NATIONAL BANK OF RWANDA
BANKI NKURU Y'U RWANDA

BNR ECONOMIC REVIEW

Vol. 14

February 2019

ISSN 2410-678 X

BNR Economic Review Vol. 14

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Foreword

The bi-annual publication of BNR Economic Review intends to avail information to the public on economic matters, focusing on features and challenges of the Rwandan economy. This 14th volume of BNR Economic Review consists of four papers, with topical issues related to monetary policy and inflation processes in Rwanda. The papers aim at providing concrete evidence-based analysis and policy recommendations that can help to improve the effectiveness of monetary policy in Rwanda.

The first article narrates the transition from a monetary targeting regime to a price-based monetary policy framework in Rwanda. After briefly outlining the role of price signals in the economy, the article discusses the operating framework of the monetary policy in Rwanda, touching on the key role played by improvements in liquidity forecasting and management. In this regard, the role played by National Bank of Rwanda for the development of interbank market in Rwanda is highlighted. The paper documents the success story of alignment between money market rates and central bank rate (CBR) in Rwanda. An empirical estimation of the transmission from CBR to money market rates shows a complete pass-through. The paper argues that degree of pass-through from money market rates to deposit and lending rates highly depends on the level of the demand for deposits and loans elasticities to the deposit and lending rates, respectively. The paper further argues that the recent development in capital market with an increasing participation of non-bank financial institutions and retail investments in government securities as well as development in money market are expected to improve the interest rate pass-through to deposit rates. The pass-through to lending rates remains insignificant, given that the economy still depends almost entirely on the banking sector as the capital market remains at early stages of development.

Given the importance of developments in financial sector for monetary policy transmission, the second article focuses on the role that bank-specific characteristics play in transmitting monetary policy actions. The article uses bank-level data to assess in the context of Rwanda one of the major transmission channels, namely the bank lending channel. The findings indicate the existence of bank lending channel of the monetary policy transmission in Rwanda, though the effect of monetary policy is moderate. On bank-specific characteristics, this study reveals that bank size and capitalization influence not only bank lending behavior, but also how a bank reacts to monetary policy stance. Specifically, loan supply by larger banks is less sensitive to monetary policy actions compared to smaller banks. Loan supply by well capitalized or more liquid banks responds more to monetary policy actions. The findings imply that financial sector soundness in terms of capital and liquidity standards is key to the effectiveness of monetary policy. Thus, NBR will continue taking into account developments observed in the financial sector during monetary policy formulation and implementation.

The central bank's capacity in modelling and forecasting inflation is a key prerequisite for the success of the price-based, forward-looking monetary policy framework. An important challenge to inflation modelling and forecasting pertains to the volatility of some components of consumer price index (CPI). The fourth paper in this volume assesses the magnitude and lifetime of inflation volatility in headline CPI and its key components in Rwanda. The study uses quarterly data for selected CPI components and other exogenous variables in an Exponential Generalized Auto-regressive Conditional Heteroscedasticity- EGARCH (1,1) model to estimate four equations of inflation volatility. The findings reveal that inflation volatility is driven by past deviations from expected inflation as well as past inflation volatility. They show that the impact of shocks to headline and housing inflations is relatively more persistent, compared to the impact of shocks to food and non-alcoholic beverage inflations. The findings further show that negative shocks to food and non-alcoholic inflation have bigger impact, compared to the impact of positive shocks. A test of forecast performance showed that EGARCH model were closer to the actuals values when compared with the forecasts produced by the currently used autoregressive moving average (ARMA) model. These findings will contribute to the improvement in the accuracy of near term CPI forecasts at National Bank of Rwanda.

One of the potential sources of inflation variability, especially in countries that have adopted market-based exchange rate regime, is exchange rates variability. As the Rwandan economy continues to sustain its growth path along with increased integration with regional and global markets, the linkages between exchange rate movements and domestic prices necessitate regular assessments. To that end, the fourth paper in this volume reexamines the exchange rate pass through (ERPT) in light of two main stages of transmission, from exchange rate movements to changes in aggregate import prices and ultimately in aggregate consumer prices. The paper employs time series data in a structural vector auto-regressive (VAR) framework to estimate the ERPT to various price indices. The main insight from the empirical analyses is that ERPT is incomplete and decreasing along the transmission chain. Shock to nominal exchange rate movements accounts for 22 percent of variability in imported goods CPI inflation (from the fourth quarter onwards) and 17 percent of headline CPI inflation variability. The finding that ERPT is incomplete suggests a partial insulation of domestic prices from exchange rate shocks that make it easier for monetary policy to achieve its main mission of price stability. However, National Bank of Rwanda should continue to take into account the FRW exchange rate in forecasting the future path of inflation.

Comments and questions can be sent to the Director of Research on phitayezu@bnr.rw, KN 6 Avenue 4, P.O Box 531 Kigali-Rwanda.

RWANGOMBWA John
Governor

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MOVING FROM MONETARY TARGETING FRAMEWORK TO PRICE-BASED MONETARY POLICY: THE EXPERIENCE OF THE NATIONAL BANK OF RWANDA

Prof. Thomas Kigabo Rusuhuzwa[1]

[1] Chief Economist and Executive Director, Monetary Policy and Research, National Bank of Rwanda

Abstract

This paper posits that the effectiveness of the price-based monetary policy adopted by National Bank of Rwanda in 2019 will highly depend on the development and functioning of financial market in Rwanda, which includes money market and capital market. The development of money market in Rwanda, as indicated by a huge rise in volume and number of transactions, and the stability of money market interest rates (converging to the CBR), has been the key achievement during the past five years in the process of moving to a price-based monetary policy and contributed to increase the interest rate pass through from central bank rate to money market rates and from money market rates to deposit rates. For the transmission to lending rates, the results indicate the pass through to be insignificant. There is need to continue developing money market, a financial system which is sound, deep and competitive as well as de risking key economic sectors to increase the effectiveness of NBR monetary policy.

Keywords: Price-based monetary policy framework, Monetary policy transmission mechanism, Rwanda

JEL Classification: E5.

1. Introduction

The National Bank of Rwanda (NBR) implemented its monetary policy under monetary targeting framework since 1997 with the objective of maintaining prices low and stable. In this framework, the transmission mechanism of monetary policy sets out from the quantity of monetary base or reserve money (B), operational target, and moves towards inflation through the money supply (M3). However, financial system development, sophistication of the economy and financial innovation, such as the use of mobile money, led to increased unpredictability in the money multiplier and the velocity of money demand, thus weakening the effectiveness of monetary targeting framework (see, for example, Kigabo and Kamanzi, 2018). As a result, the bank adopted a price-based monetary policy as new framework to be in place starting from January 2019. The main difference between the two monetary frameworks is the use of different operating targets with implication on the set of monetary transmission mechanism. In the new framework, NBR will use the price -short term interest rate- as operating target instead of monetary base used in monetary targeting regime.

An operating target is a key variable in central banks' monetary policy implementation because it influences the use of monetary policy instruments, and it is the first step in transmitting monetary policy impulses. By using reserve money as operating target, NBR's interventions on money market were aimed at correcting shifts in base money demand. By doing so, the bank accepts money market interest rate fluctuations as long as levels of base money are consistent with the quantity targets. In the new framework, using interest rate as operating target, NBR will accommodate any temporary shifts in the demand or supply of monetary base to ensure that interest rate remains close to its targeted levels. Consequently, the base money becomes endogenous as it will be a residual variable. Whatever the monetary policy framework, high fluctuations of market conditions (interest rate or quantity variable) due to the implementation of monetary policy are not desirable. To offset these undesired fluctuations of market conditions, the central bank has to conduct proper liquidity forecast to guide interventions on money market (e.g. Schaechter, 2001).

International experience shows that the effectiveness of price-based monetary policy depends on different factors including the following: stable macroeconomic environment and sound fiscal policies; sound and competitive financial system and adequate supervisory framework, a sufficient degree of institutional autonomy and operational capacity at the central bank (Ingves, 2004; Mishra et al, 2010).

The objective of this paper is to explain how the new monetary policy framework adopted by NBR in January 2019 will function, taking stock of existing market conditions that are expected to enhance the effectiveness of monetary policy in Rwanda. The paper proposes policy recommendations to address some existing challenges.

The rest of this paper is structured as follows: In the section 2, we explain how the new monetary policy functions. The section 3 take stock of existing market conditions in Rwanda expected to enhance the effectiveness of NBR monetary policy, before concluding with policy recommendations.

2. Price-based monetary policy framework

NBR has adopted the price-based monetary policy since January 2019. As mentioned above, the focus of NBR will be to align the central bank rate (CBR, previously called KRR) with interbank market rates to anchor short-term interest rates. The set of monetary transmission mechanism in this new framework can be presented as follow: from changes in CBR to changes in money market rates (interbank rates, repo rates and treasury bill rates), then from changes in money market rates to changes in market rates (deposit rates and lending rates), and finally from changes in market rates to inflation, through the impact on aggregate demand in the economy. An efficient price-based monetary policy enhances the role of price (particularly interest rates) signals in the economy, which improves savings mobilization and market allocation.

In the new framework, NBR sets an inflation band at +/-3 around the 5 percent headline inflation benchmark. Therefore, NBR will adjust the level of CBR, a change of its monetary policy stance, aiming to keep monetary conditions consistent with the inflation objective in the economy. NBR's interventions on money market will be directed by the objective of aligning CBR with interbank market rates to anchor short-term interest rates. The role of financial market Operations Committee (FMOC) which conducts liquidity forecasting and management to guide NBR's interventions on the money market will remain crucial. To contribute to the development of interbank market by encouraging banks to transact among themselves, NBR's interventions on money market will ensure that interbank rates remains attractive in a non-symmetrical band defined by standing lending and deposit rates. The standing lending rates are defined as CBR plus one percent, while the standing deposit rates are defined as CBR minus two percent. It is important to note that, though NBR will target short term interest rate, the bank will continue to monitor development in base money because it indicates the level of liquidity NBR should withdraw/inject into the banking sector, to manage short term risks to price stability emanating from monetary aggregates developments.

