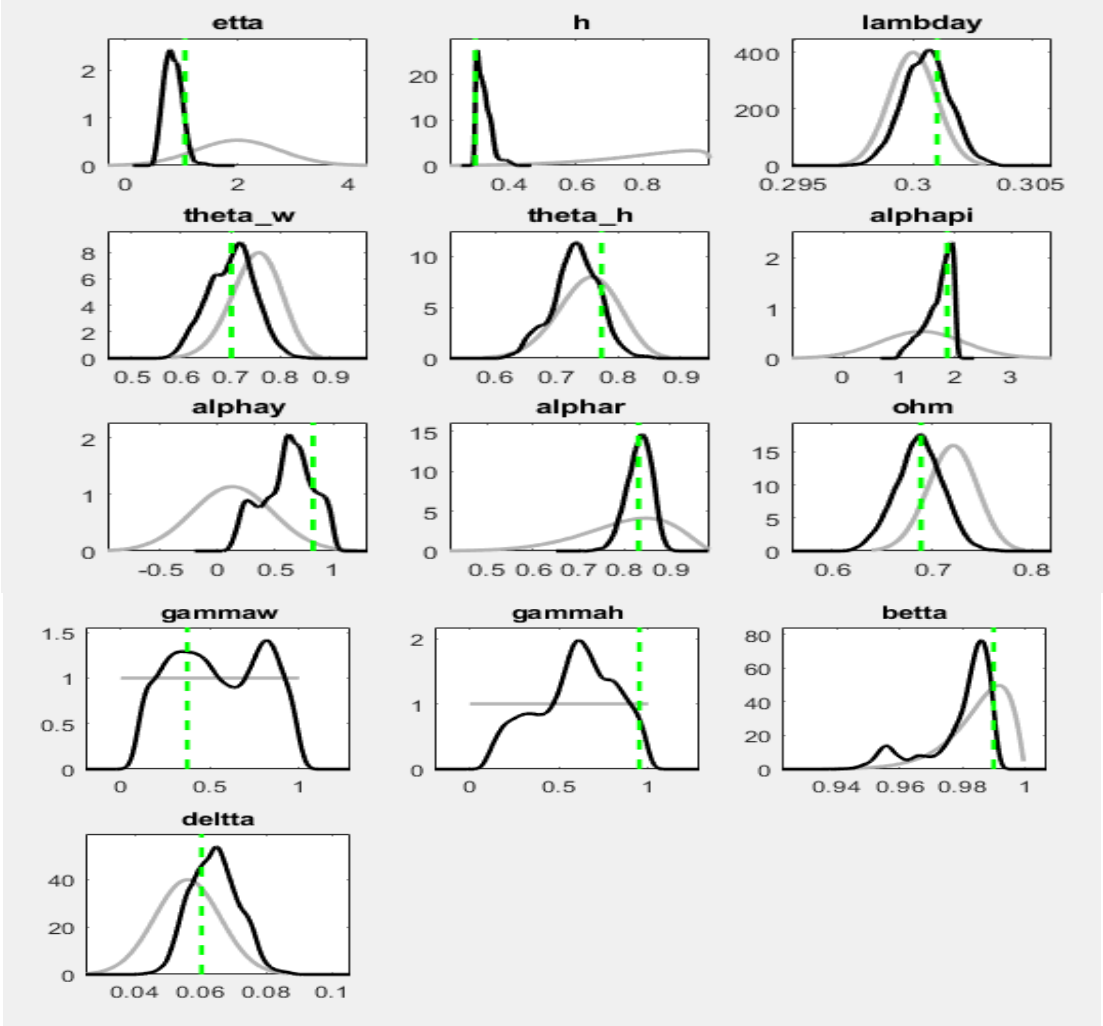

rho_g (Interval)
rho_g (m2)
rho_g (m3)
rho_pih (Interval)
rho_pih (m2)
rho_pih (m3)
rho_zetac (Interval)
rho_zetac (m2)
rho_zetac (m3)
rho_zetan (Interval)
rho_zetan (m2)
rho_zetan (m3)
sigmac (Interval)
sigmac (m2)
sigmac (m3)
sigmal (Interval)
sigmal (m2)
sigmal (m3)
etta (Interval)
etta (m2)
etta (m3)
h (Interval)
h (m2)
h (m3)
lambday (Interval)
lambday (m2)
lambday (m3)


theta_w (Interval)
theta_w (m2)
theta_w (m3)
theta_h (Interval)
theta_h (m2)
theta_h (m3)
alphapi (Interval)
alphapi (m2)
alphapi (m3)
alphay (Interval)
alphay (m2)
alphay (m3)
alphar (Interval)
alphar (m2)
alphar (m3)
ohm (Interval)
ohm (m2)
ohm (m3)
gammaw (Interval)
gammaw (m2)
gammaw (m3)
gammah (Interval)
gammah (m2)
gammah (m3)
betta (Interval)
betta (m2)
betta (m3)
deltta (Interval)
deltta (m2)
deltta (m3)

Note: The information is summarized in three graphs, with each graph representing specific convergence measures and having two distinct lines that represent the results within and between chains. Those measures are related to the analysis of the parameters mean (interval), variance (m2) and third moment (m3). The red line denotes the within-chain while the blue line represents the between-chain covariance. Convergence requires that both lines, for each of the three measures, become relatively constant and converge to each other.

iii. Prior and Posterior Estimates

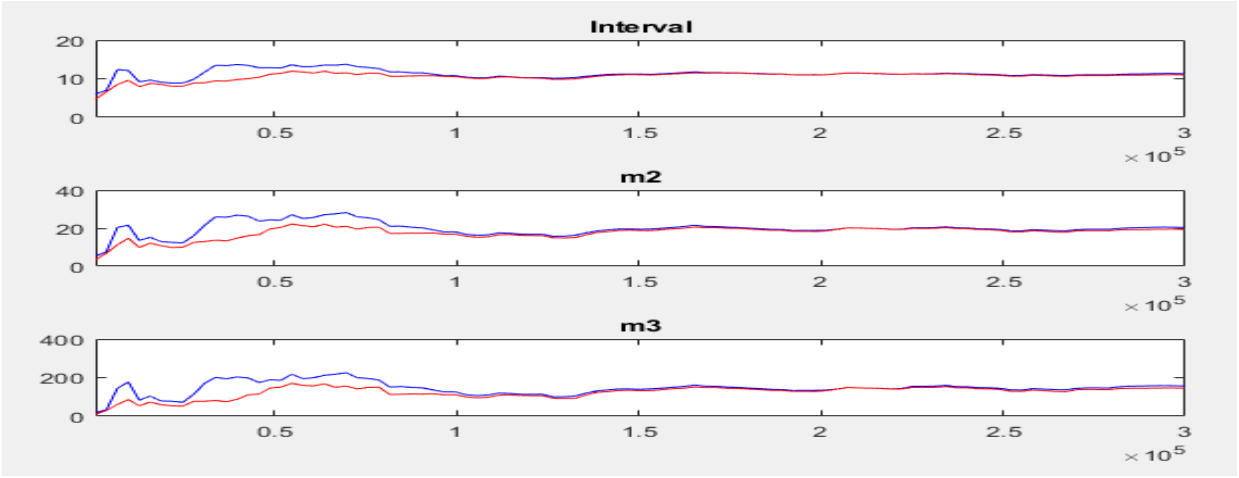




Note: the green line represents posterior mode, black line is the posterior distribution; gray line is the prior distribution.