3. Market conditions for the implementation of a price-based monetary policy in Rwanda

As mentioned, in the new monetary policy framework, NBR's interventions on money market will be guided by the objective of aligning CBR with interbank market rates to anchor short term interest rates. This stresses the importance of well-functioning banking system and interbank market in a price-based monetary policy. Interbank market represents the first link of liquidity trading in the economy and the transparent price setting mechanism; it allows the financing of short and medium term positions and facilitates, the mitigation of commercial banks' business liquidity risk, smooth financial intermediation, and enhancement of lending to the economy. Indeed, interbank market facilitates commercial banks' liquidity management, where banks can borrow/lend short term among them to balance their daily liquidity fluctuations. Hence, interbank market rate represents the return from holding liquidity, and it influences the bank's portfolio decision for holding short-term liquid assets and long-term illiquid assets.

3.1. Money market rate and transmission mechanism from CBR to money market rates in Rwanda

NBR introduced different changes in its monetary policy framework, to allow more flexibility and build foundation for the use of a price-based monetary policy. In 2008, NBR introduced the key repo rate (KRR) as a policy rate, initially to support commercial banks in their liquidity management. Since 2010, KRR was used as a tool to signal monetary policy stance, while retaining reserve money as the operating target. To reduce undue interest rate volatility, characteristic of money targeting, and accommodate the uncertainty of monetary targets, NBR introduced a flexible monetary programming framework in 2012. This included quarterly averaging of reserve money targets, increase in reserve requirement maintenance period to two weeks, introducing a reserve money band and an interest rate operating corridor. At the beginning, NBR introduced a symmetrical 200 basis points corridor, standing lending and deposit rates being KRR plus and minus 200 basis points. To encourage banks to transact among themselves on interbank market, the corridor was changed in June 2017 (to 100 basis points above the KRR for the standing lending rate and 100 basis points below the previous day's closing repo rate for the standing deposit rate).

In the new framework, NBR decided to link both standing lending and deposit facilities' rates to CBR. The standing lending facility rate is defined as CBR plus one percent while the standing deposit facility rate is defined as CBR plus two percent.

Flexibility in the reserve money program and improvement in liquidity forecasting and management contributed to increase activities on money market, and align money market rates (repo rates, Treasury bill rates and interbank rates) with the central bank rate. The spread between interbank rates and central bank rates reduced significantly from 112 basis points in 2014 to only 15 basis point in 2018. In addition, total transactions amounted FRW 613 billion between 2013-2015 and FRW 1,588 billion between 2016-2018, that is an increase of 159.1%. Furthermore, money market rates have become less volatile in Rwanda in recent period (2015-2018). Measured by standard deviation, volatility in repo rates reduced significantly by 71.4% from 2.1 (between 2012-2014) to 0.6 (between 2015-2018), while it reduced by 80.8% from 2.6 to 0.5 for the interbank rates. As a result, the transmission mechanism from central bank rate, represented by repo rates capturing daily NBR interventions on money market, to money market rates (interbank rates and Treasury bill rates at maturity) has significantly improved.

3.1.1. Transmission from CBR to money market rates in Rwanda

The assessment of the interest rate pass- through is generally based on a marginal pricing model which states that a bank sets an interest rate equal to the marginal cost of funding approximated by a market interest rate and a constant mark-up (Tieman, 2004; De Bondt, 2002; Borio, 1997).

$$i_t^m = \alpha + \beta i_t^p + \varepsilon_t \qquad (1)$$

Where β is the pass through parameter. The corresponding Error Correction Model can be specified as follow:

$$\Delta i^m{}_t = \gamma_1 + \gamma_2 \Delta i^m{}_{t-1} + \gamma_3 (i^m{}_{t-1} - \beta i^p{}_{t-1} - \alpha) + \nu_t \qquad (2)$$

In such an ECM, the coefficient γ_3 indicates the speed of adjustment of the short run dynamics to the long run equilibrium relationship. A high level of this coefficient indicates a faster market response to the policy rate. Before estimating the long run relationship between repo rates and each money market rates (using Engle Granger cointegration test), we have first performed unit roots test on all data series, using the standard augmented Dickey-Fuller test and all variables are I(1) at the 5 percent uncertainty level.

As indicated in the table 1 and 2 in appendix, the pass through is complete, with estimated C (2) varying between 1.06 and 1.1, except for TB for 12 months where estimated C (2) is 0.79. The estimation of error correction model show that all adjustment coefficients are statistically significant but are low, they vary between -0.06 and -0.24 as indicated in table 2 in appendix. Lower adjustment coefficients in short term is due to, among other factors, the use of a long term period including time when money market was less developed than today.

To assess if the above results are constant over time or whether they evolved over time, we considered two sub samples: the first one starting in January, 2009, and ending with December, 2012, the year when BNR introduced different innovations in its reserve money program. The second sub sample, starts in January, 2013, and ends in December, 2018. The Chow breakpoint test shows that coefficients in the regression between interbank rates and repo rates are not stable over time, they are different in the two sub samples: January 2009 - December 2012 and January 2013-December 2018.

Table 1: Chow Breakpoint Test: 2012M12

Null Hypothesis: No breaks at specified breakpoints
Equation Sample: 2009M01 2018M12

F-statistic	13.04017	Prob. F(2,116)	0.0000
Log likelihood ratio	24.33631	Prob. Chi-Square(2)	0.0000
Wald Statistic	26.08035	Prob. Chi-Square(2)	0.0000

Following the same estimation procedure, estimation results for the two different samples clearly differ. Analyzing the link between the interbank rate and Repo rates, tests show the absence of long run relationship between the two variables in the first sub sample. In the second sup sample, estimated coefficients improved compared to the full sample. The long run coefficient increased from 1.1 to 1.22. The adjustment coefficients in the ECMs show significant improvement in adaptation of short-term dynamics to the long-run equilibrium compared to results from the regressions of the full sample. The estimated adjustment coefficient more than doubled in the sub sample January 2013-December 2018, standing at -0.26 compared to -0.12 in the full sample.

These results show that the first part of the interest rate channel of monetary policy has become more effective, indicating that NBR could rely on its interest rate policy to a larger extent than in the past. These findings also show a successful gradual shift from monetary targeting framework to price-based monetary framework. However, the deepening and broadening of the interbank market have to remain vital to NBR's agenda, as it adjusts to economic development.

3.2. Transmission from money market rates to market rates (deposit and lending rates) in Rwanda

The interest rate pass-through to deposit and lending rates highly depend on the level of financial system development. By reducing information and transaction costs, financial systems contribute to lower the cost of channeling funds between borrowers and lenders (Levine, 2005). In addition, a well-functioning financial system can make it easier for people to diversify risk by offering a broad range of investment opportunities with different risk profiles like equity (high risk) and government bonds (low risk). Furthermore, savers are generally unwilling to delegate control over their savings to investors for long period. Financial system creates the possibility for savers to hold liquid assets like equity, bonds or demand deposits that they can sell quickly and easily if they seek access to their savings; simultaneously, transforming these liquid financial instruments into long term capital investments. By providing liquidity, i.e. the ease and speed with which agents can convert assets into purchasing power at agreed prices, financial intermediaries and markets facilitate management of risks. A well-developed financial system offers different options of financing the economy. Generally, banks provide short term loans while capital market loans can typically be longer tenured and benefit from fixed versus variable interest rates.

Corporate bond markets play an important role in the financial system and economic development, by supporting private sector and economic growth. Within capital markets, corporates have access to a range of financial instruments including the traditional asset classes: equities (stocks), cash equivalents (money market instruments) and fixed income bonds, which typically refer to debt securities with greater than one-year maturity. As corporations require an increasing amount of working and growth capital to grow, corporate bond markets are alternative important sources of financing in addition to the banking system. Thus, capital markets also contribute to diversify sources of credit, and associated risk, which leads to greater level of financial market stability. In addition, because the investment in corporate bond markets require information disclosure, greater corporate governance and adherence to a uniform set of market standards, corporate bond markets promote greater market discipline and transparency (e.g. see Yang et al, 2001; Leiderman et al, 2006; De Bondt, 2002; Mishra et al, 2010).

Based on the elements above, it is easy to understand that the degree of pass through from money market rates to deposit and lending rates highly depends on the level of the demand for deposits and loans elasticities to the deposit and lending rates respectively. The elasticity of demand for deposits depends on different factors, including imperfect substitution between bank deposits and other investment facilities with the same maturity, and flexibility like money market funds and T-bills. The recent development in capital market with an increasing participation of non-bank financial institutions and retail investments in government securities is expected to improve the interest rate pass through to deposit rates. The elasticity of demand for loans, on the other hand, depends on different factors including substitution between bank lending and other types of external finance, like equity or bond markets, high concentration of the banking sector which can lead to monopolistic market, and the cost of shifting from one bank to another (switching costs). This explains why the interest rate pass through to lending rates is lower in developing countries, where the economies depend almost entirely on the banking sector rather than capital market as it less developed or non-existent.