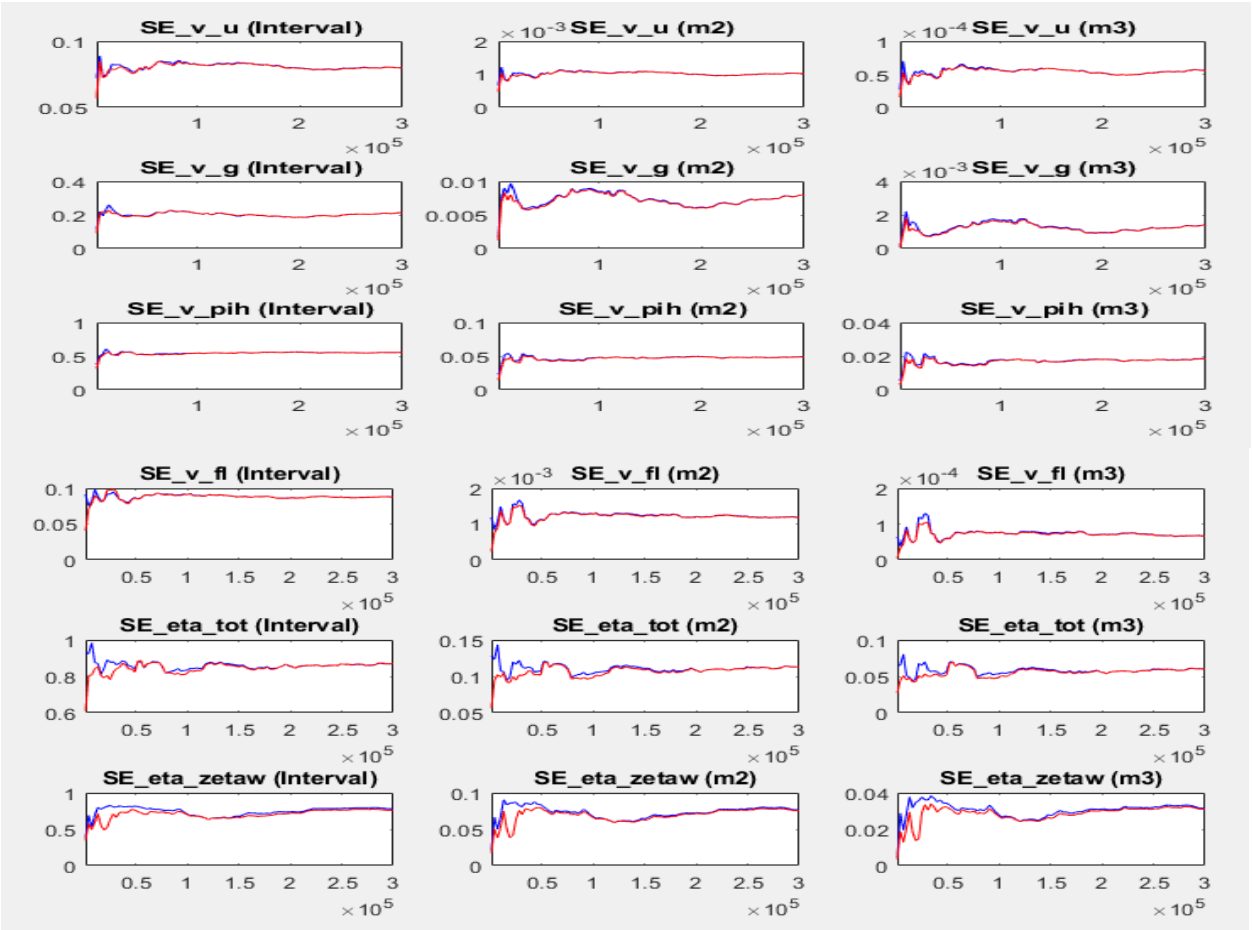
Appendix 7A

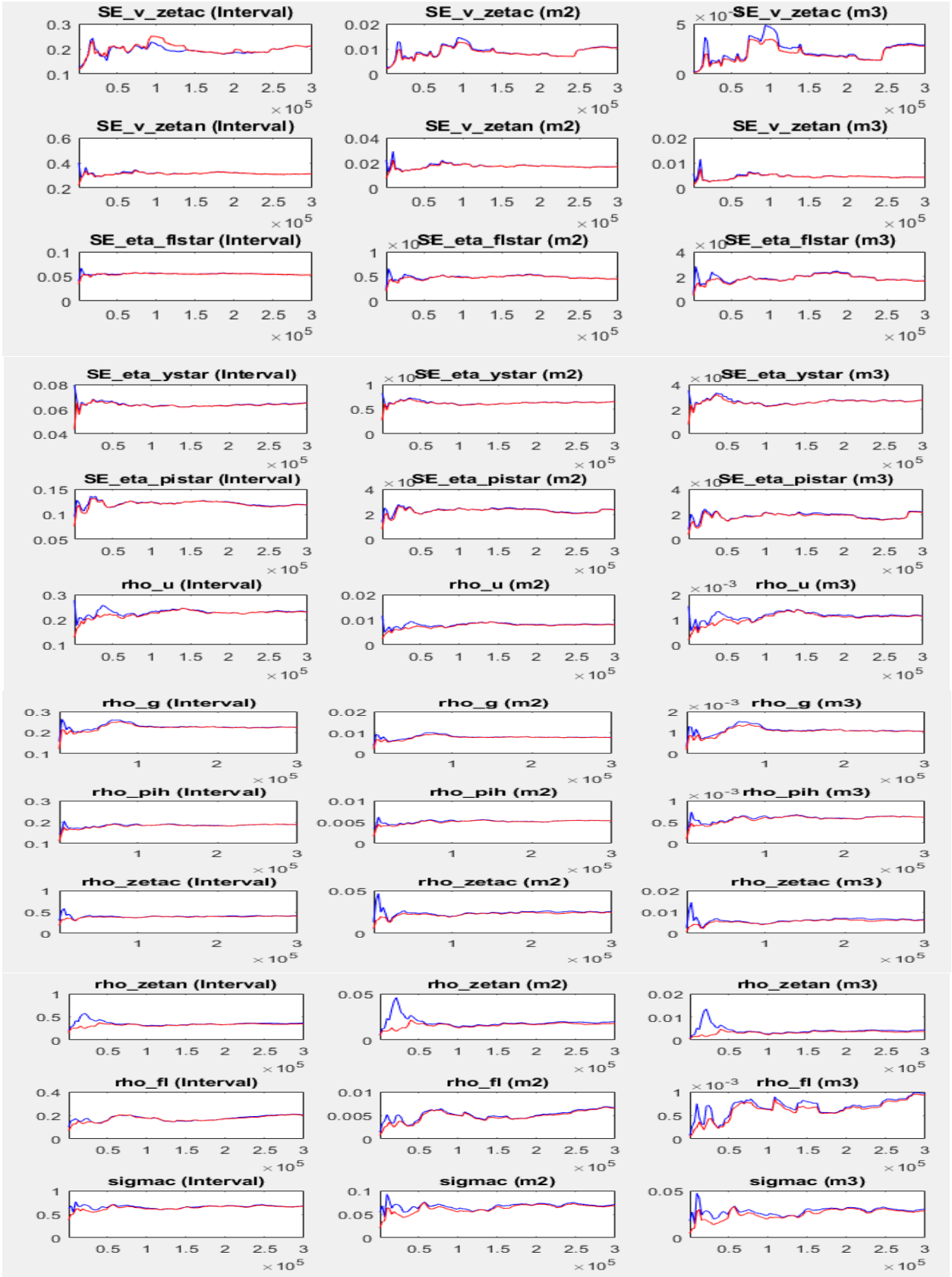
i. Multivariate Convergence Diagnostics of the Preferred HANK Model

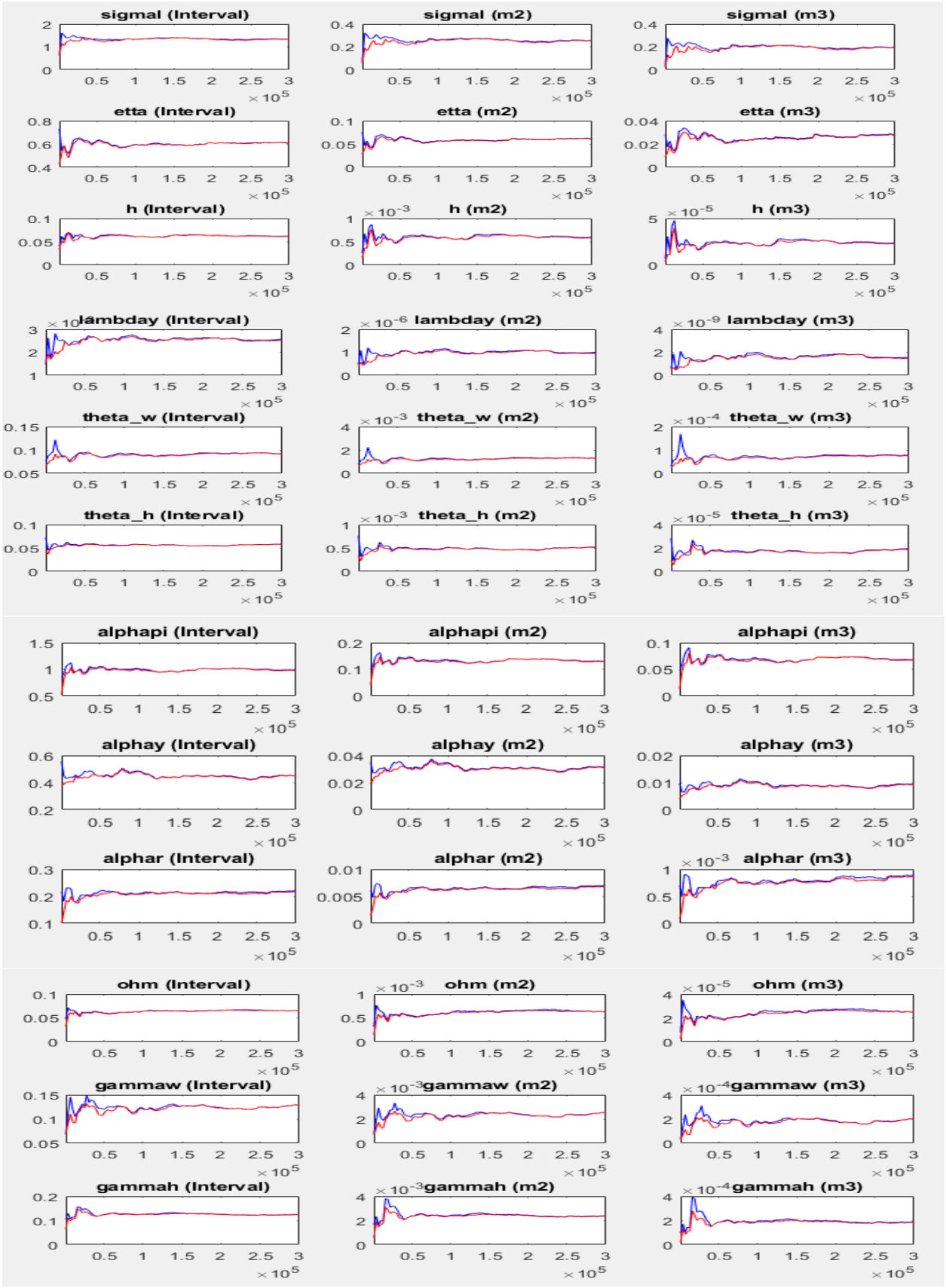


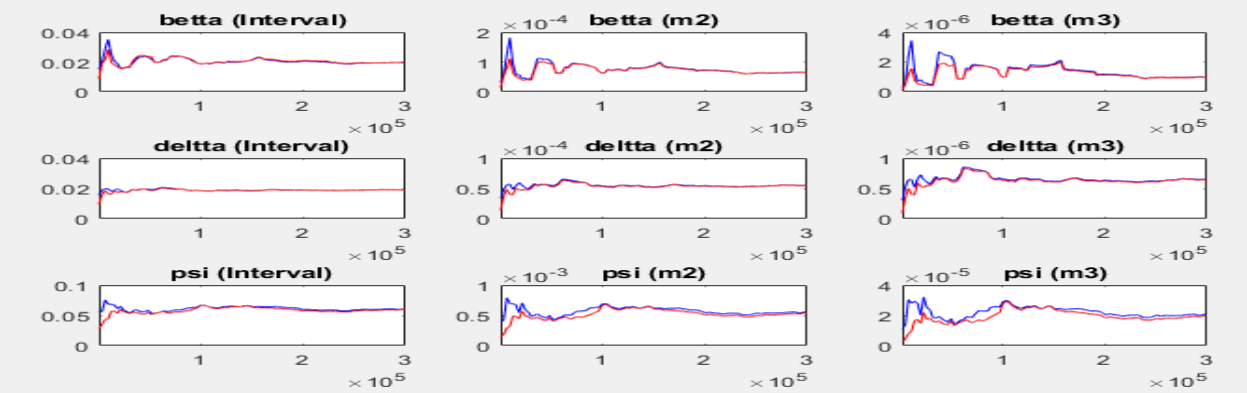
Note: The red line denotes the within-chain while the blue line represents the between-chain covariance matrices. No serious convergence problems as the pooled ($blue$) and within (red) chain covariance matrices for most parameters are sufficiently closed together in most periods.