3.2.1. Interest rate pass through to deposit rates in Rwanda

The results of estimation of the long-run equilibrium equation for the deposit rates, as well as the ECMs are presented in in table 3 and 4 respectively. The estimated coefficients indicate that in the long run deposit rates for all maturities react to changes in money market rates, the pass through is observed to slow (coefficients vary between 0.25 and 0.5), except for the weighted deposit rates where the coefficient is surprisingly high (varying between 0.9 and 1.1). Interestingly, in the short term, the speed of adjustment to long run equilibrium is higher for deposit rates at short maturity, varying between -0.24 for one year deposit rates to -0.54 for one month deposit rates.

We have assessed the heterogeneity in interest rate transmission across individual banks to test if, interest rate pass through to deposit rates varies from the size of banks in terms of assets. Results of estimation show that for the two biggest banks, there is no evidence of pass through. Either there is no cointegration between deposit rates for a bank and money market rates, or where the cointegration is confirmed, long run coefficients are not significant. For three not big banks were data are available, there is a clear evidence of interest rate pass through to deposit rates with long run coefficients varying between 0.37 and 0.55, except one small coefficient (0.18); short term coefficients vary between -0.40 and -0.80 and R-square about 0.5.

Table 2: Interest rate pass through to deposit rates by bank

Bank 1	Money market rates	Long run coefficient	Short term coefficient
	Repo rates	0.6	-0.40
	Interbank rates	0.55	-0.60
	Tb 1month	0.42	-0.51
	TB 3 months	0.41	-0.49
	TB 6 months	0.44	-0.49
	TB 12 months	0.51	-0.62
Bank 2	Repo rates	0.46	-0.51
	Interbank rates	0.41	-0.54
	Tb 1month	0.32	-0.52
	TB 3 months	0.31	-0.52
	TB 6 months	0.38	-0.56
	TB 12months	0.37	-0.49
Bank 3	INTBR	0.18	-0.80
	Tb12 months	0.19	-0.81

3.2.2. Interest rate pass through to lending rates in Rwanda

For the lending rate, the pass-through is not significant. Some cointegrating relationships were identified, but all coefficients (short term and long term) were not significant. These results could be explained by a high level of some banks' market power on the loan market, absence of a well-developed capital market, particularly corporate bond market, the structure of the economy limiting the link between financial system and the real economy and the level of monetization of the economy as well as financial deepening, with M3 and bank credit to the private sector standing at 24.7% and 19.3% end 2018 respectively. However, these results may also be explained by the simple methodology used to assess the pass through to ending rate. The use of econometric models including more variables and bank specific characteristics may give more robust results.

4. Conclusion and policy recommendations

NBR adopted the price-based monetary policy since January 2019. In this framework, the transmission mechanism will be from changes in CBR to changes in money market rates (interbank rates, repo rates and treasury bill rates), then from changes in money market rates to changes in market rates (deposit rates and lending rates), finally from changes in market rates to inflation, through the impact on aggregate demand in the economy. This paper shows that the effectiveness of the price-based monetary policy will highly depend on the development and functioning of financial market in Rwanda, which includes money market and capital market.

The development of money market in Rwanda, as indicated by a huge rise in volume and number of transactions, and the stability of money market interest rates (converging to the CBR), has been the key achievement during these past five years in the process of moving to a price-based monetary policy. For an effective price-based monetary policy, there is a prerequisite of a well-functioning interbank market since it is the primary link of liquidity trading in the economy, and a tool for bank's liquidity management.

The results of the analysis, indicate that the transmission from money market rates to deposit rates exist among the different maturities, though the pass through is moderate. Therefore, it is safe to say that NBR can rely on its interest rate policy. However, there is still room of improvement. On the one side, non-bank economic agents should be motivated to invest more in government securities as additional saving opportunity. This will lead to a stronger interest rate pass through to deposit rates. On the other side, NBR and other stakeholders will need to continue working together to have in place a financial system which is sound and competitive because big banks react less to change in policy rate than medium and small banks.

For the transmission to lending rates, the results indicate the pass through to be insignificant. Therefore, strategies should be developed to facilitate further financial sector deepening and increase the level of monetization of the economy. A number of research show that beyond a certain level of financial development, estimated at around 80–100 per cent of private credit to GDP, financial sector development can negatively affect the economic growth by increasing the probability of large economic booms and leading to potential misallocation of resources (Cecchetti and Kharroubi, 2012:5; Rajan, 2005, Ize, 2011 and IMF, 2012a).

In this regard, by end of 2018, M3/GDP was 24.7 percent and credit to private sector as percentage of GDP was 19.3 percent, leaving a big room for improvement in financial sector development and economic performance while ensuring the stability of the financial system. For example, it is estimated that policies that would increase the monetization of the economy, by raising the M3/GDP ratio by 10 per cent points would increase the long-term per capita growth rate by 0.2 to 0.4 per cent points (Easterly and Levine, 1997; Ndulu and O'Connell, 2008). In addition, increasing the monetization of the economy contribute to enlarge formal financial sector which is key for the effectiveness of monetary policy. However, while putting in place policies to develop financial systems in Rwanda, financial stability should not be overlooked.

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Appendix

Table 1: Interest rate pass through from policy rate to money market rates: Long term equation

$$i_t^m = c(1) + c(2) * Reporates_t + \varepsilon_t;$$

Money market rates	Coefficients	Estimates	R-square
Interbank rates	C(1) C(2)	1.2 1.1*	0.74
TB for 1 month	C(1) C(2)	0.35 1.25*	0.65
TB for 3 months	C(1) C(2)	1.05 1.25*	0.60
TB for 6 months	C(1) C(2)	2.2 1.1*	0.47
TB for 12 months	C(1) C(2)	4.5 0.79*	0.35
Weighted treasury bill rates	C(1) C(2)	2.4 1.06*	0.55

*: coefficients are significant at 1%.

Table 2: ECM estimation

$$(\Delta i^m)_t = c(1) + c(2)(\Delta i^m)_{t-1} + c(3) resid_{t-1} + \omega_t$$

Money market rates	Coefficients	Estimates	R-square
Interbank rates	C(1) C(2) C(3)	-0.04 0.03 -0.12*	0.05
TB for 1 month	C(1) C(2) C(3)	-0.01 -0.24 -0.24*	0.21
TB for 3 months	C(1) C(2) C(3)	-0.005 -0.5 -0.06*	0.27
TB for 6 months	C(1) C(2) C(3)	0.0009 -0.16 -0.24*	0.17
TB for 12 months	C(1) C(2) C(3)	0.01 0.31 -0.11*	0.15
Weighted treasury bill rates	C(1) C(2) C(3)	-0.004 0.34 -0.10*	0.15

Table 3: Interest rate pass through to deposit rates

Market rates	Policy rates	coefficients	Estimates	R-square	DW	Co integration
Dr1	rr	C(1) C(2)	2.9* 0.3*	0.12	1.3	Yes
	intbr	C(1) C(2	2.7 0.25	0.11	1.3	Yes
	Tb4	C(1) C(2	3.5 0.15	0.03	1.2	Yes
	Tb13	C(1) C(2	3.4 0.14	0.06	1.2	Yes
	Tb26	C(1) C(2	3.4 0.14	0.05	1.2	Yes
	Tb52	C(1) C(2	3.9 0.07 (not significant)	0.04	1.15	yes
DR3	intbr	C(1) C(2	2.9 0.5	0.34	0.9	Yes
	Tb4	C(1) C(2	3.6 0.4	0.31	0.9	Yes
	Tb26	C(1) C(2	3.3 0.41	0.27	0.85	Yes
Dr6	intbr	C(1) C(2	4.8 0.44	0.18	0.65	Yes
	Tb4	C(1) C(2	5.7 0.32	0.12	0.6	yes
	Tb26	C(1) C(2)	5.3 0.33	1.01	0.7	Yes
	Tb52	C(1) C(2)	5.22 0.31	0.08	0.6	Yes
Dr12	rr	C(1) C(2)	7.6 0.31	0.05	0.05	Yes
	intbr	C(1) C(2)	6.7 0.35	0.18	0.60	Yes
	Tb4	C(1) C(2)	7.3 0.28	0.14	0.6	Yes
	Tb13	C(1) C(2)	7.2 0.26	0.17	0.6	yes
	Tb26	C(1) C(2)	6.8 0.30	0.19	0.66	Yes
	Tb52	C(1) C(2)	6.7 0.28			Yes
WDR	rr	C(1) C(2)	2.4 1.1	0.55	0.3	Yes
	intbr	C(1) C(2)	1.2 0.9	0.76	0.3	Yes
	Tb4	C(1) C(2)	1.8 0.9	0.82	1.3	Yes
	Tb13	C(1) C(2)	1.4 0.9	0.96	1.2	Yes

Table 4: Short-term estimation

Market rates	Policy rates	Coefficients	Estimates	R-square	DW
Dr1	rr	C(1) C(2) C(3)	0.007 -0.18 -0.54	0.35	2.06
	intbr	C(1) C(2) C(3	0.01 -0.18 -0.55	0.36	2.03
	Tb4	C(1) C(2) C(3	0.001 -0.2 -0.48	0.34	2.02
	Tb13	C(1) C(2) C(3	0.01 -0.21 -0.49	0.34	2.01
	Tb26	C(1) C(2) C(3	0.001 -0.21 -0.46	0.33	2.03
	Tb52	C(1) C(2) C(3	0.008 -0.23 -0.45	0.32	2.03
DR3	inbr	C(1) C(2) C(3	0.03 -0.08 -0.47	0.29	2.05
	Tb4	C(1) C(2) C(3	0.013 -0.11 -0.42	0.26	2.07
	Tb26	C(1) C(2) C(3	0.007 -0.13 -0.33	0.20	2.08
Dr6	intbr	C(1) C(2) C(3	0.03 -0.10 -0.36	0.23	2.03
	Tb4	C(1) C(2) C(3	0.01 -011 -0.31	0.20	2.02
	Tb26	C(1) C(2) C(3	0.007 -0.11 -0.30	0.19	2.03
	Tb52	C(1) C(2) C(3)	0.002 -0.12 -0.27	0.17	2.02
Dr12	rr	C(1) C(2) C(3)	0.008 -0.25 -0.22	0.20	1.98
	intbr	C(1) C(2) C(3)	0.008 -0.25 -0.22	0.21	1.98
	Tb4	C(1) C(2) C(3)	0.005 -0.24 -0.24	0.21	2.00
	Tb13	C(1) C(2) C(3)	0.04 -0.24 -0.25	0.20	2.00
	Tb26	C(1) C(2) C(3)	0.004 -0.24 -0.24	0.20	2.00
	Tb52	C(1)	0.004	0.18	1.99