ii. Univariate Convergence Diagnostics of the Preferred HANK Model



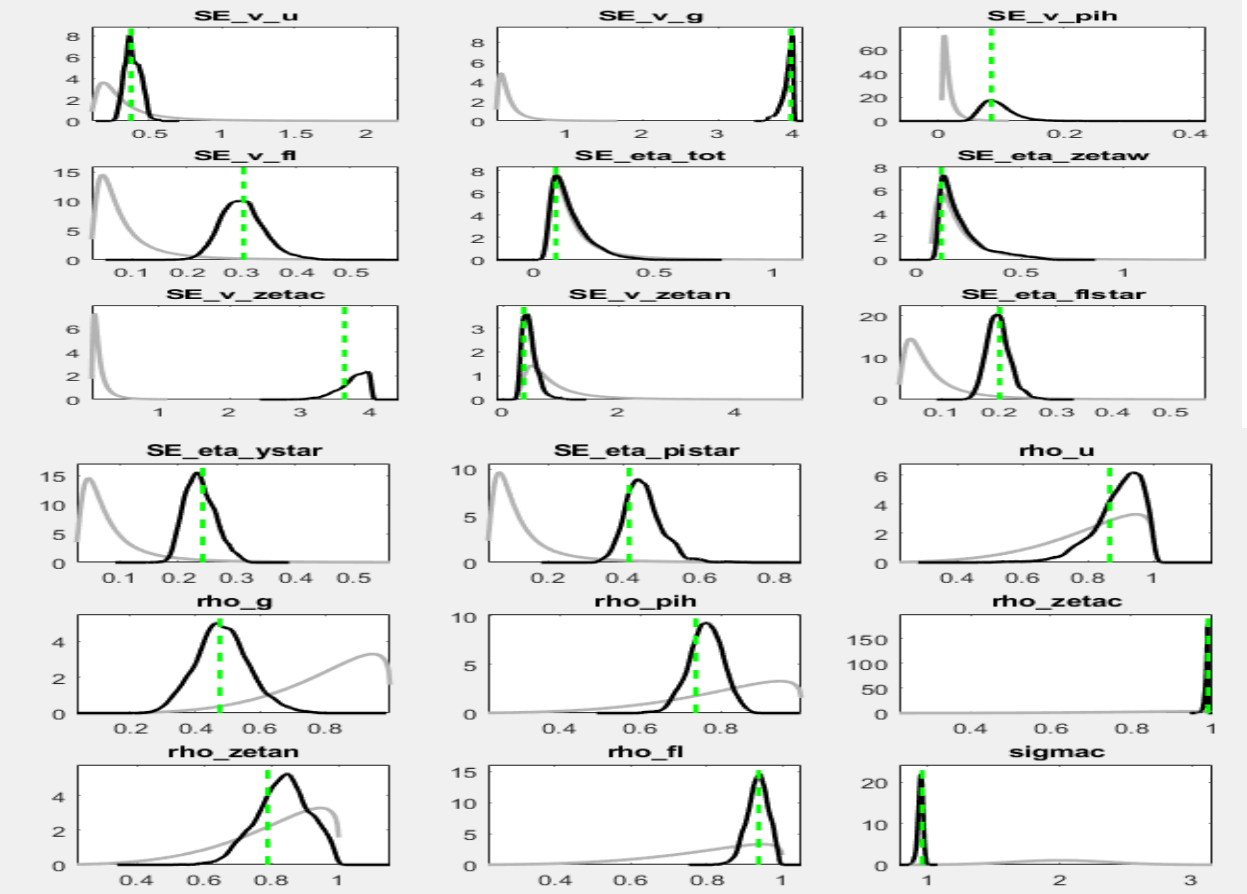

SE_v_zetac (Interval)
SE_v_zetac (m2)
SE_v_zetac (m3)
SE_v_zetan (Interval)
SE_v_zetan (m2)
SE_v_zetan (m3)
SE_eta_fIstar (Interval)
SE_eta_fIstar (m2)
SE_eta_fIstar (m3)
SE_eta_ystar (Interval)
SE_eta_ystar (m2)
SE_eta_ystar (m3)
SE_eta_pistar (Interval)
SE_eta_pistar (m2)
SE_eta_pistar (m3)
rho_u (Interval)
rho_u (m2)
rho_u (m3)
rho_g (Interval)
rho_g (m2)
rho_g (m3)
rho_pih (Interval)
rho_pih (m2)
rho_pih (m3)
rho_zetac (Interval)
rho_zetac (m2)
rho_zetac (m3)
rho_zetan (Interval)
rho_zetan (m2)
rho_zetan (m3)
rho_fl (Interval)
rho_fl (m2)
rho_fl (m3)
sigmac (Interval)
sigmac (m2)
sigmac (m3)

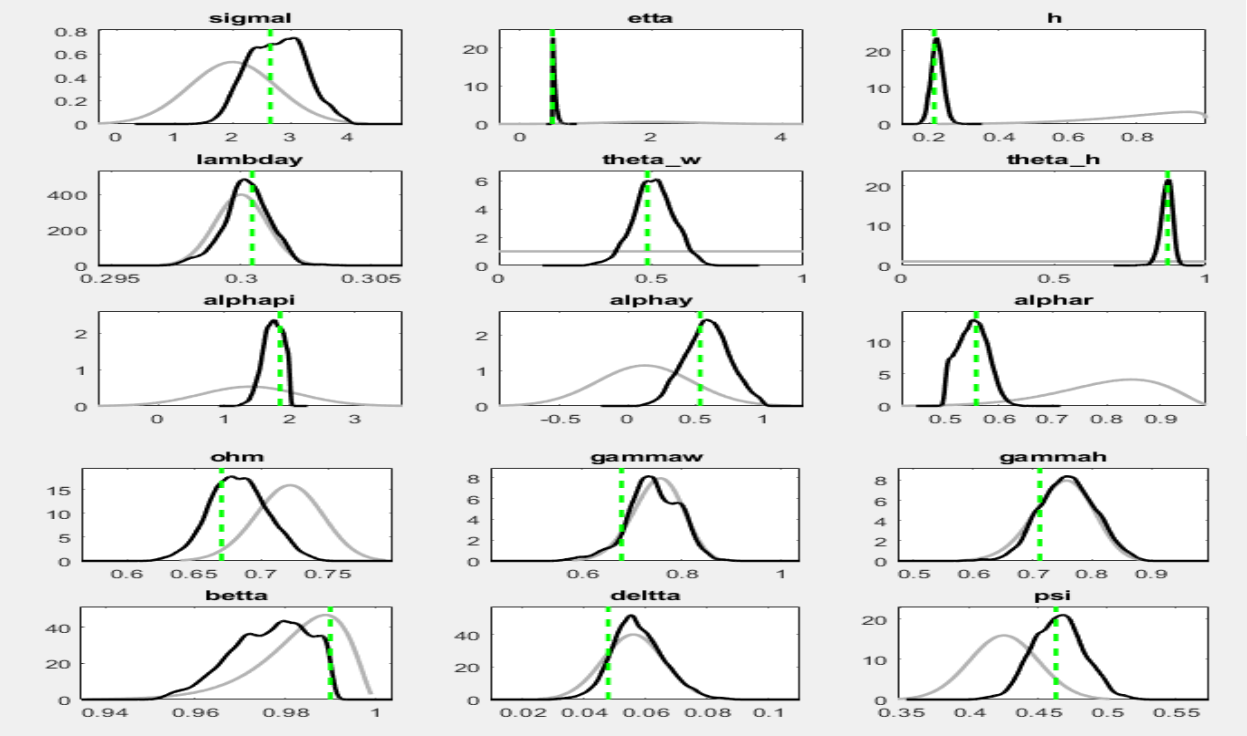

sigmal (Interval)
sigmal (m2)
sigmal (m3)
etta (Interval)
etta (m2)
etta (m3)
h (Interval)
h (m2)
h (m3)
lambday (Interval)
lambday (m2)
lambday (m3)
theta_w (Interval)
theta_w (m2)
theta_w (m3)
theta_h (Interval)
theta_h (m2)
theta_h (m3)
alphapi (Interval)
alphapi (m2)
alphapi (m3)
alphay (Interval)
alphay (m2)
alphay (m3)
alphar (Interval)
alphar (m2)
alphar (m3)
ohm (Interval)
ohm (m2)
ohm (m3)
gammaw (Interval)
gammaw (m2)
gammaw (m3)
gammah (Interval)
gammah (m2)
gammah (m3)



Note: The red line denotes the within-chain while the blue line represents the between-chain covariance matrices.

iii. Prior and Posterior Estimates of the Baseline HANK model

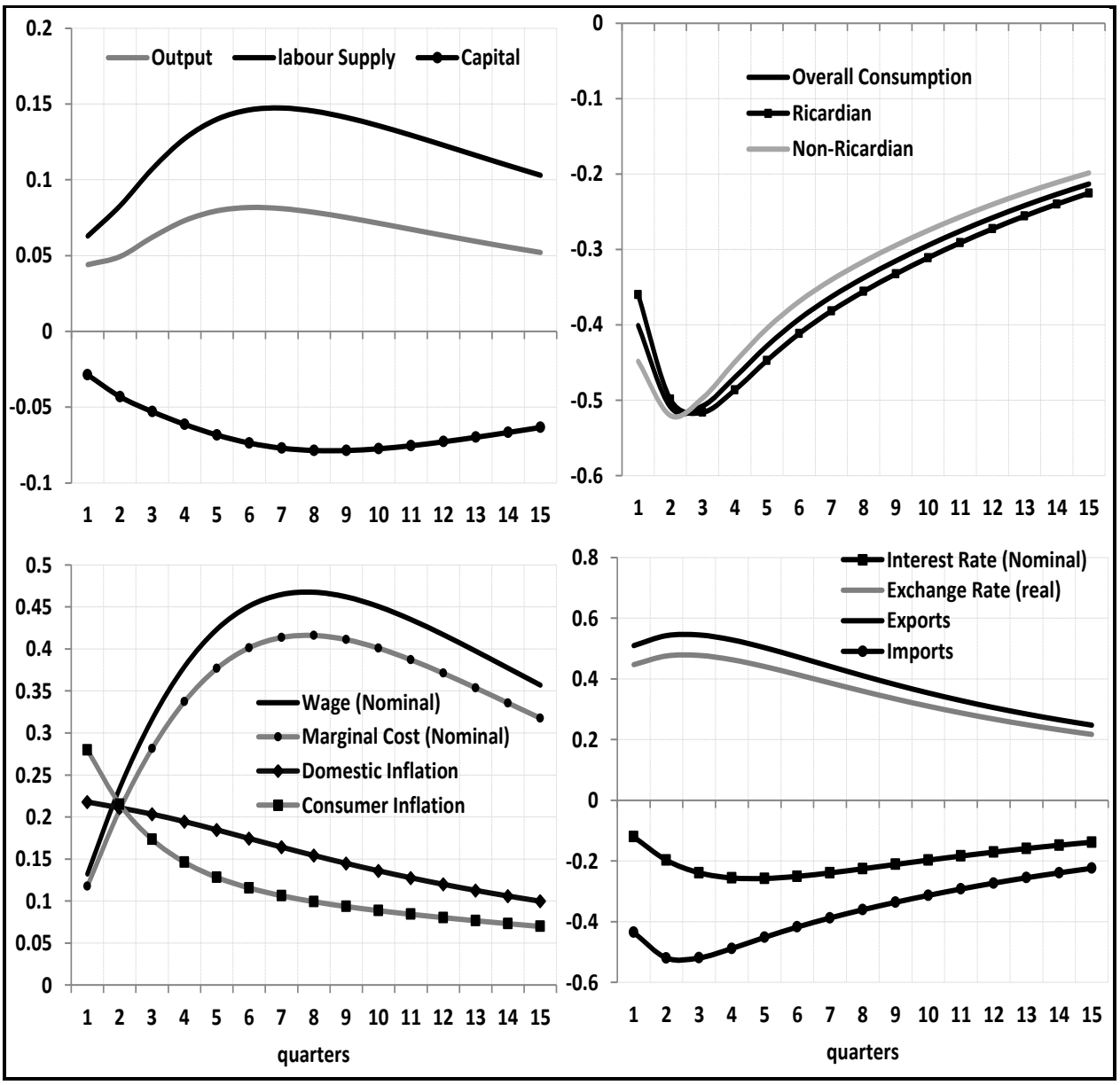




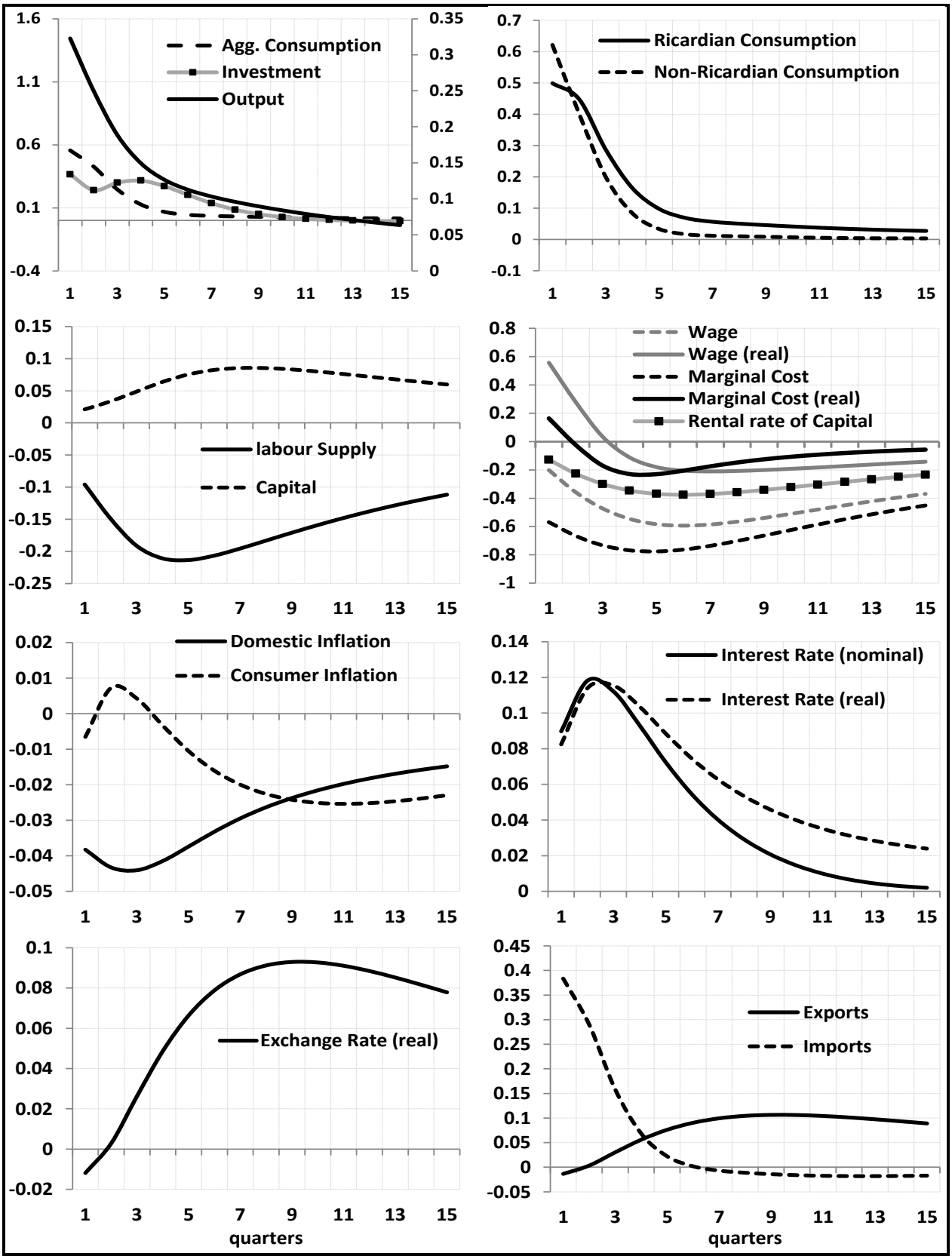
Note: the green line represents posterior mode, black line is the posterior distribution; gray line is the prior distribution.

Appendix 7B

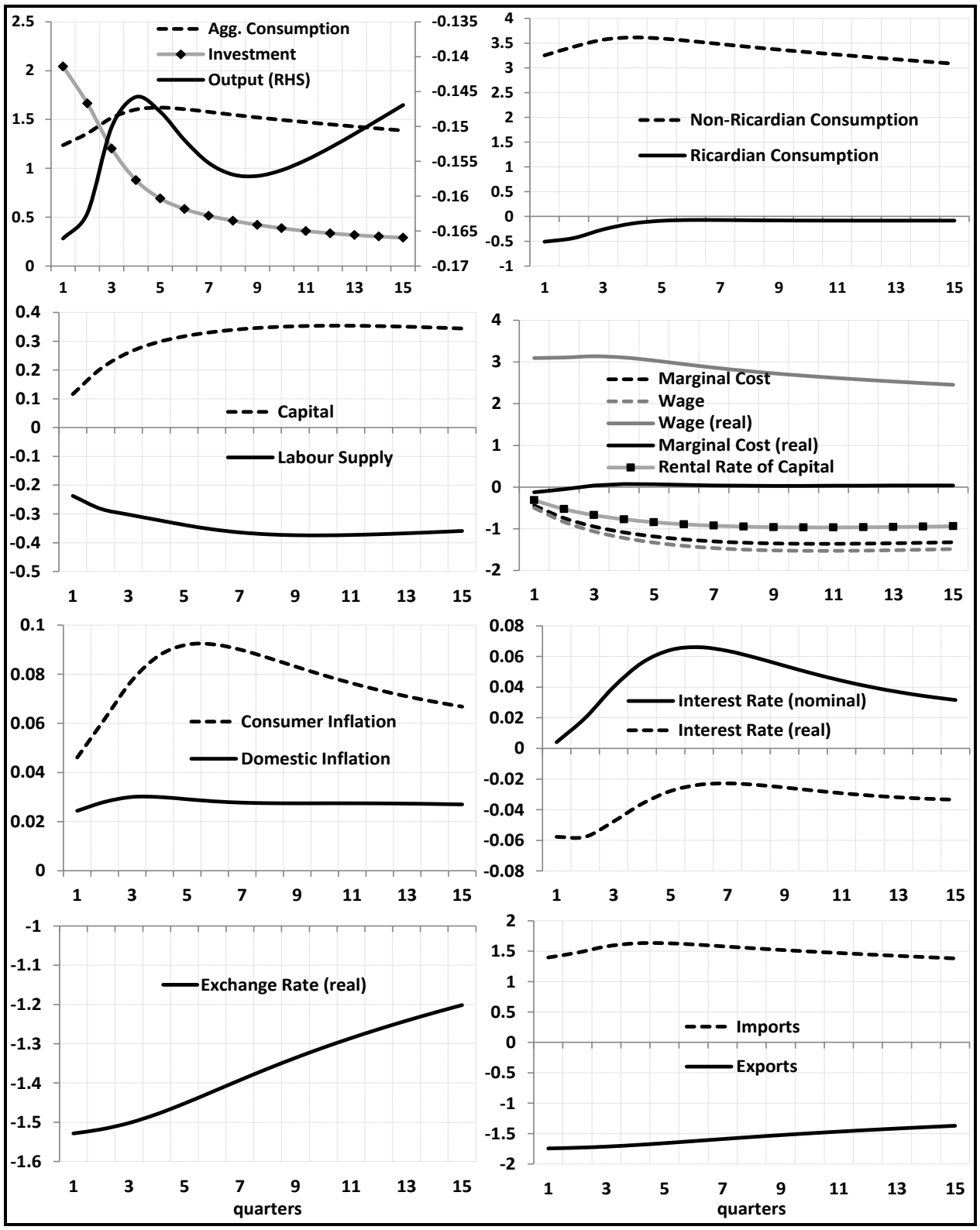
i. Effects of Expansionary Monetary Policy Shock in Sticky Price/Wage Regime