		C(2) C(3)	-0.25 -0.19		
WDR	intbr	C(1) C(2) C(3)	-0.004 0.34 -0.1	0.15	2.1
	Tb4	C(1) C(2) C(3)	-0.04 0.35 -0.19	0.17	2.2
	Tb13	C(1) C(2) C(3)	-0.006 0.53 -0.7	0.26	2.1
SLR	rr	C(1) C(2) C(3)	0.004 -0.16 -0.55	0.35	2.01
	intbr	C(1) C(2) C(3)	0.01 -0.2 -0.50	0.32	2.00

BANK LENDING CHANNEL OF MONETARY POLICY TRANSMISSION IN RWANDA: EVIDENCE FROM BANK-LEVEL DATA

KAMANZI Callixte[2] IRANKUNDA Joy[3] BAGABE James[4]

[2] Economist, Research Department, National Bank of Rwanda.
[3] Senior Economist, Monetary Policy Department, National Bank of Rwanda.
[4] Senior Economist, Research Department, National Bank of Rwanda.

Abstract

This study examines the bank-lending channel of monetary policy transmission mechanism in Rwanda using a bank-level panel data covering the period from 2012Q1 to 2018Q2. Empirical evidence on the bank lending channel is examined by estimating a bank loan supply function. Specifically, the study investigates the effect of monetary policy changes on loan supply by commercial banks as well as the effect of bank-specific characteristics on loan supply response to monetary policy shocks. These effects were estimated in a dynamic panel data framework, using a generalized method of moment (GMM).

The findings suggest that bank lending is a significant channel through which monetary policy decisions are transmitted to the economy. The results show that bank loan supply increases following a monetary policy loosening, although the effect is moderate. On the effect of bank characteristics, loan supply by larger banks is less sensitive to monetary policy change, while well capitalized banks and more liquid banks react more to monetary policy changes compared to less capitalized banks and less liquid banks, respectively.

Therefore, the National Bank of Rwanda should continue to take into account developments in the financial sector and ensure financial sector soundness in order to enhance the effectiveness of monetary policy.

Keywords: Monetary policy transmission mechanism, Bank lending channel, Panel data, Rwanda

JEL classification: E5, G21.

1. Introduction

The analysis of monetary policy transmission mechanism has been an important research area in macroeconomic literature and a special focus for central bankers. The theory of transmission mechanism asserts that monetary policy can affect aggregate demand via several channels. The most empirically evidenced channels include the interest rate channel, the exchange rate channel, other asset price channel, and credit channels (Mishkin, 1995). A good understanding of the channels of monetary policy and the factors that influence them is a key to designing tailored monetary policy strategies.

The credit channel has been given a special attention by researchers due to the leading role of banks in financial systems of different economies, especially after the 2007-2010 global financial crisis that underscored the importance of the financial sector for the monetary policy transmission. Bernanke and Gertler (1995) describe two possible mechanisms of the credit channel, namely balance-sheet channel (BSC), and bank-lending channel (BLC). The BSC emphasizes on the impact of the changes in monetary policy on the borrower's balance sheet, whereas, the BLC focuses on the possible effect of monetary policy actions on the supply of loans by the banking system. Empirically, studies use individual bank balance sheet data to test the existence of the BLC. This approach is based on the hypothesis that some bank-specific characteristics influence only loans supply and not loans demand. Thus, the sensitivity of loans supply to monetary policy actions can be captured by these characteristics.

The bank lending channel is based on the view that banks play an important role in the financial system as external source of financing for the private sector. In that case, monetary policy may directly limit the ability of banks to provide new loans, making credit less available to borrowers that are more dependent on bank's financing. As argued by Bernanke and Gertler (1989), monetary policy can affect the bank portfolio behavior through the bank asset in terms of loans, securities as well as bank reserves. For instance, a tight monetary policy will drain the reserves from the banking system, which in turn restricts the supply of loans, leading to a deceleration in economic activity and decreased inflationary pressures.

In general, two conditions must be fulfilled for a bank lending channel to exist (Bernanke and Blinder, 1988). On the one hand, borrowers are not able to fully insulate their real spending from a decline in the availability of bank loans, i.e. bank loans are imperfect substitutes for other sources of finance. On the other hand, banks are not able to fully insulate their loan supply from a monetary policy-induced change in their reserves, i.e. there are no perfect substitutes for loans in bank portfolios. If banks are able to obtain funds by tapping financial markets, monetary policy would affect banks only through changes in interest rates and no bank lending channel would be at work (Romer and Romer, 1990). Therefore, this channel is expected to be more prevalent in economies where capital markets are not developed or when access to financial markets is limited (Kashyap and Stein, 1997).

In Rwanda, some features of the financial sector can be potentially conducive for a bank lending channel. By 2018, the banking sector holds 65.5 percent of the financial sector assets (with an average of 66.7 percent over the past six years) and remains the dominant lending source to the private sector. Loans and advances continue to be the largest component of banks' assets, accounting 57.7 percent of banks' assets over the first half of 2018. Deposits are primary funding source for the banking system with the share of 78.2 percent of total liabilities (BNR, 2018). The capital market of Rwanda is in its infancy, with eight listed companies and total turnovers of the stock exchange representing only one percent of GDP. Under such circumstances, the bank lending channel is potentially a considerable channel of monetary transmission in Rwanda.

However, the bank lending channel in Rwanda may have some limitations given that the economy is still underfinanced by banks. By end 2017, the ratio of credit to private sector relative to GDP stood at 19.3 percent as of 2017 with the average of 17.5 percent over the past six years, while the same ratio relative to non-agricultural GDP stands at 27.9 percent in the same period and averaged at 24.8 percent between 2012 and 2017.

A number of empirical studies have investigated Rwanda's monetary policy transmission (Berg et al, 2013; Davoodi et al, 2015; Kigabo et al, 2015; Kigabo et al, 2016; Kigabo, 2018). These studies mainly used aggregated time series data analysis to investigate monetary policy transmission. The important findings of these studies have mainly suggested that the interest rate and exchange rate channel are weak, though the latter has started improving after the introduction of more flexibility in the exchange rate policy. The studies have also shown that monetary policy shock has significant effect on the volume of bank loans to the private sector and real GDP, even if the magnitude of the effect is still low.

However, the analyses in the above-mentioned studies have some limitations, mainly pertaining to aggregated data analysis. Aggregated data obscure individual banks' asymmetric behavioral response to policy changes and other shocks. This limits the assessment of distributive patterns inherent in individual bank characteristics, and how these interact with monetary policy actions to influence lending behavior (Chilese, 2017). The current empirical evidence about the way monetary policy is transmitted to the real economy in Rwanda is still unclear and, therefore, the strategic importance of the role of banks in propagating the monetary policy impulses remains under-researched.

The purpose of this study is to fill that knowledge gap. The aim is to utilize bank-level data in order to exploit the heterogeneity of commercial banks in assessing how these influence banks' lending response to monetary policy shocks in Rwanda. This assessment of the bank-lending channel in Rwanda focuses on the role that bank-specific characteristics play in transmitting monetary policy impulses. To the best of authors' knowledge, this is the first attempt at quantifying the monetary transmission mechanism in Rwanda using micro-level data.

The rest of the paper is organized as follows: Section 2 reviews the theoretical and empirical literature on bank lending channel. Section 3 discusses the stylized facts on banking sector and monetary policy transmission in Rwanda. Section 4 highlights the methodology used in this study to investigate the effectiveness of bank lending channel in Rwanda. Section 5 presents and interprets the empirical results. Finally, section 6 gives the conclusion and policy implications.

2. Literature review

In this section, theoretical and empirical literature on monetary policy transmission mechanism is reviewed. In consideration of the main objective of this paper, the focus of literature review is on assessments of the bank lending channel based on bank characteristics.

2.1. Theoretical Literature

There are several ways in which monetary policy is transmitted to the real economy. Bernanke and Blinder (1988; 1992), Christiano et al (1992), Mishkin (1995), among others have identified four main channels through which changes in monetary policy actions are transmitted to the economy: (i) interest rate channel, (ii) exchange rate channel, (iii) assets price channel and (iv) credit channel.

The credit channel view acknowledges the existence of informational imperfections in financial markets and assigns an active role to the supply of bank loans in monetary transmission via two "sub-channels". One is the balance sheet channel, which states that tight monetary policy may worsen borrowers' risk characteristics and reduce the supply of loans, and another is the bank lending channel, which states that the central bank policy can affect bank balance sheets, hence the supply of loans (Benkovskis,2008). The latter, i.e. the bank lending channel, is of special interest for this paper, as it focuses more specifically on the particular role of banks in the transmission mechanism.