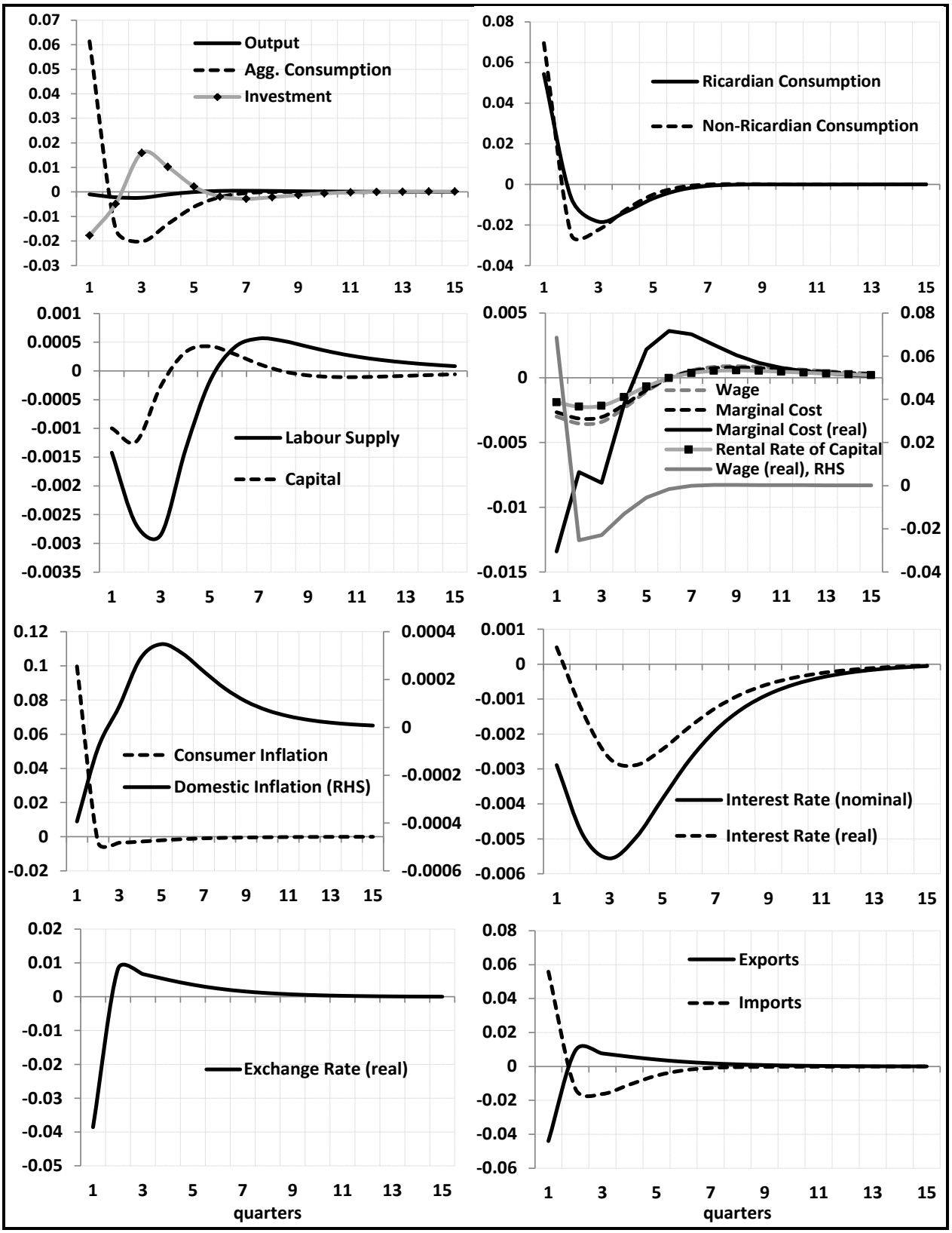
ii. Effects of an increase in Productivity



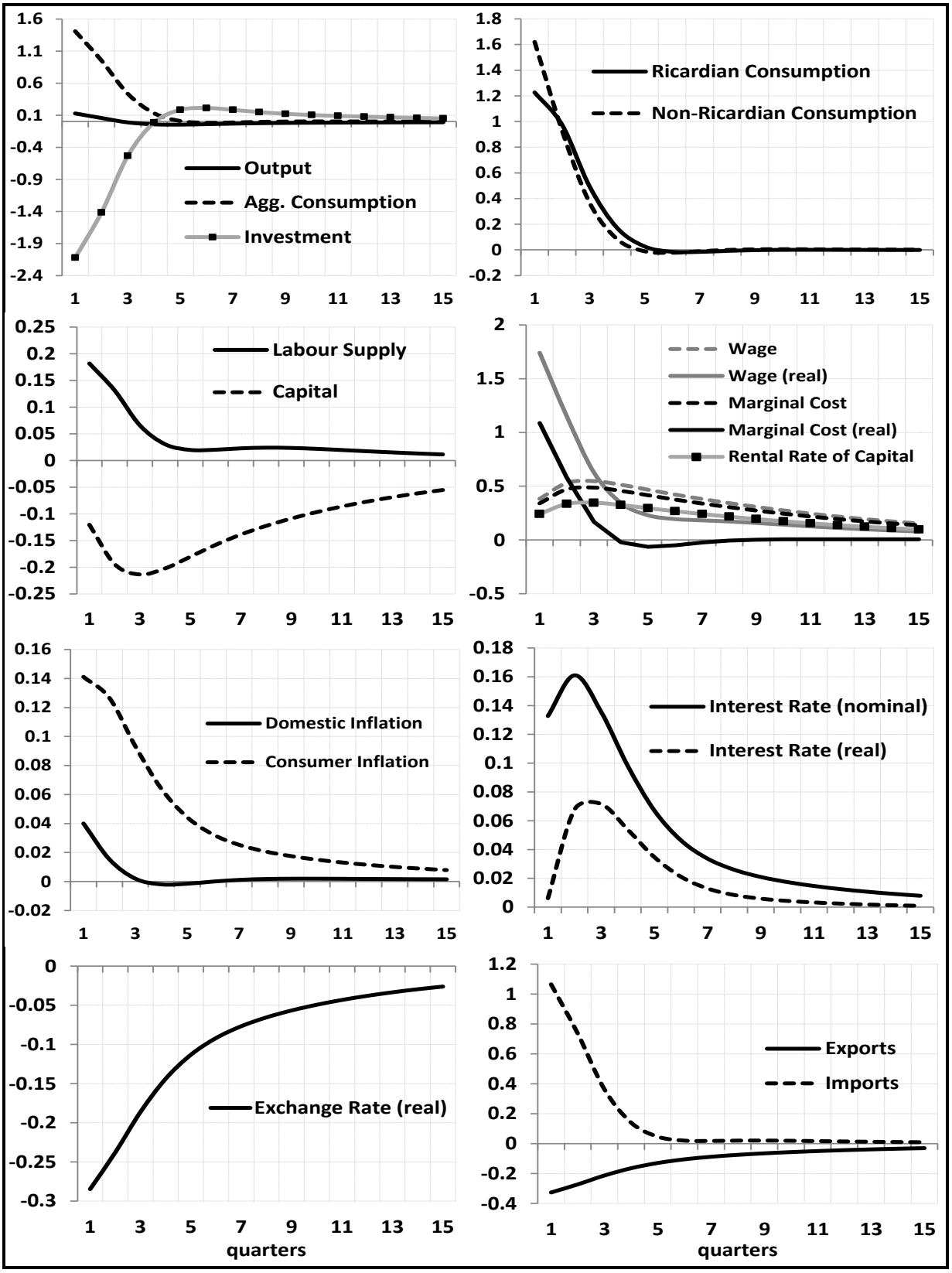
iii. Effects of Positive Preference Shock



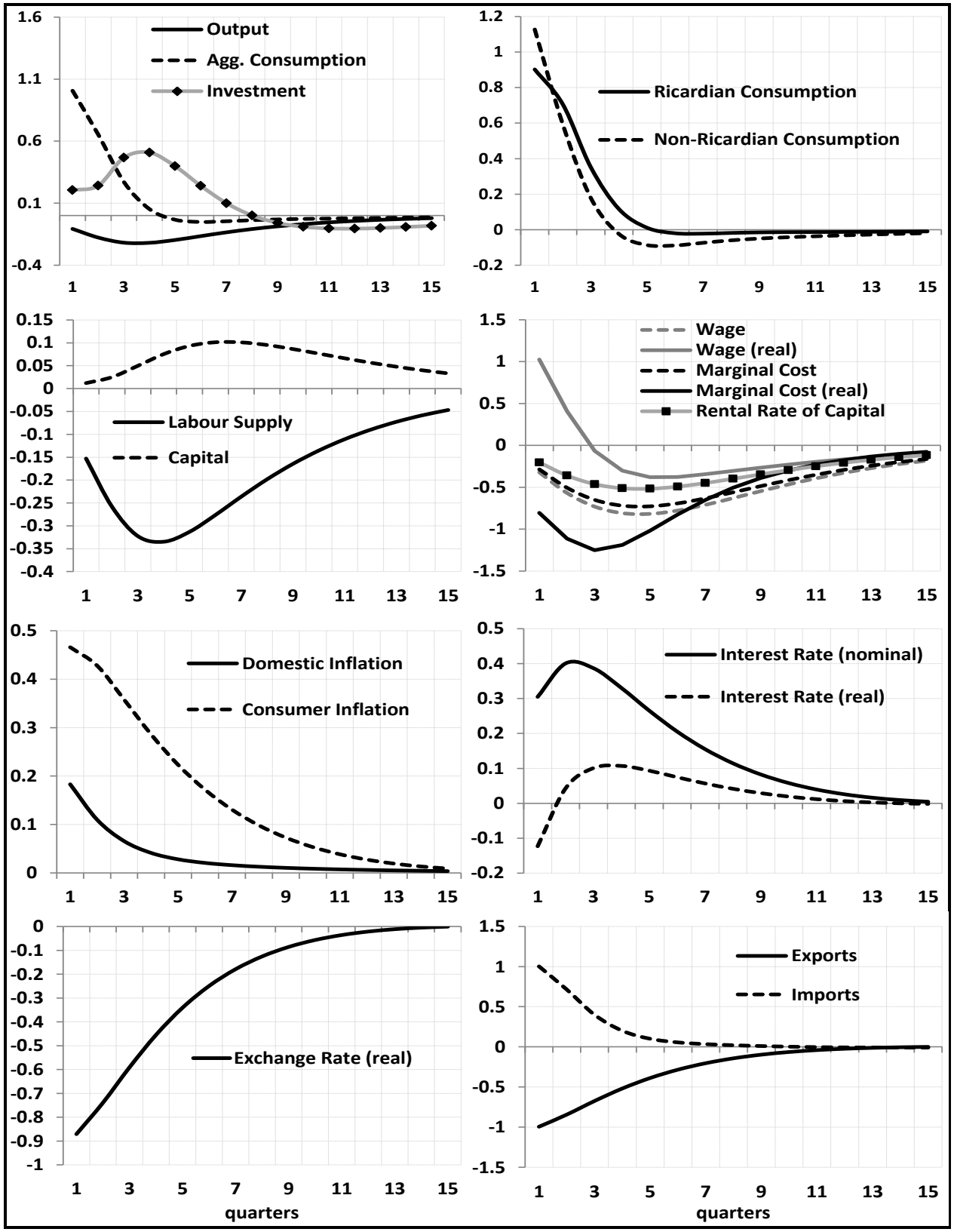
iv. Effects of a decline in Exchange Rate Risk Premium (UIP Shock)