For the bank lending channel to be operational (i.e. for monetary policy to have an effect on the economy via the banking sector loan supply) there are two conditions that must be met, namely (i) borrowers depend on credit facilities provided by banks and (ii) lending activities of banks are constrained by monetary policy stance (Apergis and Alevizopoulou,2011). According to Morris and Sellon (1995), the costs of obtaining information about a firm's (financial) condition are greater for smaller firms, thus small firms find it difficult and more costly to obtain credit. Banks have a comparative advantage over other intermediaries in information processing that enable them to lend to smaller firms at a lower cost. Therefore, as in most parts of the world, banks are major sources for financing for the private sector, especially for smaller firms. The banks' role then in the transmission of monetary policy becomes evident through the bank lending channel (Bayangos, 2010).

Response of banks to monetary policy actions crucially depends on their balance sheets structure. Different responses of banks with different characteristics to changes in monetary policy can help to identify changes in bank loan supply (Kashyap and Stein, 1997). In the bank lending channel, asymmetric information problems between banks and the depositors create constraints for these banks to have access to sources of loanable funds other than demand deposits (Kashyap and Stein, 2000). It will be more difficult and costly for smaller and undercapitalized banks than banks with sufficient capital and with higher liquidity level, to replace loan supply with other sources of funds (Coll et al, 2005). If these banks are not able to provide viable alternative sources of loanable funds with the tightening of the monetary policy, they will be pressured to limit their lending activities, thus, transmitting the effect of the policy stance into the economy

(Olivero and Jeon, 2011). Kashyap and Stein (2000) have provided evidence that bigger banks with sufficient capital and liquidity are more likely to have the sources to cushion the effects of monetary policy tightening. Sources of loanable funds other than demand deposits (e.g. from interbank, external borrowings and financial markets) are available to these larger banks, thus providing them with alternative forms of loan fund supply. With their access to other forms of sources for their loan supply, bigger banks are less likely to restrain on their lending activities as compared to smaller banks (Schnatter and Kauffman, 2006).

It is argued that the stronger the banking sector, the weaker the expected impact of policy movements will be since balance sheets of large, healthy banks are not sensitive to policy because their reserve contraction can be readily offset with alternative forms of financing. The strength of the banking sector is commonly measured by a number of indicators including the size, liquidity and capitalization of banks, market power and the ownership structure of the banks.

For bank size, larger banks explore economies of scale and scope more efficiently; acquiring information about them is less expensive, therefore they obtain non-deposit sources more easily. They are expected to diminish the efficiency of the monetary policy, since it has less effect on their capability to acquire non-deposit sources as compared with smaller banks (Stein, 1998).

Excess liquidity can be seen as a substitute for the additional debt or equity required for expanding a bank's loan portfolio. Hence, the more liquid a bank, the lower the marginal (opportunity) cost of an additional credit. In addition, given the financial stability issue, banks active are also subject to minimum liquidity requirements. Taken together, these two elements imply that more liquid banks should encounter more and should be in a better position to take advantage of profitable lending opportunities. A tightening of monetary policy will tend to reduce the reserves held in the banking sector. This in turn may translate into lower deposits and, for banks with low levels of excess liquidity, increased pressure to reduce the size of their loans portfolio. As a consequence, a given level of liquidity is more likely to constrain a bank's lending activity when the central bank tightens its monetary policy (Bichse and Perrez, 2004).

Bank capitalization influences the bank lending channel owing to imperfections in the market for debt. In particular, bank capital influences the capacity to raise unsecured forms of debts and therefore banks' ability to contain the effect of a deposit drop on lending. The mechanism is the following. After a monetary tightening, reservable deposits drop and banks raise non reservable debt in order to protect their loan portofolios. As these non-reservable funds are uninsured (i.e. bonds), banks encounter an adverse selection problem (Stein, 1998); low-capitalized banks, perceived to be riskier by the market, have greater difficulty issuing bonds and therefore less able to shield their credit relationship (Sishan and Opiela, 2000). In every country where banks are subject to capital requirements, the maximum size of a bank's loans portfolio is a function of its capital base. As a consequence, a bank's lending capabilities will be constrained, at some point, by its capital base. Second, a bank's capital is a sign of its financial strength, i.e. the higher a bank's capital, the lower its marginal debt or equity funding cost. Hence, ceteris paribus, better-capitalized banks should encounter more profitable lending opportunities.

The ownership of the banks is also considered as bank characteristics that may affect the way they react to monetary policy actions. Ashcraft (2001) discusses the importance of ownership structure for the working of the lending channel. He argues that affiliated banks react less sensitively to increases in the monetary policy interest rate because the presence of internal capital markets weakens the influence of the financial constraint faced by the subsidiary bank. He finds evidence for this hypothesis in an analysis of U.S. banking data on affiliated and non-affiliated banks. De Bondt (1999) subdivides its sample between foreign and domestic-owned banks, putting forward that foreign-owned banks may have better access to the international capital markets and other foreign sources of funds than much larger wholly domestic-owned banks. Monetary policy contractions may be tempered by the ability of international banks to borrow funds offshore. He finds stronger evidence for a lending channel when foreign banks are dropped from the sample.

Brissimis et al. (2014) proposed a new important bank characteristic that generates a differential effect of monetary policy on bank lending, namely bank market power. They provide two theoretical arguments that give market power a special role in the monetary transmission mechanism through banks. First, banks with high market power should have easier access to uninsured finance, which would make their lending less dependent on central bank funding and therefore on monetary policy shocks. Second, high market power is usually associated with higher profits, and this implies that the respective banks may be less interested in engaging in very risky activities. Thus, an expansionary monetary policy will imply that the search-for-yield mechanism of the bank-lending channel may be less potent for these banks.

2.2. Empirical Literature

The limitation of aggregated time series data analysis in identification of bank lending channel has led some researchers to recourse to a new methodology based on a panel data approach. The new approach aims at allowing the assessment of distributive patterns inherent in individual bank characteristics, and how these interact with monetary policy actions to influence lending behavior. In this sub-section, we provide empirical evidence on the BLC from across the global.

Kashyap and Stein (1995) provided the foundation to this new aspect of empirical literature, which received a major impetus by disaggregated data availability mainly in the U.S. and the EU. They sought to assess the impact of a monetary tightening on the volume of bank loans using U.S. data. They found that there is a difference between the response of small and large banks. A higher interest rate leads to a significant decrease in small banks' loans, but not in large banks' loans. Therefore, small banks are more sensitive to monetary policy shocks than large banks. However, their methodology suffers from a limitation; other bank characteristics like liquidity were ignored, i.e. how banks with a large buffer stock of liquid assets can insulate their loans from the effects of monetary policy actions. For a bank of a given size, a contractionary monetary policy would bring about loans to decline less the more liquid a bank is. In order to improve the inference, Kashyap and Stein (2000) went ahead and introduced liquidity characteristic in their analysis. They reported that small banks are on average more liquid than large banks, which may mitigate the effectiveness of the bank lending channel. Thus in separating banks, not only by size but also by liquidity, they found that smaller banks with the least liquid balance sheets were more responsive to policy actions.

Kishan and Opiela (2000) extended the above analysis by further considering a bank's degree of capitalization. Bank capital is an indicator of bank health and therefore an indicator of a bank's ability to raise funds from alternative sources during contractionary monetary policy periods. Moreover, prudential supervision in particular capital adequacy requirements may affect the composition of bank asset portfolios in the sense that well capitalized banks are less constrained during periods of tight monetary policy, since these banks can isolate, to some extent, their loan portfolio from monetary shocks. The authors showed empirically using U.S. quarterly data over the period [1980:1-1995:4] for 13,042 commercial banks that the smallest and least capitalized banks are the most responsive to monetary policy. However, for large banks responses to monetary policy impulses are not significant implying that a bank-lending channel may not hold in total.

A recent study was by Gambarcota and Marquez-Ibanez (2011) who uses bank specific panel data for the period Q1 1999 to Q4 2009 in Europe and USA. The objective of the study was to investigate the effects of bank specific characteristics on the bank-lending channel during the financial crisis. Using dynamic panel data methods for over 1000 banks, they find that banks business models had significant impact on the supply of credit or the bank-lending channel. Specifically, they find that short-term funding and securitisation activity have significantly changed the way banks react to monetary policy shocks due to their impact on their balance sheets.

In the European countries, Kashyap and Stein (1997) found that the importance of the bank lending channel varies according to the countries. In the United Kingdom (UK), the banking lending channel is weak, while it is stronger in Italy and Portugal. In other countries, the banking lending channel is of medium importance. Favero et al. (1999) also affirmed the importance of the bank lending channel in France, Germany, Italy and Spain. The differences were attributed to the different financial system, macroeconomic conditions as well as the regulatory framework of the banking system in countries under the study. De Bondt (1998) further verified the importance of the bank lending channel in Europe, which he found to be stronger in Germany, Belgium and the Netherlands and not as significant in the United Kingdom. Jimborean (2009) used the GMM model and disaggregated data in Central and Eastern Europe countries, over the period from 1998 to 2006. He found that small banks modify lending more than large banks, after monetary policy shocks. It was evident that monetary policy has a stronger effect on small banks compared to large banks.

In their study on bank balance sheets in the euro area, Ehrmann et al (2001) show that bank loans shrink significantly after a monetary contraction both on the aggregate euro area as well as on the country level. Using micro data, they find that the size of liquid assets is an important factor that characterizes the response of banks to changes in monetary policy: in general, the less liquid banks appear to react more strongly than more liquid banks. In contrast to findings in the U.S., effects of size and the degree of capitalization of a bank appear to be less important on the way European banks adjust their lending to interest rate changes. This can be partly explained by a lower degree of informational frictions in euro area, where government role, bank networks, and very few bank failures altogether contribute to a reduction in problems of asymmetric information.