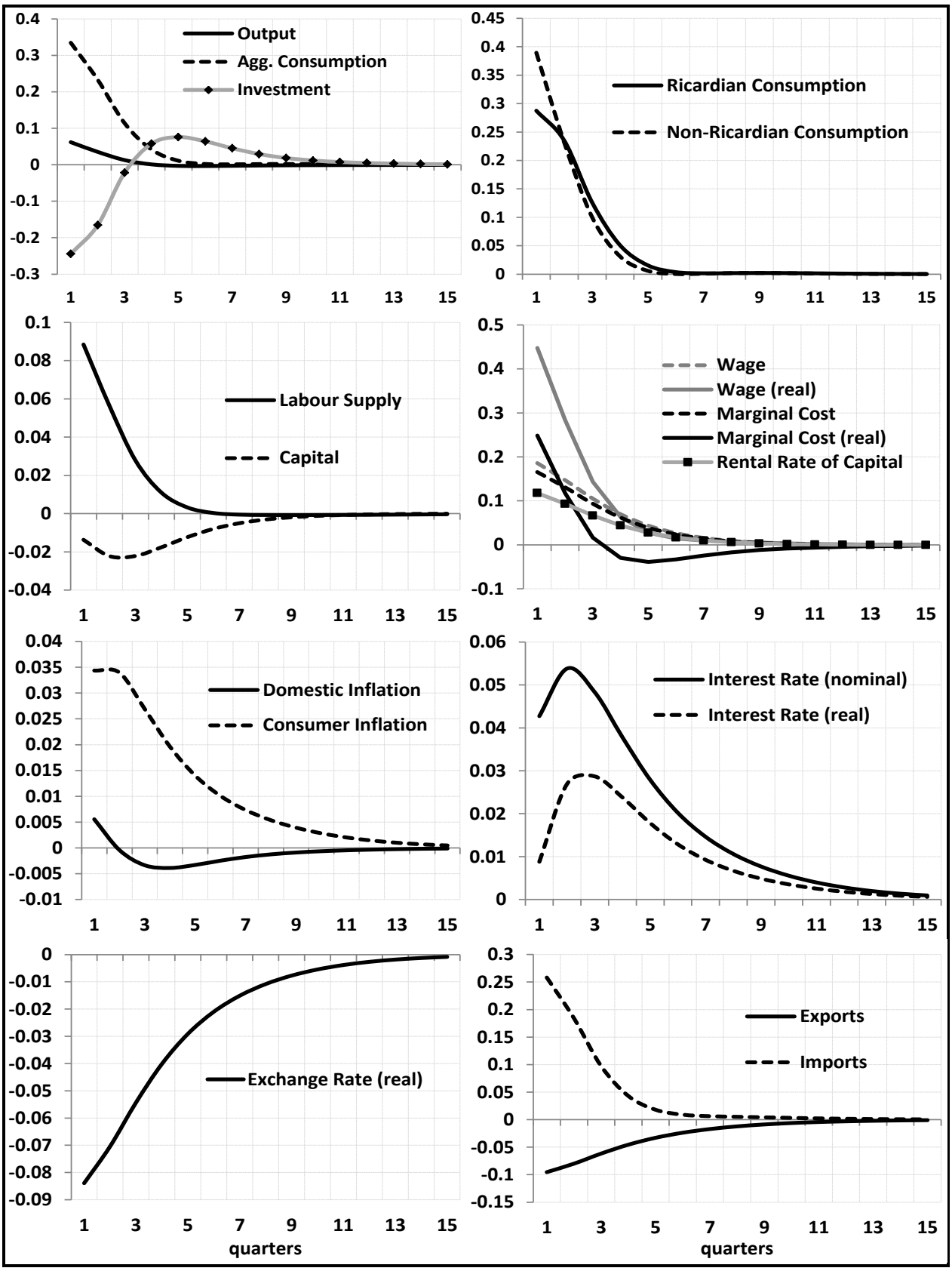
v. Effects of Labour Supply Shock



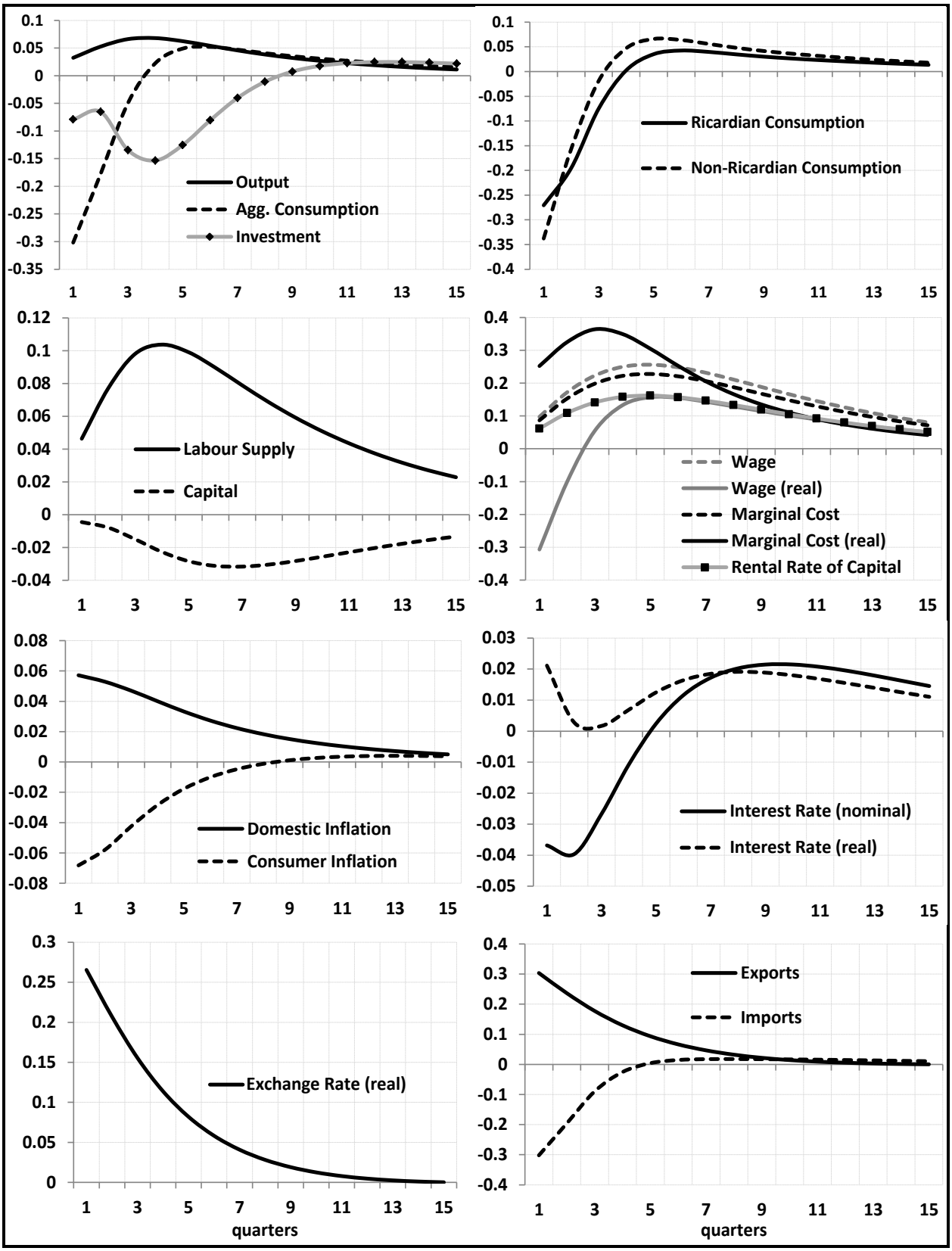
vi. Effects of higher domestic price mark-up



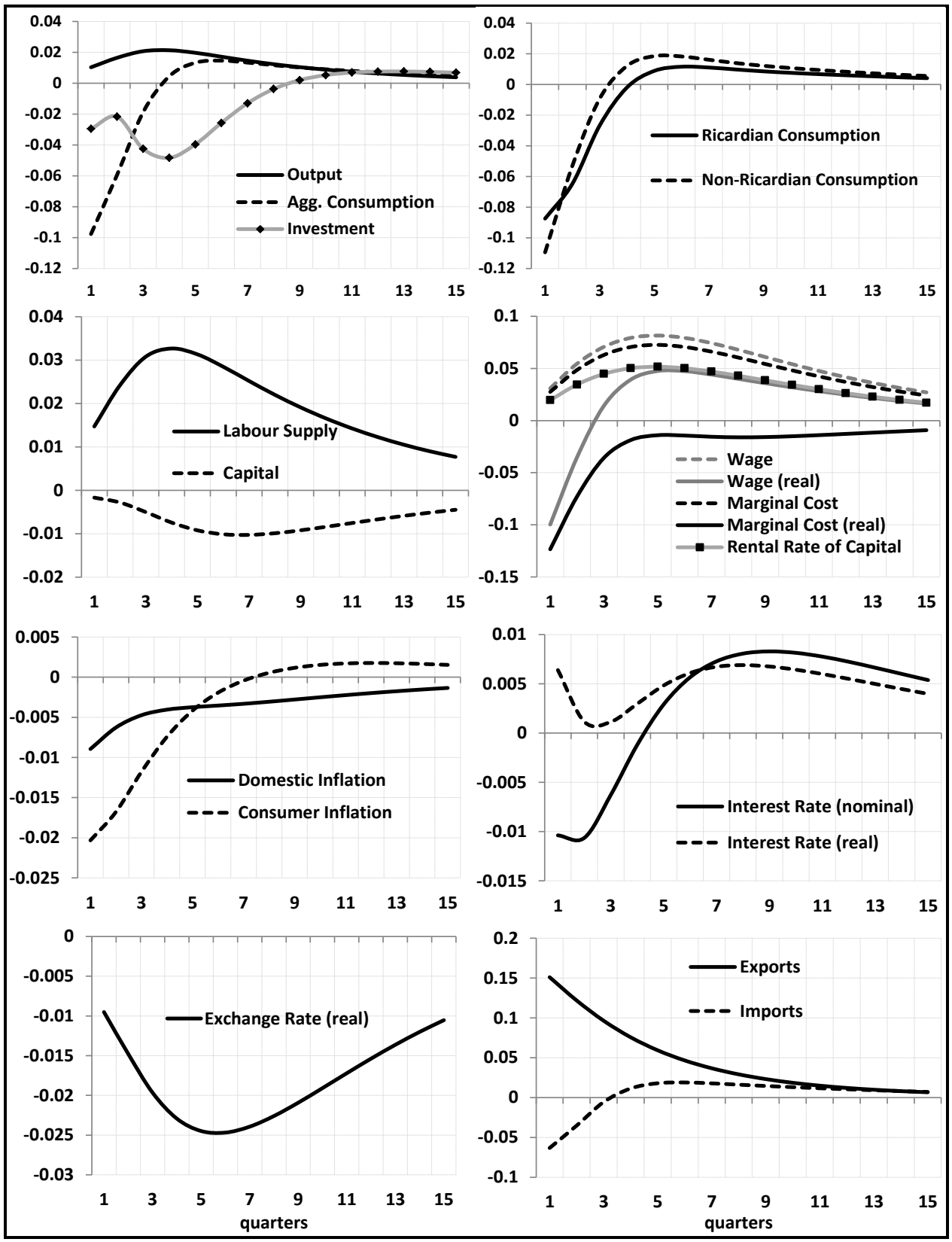
vii. Effect of adverse **w**age mark-up shock



viii. Effect of Foreign Policy shock



ix. Effect of Positive foreign output shock



x. Effect of positive foreign inflation shock