A paper by Benkovskis (2008), explores the role of commercial banks in the transmission of monetary policy in Latvia using the panel data method developed by Kashyap and Stein (1995). Specifically, they estimate a bank loan function that takes into account monetary policy and macroeconomic variables but also bank-specific factors. Their empirical results suggest that there is heterogeneity in the response of banks to monetary policy. In particular, they find that some banks have a statistically significant negative reaction to monetary policy while the others do not. Further, they find that monetary policy has an effect on small bank, domestically owned, with lower liquidity and lower capitalization.

Hosono (2006) examined how banks' responses to monetary policy varied according to their balance sheet using yearly Japanese bank data covering the period [1975-1999]. Estimating a fixed bank effect model using GMM two-step method, he found evidence that supports the lending channel for banks that are smaller, less liquid and more abundant with capital.

Using disaggregated bank level data set, Zulkey et al (2010) investigated the relevance of bank-lending channel (BLC) of monetary policy in Malaysia. A dynamic panel data method namely GMM framework proposed by Arellano and Bond (1991), Arellano and Bover (1995), and Blundell and Bond (1998) was used in estimating the dynamic of banks' loan supply function. The empirical evidence has stated that monetary policy shocks is significantly and negatively influenced the banks' loan supply, and therefore has supported the existence of BLC in Malaysia. In addition, several bank-characteristics variables namely bank liquidity and bank capitalization (capital adequacy ratio) are also statistically significant in influencing the banks' loan supply. Therefore, the implementation of monetary policy is effective in influencing economic activity via bank balance sheet position, in particular bank loans.

Using bank-level data for nine Asian economies during 2000–2013, Ananchotikul and Seneviratne (2015) found that banks could potentially play a pivotal role in monetary policy transmission. They showed that heterogeneity of bank characteristics (e.g., ownership type, financial position), degree of foreign bank penetration of the domestic banking sector, and global financial conditions all have a bearing on the response of domestic credit to changes in domestic monetary policy, and may account for the apparently weak credit channel at aggregate level.

Studies have also found evidence of BLC operation in Africa. Sichei (2005) investigated the existence of BLC in South Africa by using a specification as in Kashyap and stein (1993). Sichei (2005) regressed the total stock of gross loans on their lag, real GDP, and indicator of monetary policy, a vector of bank characteristics (size and capitalization) and the interaction of monetary policy and the bank characteristics. The findings supported that the joint effect of monetary policy and bank characteristics were statistically significantly and positive, implying banks with stronger balance sheets could cushion the effects of a tight monetary policy on their loan portfolio. Moreover, Sichei and Njenga (2010) investigated existence of BLC in Kenya by using data from banks annual audited balance sheets. They employed an IS/LM model with bank credit, in line with Bernanke and Blinder (1988). As a measure of capitalization, they used the ratio of excess capital to total risk-weighted assets; and for liquidity, they used the ratio of excess liquid assets to total liabilities. Sichei and Njenga found that, monetary policy had a more pronounced effect on banks with less liquid balance sheets and on those less capitalized.

By using a modelling approach similar to Ehrmann et al. (2001), Chibundu (2009) examined existence of BLC in Nigeria by regressing total loans on its own lag, a measure of policy rate, GDP, inflation and bank characteristics, namely, size, liquidity and capitalization. The results were consistent with a weak BLC. The size and liquidity positions of banks were found to act as a source of information asymmetry that influenced banks' behavior on loan supply following changes in monetary policy. Using bank micro level data, Opolot (2013) examined the relevance of bank lending channel in Uganda with special emphasis of the impact of individual bank characteristics of size, liquidity, and capitalization on the banks' loan supply function. The empirical results indicate the presence of the bank lending channel of the monetary policy transmission mechanism in Uganda. In addition, individual bank-characteristics of liquidity and capitalization also play a significant role in influencing the supply of bank loans. Mbowe (2016) found the bank lending channel operates in Tanzania, suggesting that bank loans are important channel through which monetary policy shocks are transmitted to the economy. More importantly, banks react asymmetrically to policy changes influenced by size, capital strength, and ownership structure. The lending channel is stronger through domestically-owned banks and privately-owned banks than it is with foreign-owned banks and public-owned banks.

The recent study on bank lending channel by Chileshe (2017) for case of Zambia, examined the bank-lending channel of monetary policy for Zambia using a bank-level panel data covering the period Q1 2005 to Q4 2016. Specifically, the study investigated the effects of monetary policy changes on loan supply by commercial as well as the effect of bank-specific factors on response of loan supply to monetary policy shocks. In addition, the study investigated whether the level of bank competition does affect the bank-lending channel. The results show that loan supply is negatively correlated with policy rate implying that following monetary policy tightening loan supply shrinks. Further, the results indicate that size, liquidity and bank-competiveness have effects on credit supply while capitalization has no effect. Specifically, the results showed that larger banks, banks with more market power, well-capitalized banks and liquid banks respond less to monetary policy tightening and vice-versa.

In summary, the discussed literature provides the evidence that banks play an important role in monetary transmission mechanism in different economies, and the bank lending channel exist. On bank characteristics, the effects tend to be different across the globe. Generally, there is a heterogeneity effect of monetary policy on bank loans but the effects vary by the reason of economies and banks' structures.

3. Stylized facts on banking sector and monetary policy transmission in Rwanda

This section discusses the banking sector and some features of the financial system in Rwanda that are likely to influence the operation of bank-lending channel of monetary policy transmission mechanism.

3.1. Stylized facts about Rwanda's financial sector

The Rwandan financial system continued to grow over time and financing the private sector. In numbers, it grew from 34 institutions in 2010 to 516 institutions in June 2018. It consists of 16 banks, 473 microfinance institutions, 16 insurance companies and 11 pension Funds (including 1 Mandatory and 10 voluntary pension schemes)5, the payment system which are all regulated and supervised by National Bank of Rwanda (NBR) and the capital market which is regulated by the Capital Market Authority (CMA). In terms of assets, the ratio of total assets (of the financial sector) relative to GDP increased to 35.3 percent in 2017 from 27.7 percent in 2012.

The banking sub-sector remains the largest component of Rwanda's financial sector with a share of 66.7 percent (average from 2012-June 2018) of the total assets though its share has been declining as MFI's share has been slightly increasing.

3.2 Implications of the financial structure on the bank lending channel

The structure of the Rwandan financial sector plays a key role in the monetary transmission mechanism. Given its significant size in the financial system, the banking sector remains the large source of credit in Rwanda, which is one of the main conditions for effective bank lending channel of monetary transmission. Banks loans represent a share of 78.9 percent as of June 2018 in the financial sector's loans and an average of 78.6 percent over the past six years, which imply that the bank-lending channel might be stronger.

Table 1. Structure of Rwandan financial sector

	Dec-10		Dec-15		Dec-16		Dec-17		Jun-18	
	Number	Share in TA	Number	Share in TA	Number	Share in TA	Number	Share in TA	Number	Share in TA
Banking Sector	14	71.3	17	66.7	16	66.9	17	66.4	16	65.5
Insurance	8	10.2	14	9.7	15	9.7	16	9.9	16	9.8
Mandatory pension Fund	1	14.9	1	17.2	1	17.1	1	17.7	1	17.4
Private pension Schemes									10	0.7
MFIs	11	3.7	494	6.4	472	6.3	470	6	473	6.6
Total	34	100	526	100	504	100	504	100	516	100

Source: BNR (2018)

Similar with other developing countries, the market power of few banks and less developed capital market are a hindrance to the private sector to mobilize resources as an alternative to banks loans which may define the importance of the bank lending channel in Rwanda. Rwandan Stock Exchange market is still in its

[5] BNR (2018)

early stage with eight listed companies and total turnovers that represent only one percent of GDP.

NBR monetary policy has been working through its impact on the volume of loans to the private sector (or amount of M3) than through the cost of loans (Kigabo, 2016). Loans and advances remain the largest component of banks' assets constituting 57.7 percent of banks' assets in June 2018 (58.8 percent in June 2017) followed by cash and bank balances representing 21.6 percent (June 2017: 21.8 percent) and government and other securities at 14.5 percent (June 2017: 12 percent).

Table 2. Loans Concentration in banks assets

	Jun. 12	Jun-13	Jun-14	Jun-15	Jun-16	Jun-17	Jun-18
Loans & Advances	55.4	57.1	51.2	55.4	58.1	58.8	57.7
Cash and bank balances	23.9	24.8	30.8	23.4	18.7	21.8	21.6
Government and other securities	11.0	8.5	10.8	13.5	16.6	12.0	14.5

Source: Authors' calculations.

However, loans distribution remains concentrated in two sectors: Public works and building and commerce restaurant and hotel with a combined average share of 65.4 percent (2012-June 2018) of total banking sector loans, implying limited impact of monetary policy actions on the entire economy.

Table 3. Share of New loans by sector of activity (percent)

	2012	2013	2014	2015	2016	2017	Jun-18
Non classified activities	16.6	12.0	9.6	9.0	10.2	11.0	12.8
Agricultural, fisheries& livestock	2.1	1.9	1.3	1.9	1.6	1.1	1.4
Mining activities	0.0	0.0	0.0	0.0	0.2	0.1	0.1
Manufacturing activities	7.4	9.3	11.1	6.9	7.8	7.3	8.2
Water & energy activities	0.8	1.2	3.9	0.2	2.5	2.4	0.0
Public works and building	22.4	19.7	21.2	32.0	26.2	28.0	25.3
Commerce restaurant and hotel	40.7	45.8	41.7	37.7	42.8	37.7	36.2
Transport & warehousing & communication	6.1	6.2	6.5	7.3	5.1	8.9	12.0
OFI &Insurances and other non-financial services	0.9	1.3	0.7	2.0	0.7	1.1	0.2
Services provided to the community	2.9	2.7	4.0	3.0	2.8	2.4	3.7
TOTAL	100	100	100	100	100	100	100

Source: Authors' computations.

The financial deepening improved though still limited with the ratio of credit to private sector relative to non-agricultural GDP representing 27.9 percent thus limiting the impact of monetary policy to the real economy. This is a common characteristic across Sub-Saharan African (SSAs) Countries with few exceptions such as South Africa. On average, domestic credit to private sector ratio to GDP stood at 28.3 percent in 2017 in SSA, against 19.3 percent in Rwanda.

Table 4: Financial Development in Rwanda

	2012	2013	2014	2015	2016	2017
Deposits as % of GDP	17.4	18.5	20.2	22.4	21.7	21.4
CPS[6] as % of GDP	15.1	15.4	16.6	19.7	19.3	19.3
CPS as % of Non-agricultural GDP	21.4	21.6	23.3	27.4	27.3	27.9
M3 as % of GDP	19.8	20.9	22.4	24.8	23.9	23.6
M3 as % of Non-agricultural GDP	27.9	29.3	31.4	34.5	33.8	34.2

Source: Authors' calculation

4. Methodology

In this section, we present how the econometric model is specified and underlying best practice method used to analyze data. In the last sub-section, we discuss the dataset used with detailed description of the variables used in the model.

4. 1 Model specification

This paper makes use of a model specification that permits to assess the effectiveness of the lending channel. The applied model specification was inspired by that of Kashyap and Stein (1995), and adopted by the majority of authors (Gambarcota and Marquez-Ibanez, 2011; Ahtik, 2012; Mbowe, 2016; Chilese, 2017) who analyzed transmission mechanism using the bank level data. This allows us to check whether bank lending responds to monetary policy shocks, and, if so, whether there are important cross-sectional differences in the responses of banks with varying characteristics.

In order to perform this analysis, bank characteristics such as bank size, capitalization, liquidity, market power and ownership structure are used. Macroeconomic indicators (Gross domestic product, inflation and non-

[6] CPS is Outstanding Credit to Private Sector

performing loans) are included to allow the model to capture cyclical movements as well as to isolate the changes in total loans caused by movements in loan demand. This is because a fall in credit growth following monetary policy tightening could be due to a fall of demand for credit by borrowers, which is also resulted from macroeconomic factors such as slowdown in economic activities and high prices/costs (Ehrmann et al, 2001). The inclusion of GDP in the model should be appropriate for Rwanda where an average of 8.0% real GDP growth was observed in the last decade, because higher GDP growth is assumed to translate into higher credit growth. In line with Guo and Stepanyan (2011), GDP growth entered the model in its lags in order to avoid the problem of reverse causality, that is, high credit growth leads to higher GDP growth. Despite the price stability observed in Rwanda, inflationary pressures have also been experienced from time to time, generally emanating from the rise in food and energy prices in the world market. Therefore, inflation captures the effects of expected inflation on real credit growth. To capture credit-rationing behavior, we introduce the non-performing loans (NPLs) as a proxy for credit risk.

In addition, the level of market power by banks and ownership structure are also included in the model to test their likely influence in the bank lending behavior.

Thus, the underlying econometric model is written as follows:

$$\Delta\log(L_{i,t}) = \lambda_i + \sum_{j=1}^{p}\delta_j\,\Delta\log(L_{i,t-j}) + \sum_{j=0}^{p}\gamma_j\,\Delta\log(y_{t-j}) + \sum_{j=0}^{p}\omega_j\,\pi_{t-j} + \sum_{j=1}^{p}\mu_j\,\Delta\log(NPL_{i,t-j}) + \sum_{j=1}^{p}\alpha_j\,\Delta r_{t-j} + \sum_{j=1}^{p}\beta_j\,\Delta X_{i,t-j} + \varphi OWN + \sum_{j=1}^{p}\tau_j\left(\Delta X_{i,t-1} * \Delta r_{t-j}\right) + \varepsilon_{it} \qquad (1)$$

Δ and log indicate first difference and natural logarithm of the variables, respectively. λ_i captures bank-specific fixed effects while εit is the white noise error term. Individual banks are denoted by i (i =1,….,N) , t indicates the time observation for each variable, and p is the number of lags. The variable $\mathbf{L_{i,t}}$ is the amount of loans by bank i at time t.

y is the real GDP while, π and NPL stand for the inflation rate and non-performing loans respectively.

The variable r denotes the appropriate interest rate measuring the monetary policy stance, here captured by the repo rate (mainly due to absence of active central bank policy rate). Higher values of r correspond to a tighter monetary policy stance. It is assumed that, tighter monetary policy stance should result in slower credit growth and its coefficient is therefore expected to be negative. Because there will usually be a lag for monetary policy to take effect, and there may be reverse causality problem, lagged repo rate was used instead.

$\mathbf{X_{i,t}}$ stands for chosen variables to represent bank characteristics, namely bank size, liquidity, capitalization and market power.

The interaction variable $\Delta\mathbf{X_{it-1}} * \Delta\mathbf{r_{t-j}}$ was included to measure the interaction of the monetary policy rate with the bank characteristics. The distributional effects of monetary policy should be reflected in a significant interaction term of the bank specific characteristic with the monetary policy indicator. The usual assumptions in the literature are that a small, less liquid or less capitalized bank reacts more strongly to the monetary policy change than a bank with a high value of the respective bank characteristic. This would imply positive coefficients on the interaction terms.

OWN is the dummy variable to capture the ownership structure of banks.

4.2. Empirical framework

The study employs the generalized method of moments (GMM) dynamic panel estimator proposed by Arellano and Bond (1991), Arellano and Bover (1995) and further extended by Blundell and Bond (1998). The advantage of the framework is that it helps control for potential biases induced by endogeneity (the correlation between the lagged dependent variable and the error term), because of the inclusion of lagged dependent variables as regressors. The presence of the lagged values of the dependent variable on the right hand side could imply that the error term is correlated with the independent variables thereby violating one key assumption of the Ordinary Least Squares approach (OLS). In other words, estimating both a dynamic panel data model using fixed or random effects could produce biased and inconsistent results. In addition, the endogeneity problem could arise in the model because monetary policy decisions maybe affected by the conditions in the financial sector.

In the GMM literature, it is proposed that the estimation be carried out in first differences in order to get rid of the individual effects as well as using instruments to help in obtaining unbiased and consistent estimates (Benkovkis, 2008). Using the orthogonality conditions between lagged values of the dependent variable and disturbances; lagged values of the dependent variable with second and more lags serve as instruments. Further, to deal with the endogeneity problem two approaches have been proposed. First, right-hand side variables enter the model with at-least one lag. Second, lagged levels of predetermined variables such as bank-specific variables are used as instruments. Finally, the strictly exogenous variables such as GDP in first differences are instrumented by higher lags of themselves.

4.3. Data Sources and Variables Description

Data utilized in this study are obtained from different sources. Data on bank specific variables and non-performing loans are obtained from the quarterly balance sheets of 10 out of 11 licensed commercial banks operating in Rwanda over the period 2012Q1 to 2018Q2. One bank is not considered due to the insufficient data coverage with the sample period. The period was chosen to enrich the sample by including a large number of banks including some new and big banks on the market. Data on financial variables such as interest rate are from the National bank of Rwanda database while GDP and inflation rate are obtained from the National Institute of Statistics of Rwanda.

As mentioned earlier, bank characteristics may be a source of banks' asymmetric reaction to monetary policy changes. Therefore, captured in the model are vectors of bank-specific characteristics: asset size; liquidity; and capitalization, as specified by variable *x* in the model equation. As commonly applied in other similar studies, for the asset size, logarithm of total assets was used; while liquidity and bank capitalization were captured as the ratio of liquid assets (cash, interbank lending and securities) to total assets and the ratio of bank equity capital plus reserves to total risky weighted assets, respectively. As shown below, bank characteristics variables are defined as deviations from the cross-sectional mean at each time period in the case of the size variable, so as to remove its trend, or the overall mean in the case of the bank strength variables (liquidity and capitalization) which do not have trend. All three criteria are normalized with respect to their average across all the banks in the sample in order to get indicators that sum to zero over the observations. This means that, for the regression model in equation, the average of the interaction terms $(\Delta X_{i,t-1} * \Delta r_{t-j})$ is zero and the respective coefficient can be interpretable as the overall monetary policy effects on loans. If the coefficients on these interaction terms are statistically significant while the coefficient associated to change in monetary policy stance (Δr) is negative, then it is another indicator of the working bank lending channel.

For bank i at time t, the size (S), liquidity (LQ) and capitalization (CA) indicators are therefore computed as:

$$S_{it} = LogA_{it} - \frac{1}{N}\sum_{i}^{N} LogA_{it}$$

$$LQ_{it} = \frac{LA_{it}}{A_{it}} - \frac{1}{T}\sum_{t=1}^{T}\left[\frac{1}{N}\sum_{i=1}^{N}\frac{LA_{it}}{A_{it}}\right]$$

$$CA_{it} = \frac{C_{it}}{TRWA_{it}} - \frac{1}{T}\sum_{t=1}^{T}\left[\frac{1}{N}\sum_{i=1}^{N}\frac{C_{it}}{TRWA_{it}}\right]$$

N, A, LA,C and TRW represent number of banks, assets, liquid assets, core capital and total risky weighted assets respectively.

For bank size, larger banks are expected to respond less to monetary policy actions compared to small banks, since larger banks are less prone to asymmetric information and may explore economies of scale and scope more efficiently.

As emphasized by Stein (1998) banks endogenously increase liquid assets when they expect problems with acquiring non-deposit sources. When compared with banks that did not manage to increase their liquid assets banks with higher levels of liquid assets are expected to reduce the efficiency of monetary policy (Ahtik, 2010a). The same applies to banks with higher capital adequacy ratio, since they are not limited with capital adequacy demands.

The market power by bank is generally proxied by Lerner condition or HHI index; due to low level of bank competition in Rwanda, this study used the share of loans by bank in total loans of the banking system to represent the market power of each bank. Banks with high market power are expected to be less sensitive to monetary policy actions.

Real Gross Domestic Product (Y) represents a proxy for demand. It is expected to have a positive effect on the amount of loans. Higher GDP is associated with greater optimism causing increase in consumer and investment spending. Hence, positive coefficient is expected.

Inflation rate (π) is also used as proxy for demand, although its influence remains ambiguous. On one hand higher inflation increases risk and decreases loan demand, while on the other hand increases spending due to the phenomenon of money illusion.

The non-performing loans (NPLs) accounts for their cost implications on commercial banks when they need to make loan loss provisions, it is therefore expected to have negative coefficient, since an increase in NPLs will make banks hesitating to lend and become more cautious, hence reducing the loan supply.

Dummy for ownership (OWN) takes the value of 1, if bank is in domestic ownership and the value of 0 if bank is foreign owned. It is expected that foreign owned banks enjoy the benefit of connection with their larger mothers from abroad that enable them to finance cheaper. Therefore, it is expected that domestic ownership increases efficiency of monetary policy.

4.4. Descriptive statistics

Table 5 summarizes descriptive statistics of the variables used in the empirical model.

Table 5. Descriptive statistics of the variables

	Loans supply (in million FRW)	Total assets (in million FRW)	Liquid Assets (in million FRW)	Bank Capital (in million FRW)	Market power (in %)	NPLs (in million FRW)	GDP (in billion FRW)	Inflation	Repo rate
Mean	86.2	154.4	51.3	20.0	0.10	6.5	1,455	4.0	4.5
Maximum	479.8	759.8	238.3	115	0.38	31.8	1,752	7.9	7.4
Minimum	2.6	7.8	1.15	1.5	0.01	0	1,177	0.9	1.9
Std.Dev	87.6	145.4	48.1	22.0	0.09	6.1	183	2.1	1.6
Skewness	2.5	2.2	2.1	2.6	1.7	1.4	0.11	0.2	0.3
Kurtosis	10.3	8.4	7.6	9.3	5.4	5.3	1.7	2.0	2.1
Jarque_Bera	282.7	14.76	18.32	6.86	6.07	4.2	9339.0	3.6	7.1
Probability	0.00	0.00	0.03	0.00	0.01	0.06	0.00	0.14	0.23
Observations	260	260	260	260	260	260	260	260	260

Source: Authors' computation.

Different methods were adopted by many researchers in classifying banks according to their size, liquidity and capitalization. In consideration of financial system of each country, we followed the recent studies (Gambarcota and Marquez-Ibanez, 2011; Ahtik, 2012; Mbowe, 2016; Chilese, 2017) that used the average variable representing each of bank characteristics to stand as the threshold level. If a bank falls below the average, it is therefore classified as small bank, less capitalized or less liquid. However, one bank can be small in size, but well capitalized or large liquid.

The below statistics indicate the difference in loans given by banks, with considerable diversity in size of loans as it is well captured by the large dispersion in loan supply. The similar tendency is observed in bank characteristics, with high standard deviations of in total assets, bank capital and liquid assets, indicating the difference in size, capitalization in liquidity of banks. The power of the banks is also different with the consideration of a bank with a share of 38 percent of total loans with another bank with only 1 percent. The level of Nonperforming loans differs across the banks, where the maximum NPLs per quarter went to 31.8 million RFW compared to the minimum of zero NPLs.

The ownership of the banks, being the dummy variable is not presented in table. The ownership structure is a bit complex given that only two banks in the sample are legally domestic and the ownership of some banks has been varying overtime.

5. Empirical results

In this section, estimation results of the model are presented. The empirical results are summarized in tables 6 and 7. Table 6 reports the estimation results of the determinants of the banks' loan supply by using difference GMM estimation. Here, the full model was examined to assess overall effects of variables on loan supply in Rwanda.

The lagged loan supply is significant with high coefficient (0.89), implying that the lending behavior of the banks in Rwanda is persistent, as largely determined by the loan supply in the previous quarters.

The results show that the effects of macroeconomic variables are significant and robust across the model with exception of inflation. One percent increase in GDP leads to 0.25 percent increase in loan supplied by banks, suggesting the importance of level of economic activity (i.e. the market demand) as a stimulus for loan demand. The coefficient of non-performing loan (NPL) is found to be negative and statistically significant. An increase in NPL by one percent in the previous year reduces current loan supply by 0.03 percent, implying that NPL discourage the lending by banks in Rwanda. Banks become more cautious and limit the lending to borrowers to insulate against the risk of loan default.

As expected, the lagged monetary policy variable (repo rate) is negatively and statistically significant, although the effect is minimal as reflected in the small coefficient. The smaller size of the coefficient can be explained by the indirect relationship between the monetary policy variable and credit growth in the sense that tight or loose monetary policy would first affect the short-term rates, which in turn affects market lending rates and subsequently growth in credit. In addition, banks may not adjust their lending behavior immediately, as some loan agreements may have been already signed. These results confirm the existence of a bank lending channel of monetary policy transmission in Rwanda.

Table 6: GMM-in Difference Estimates of Loan supply function for Rwanda; One-Step Results

Variable	Parameter	coefficient	Standard error	P. Value
Constant/Intercept	λ	0.50	0.23	0.03
$\log(L_{i,t-1})$	δ	0.89	0.02	0.00
Macroeconomic variables				
$\log(y_{t-1})$	γ	0.25	0.065	0.00
π_{t-1}	ω	0.001	0.001	0.29
$\log(NPL_{i,t-1})$	μ	-0.03	0.003	0.000
r_{t-1}	α	-0.004	0.002	0.077
Bank characteristics				
$Size_{i,t-1}$	β	0.124	0.02	0.000
$Liquidity_{i,t-1}$	β	0.041	0.037	0.26
$Capital_{i,t-1}$	β	0.184	0.05	0.00
$Market\_Power_{i,t-1}$	β	0.13	0.09	0.16
Ownership	φ	0.003	0.012	0.76
Interaction terms				
$(Size * \Delta r_{t-1})$	τ	0.002	0.001	0.09
$(Liquidity * \Delta r_{t-1})$	τ	-0.036	0.007	0.00
$(Capital * \Delta r_{t-1})$	τ	-0.032	0.013	0.01
Number of observations : 260 Number of banks : 10 Estimation procedure: One step				

Source: Author's computations.

Looking at bank-specific characteristics, the results show that bank size and capitalization have significant effects on bank loan supply. An increase in bank size by one percent increases the loan supply by 0.12 %, indicating that as a bank's assets increase, more loans is given to the borrowers. If the bank's capital increases by 1 percent, the bank increases the lending by 0.18 percent, demonstrating the importance of sound banking system in financing the private sector. The liquidity also seems to matter in lending behavior of banks, as an increase in liquidity of banks by 1 percent would lead to higher loan supply by 0.04 percent, although its coefficient is not statistically significant.

On the asymmetrical effects of monetary policy on loan supply, size turned out to be an important bank characteristic that affects the way Rwandan banks react to monetary policy changes. The positive interaction term of bank-size and monetary policy variable implies that larger banks are likely to respond less to monetary policy shocks compared to smaller banks. This result is consistent with theoretical literature on the bank-lending channel, which assumes that lending volume by larger banks are less sensitive to monetary policy shocks than that of small banks (Kashyap and Stein, 1995).

Capitalization and liquidity, while being statistically significant, affect the responses of the banks to monetary policy change in a rather unexpected manner. The negative coefficients suggest that, compared to less capitalized or less liquid banks, well-capitalized and more liquid banks respond strongly to monetary policy. Regarding bank capital, Chileshe (2017) had also found that in Zambia, well capitalized banks respond more to monetary policy.

Theoretically, undercapitalized or less liquid banks are more affected by a monetary policy than an average bank, which is consistent with bank lending channel hypothesis. One explanation may pertain to measurement of capitalization and liquidity in the model. Another explanation would be that well capitalized and liquid banks could be more willing to respond to monetary policy loosening as they can feel safe and be able to buffer possible loans losses (Brissimis and Delis, 2009).

To avoid over-parameterization and unmask possible heterogeneities, the data set was split into two to assess whether monetary policy transmission is uniform in small banks and large banks, less and more liquid banks, less and well-capitalized banks and the results are summarized in Table 7.

The findings confirmed the impact of policy rate change to loans supply of banks by category. It is well captured that both small and large banks respond significantly to monetary policy actions. The reaction of relatively less liquid and less capitalized banks is negative and statistically significant as expected, while being not statistically significant for more liquid and more capitalized banks. These findings lend support to role of bank characteristics in monetary policy transmission mechanism in Rwanda and a potentially working bank lending channel.

Table 7: Distributional effect of monetary policy on loan supply by group banks

	Small banks	Large banks	Less liquid	More liquid	Less capitalized	More capitalized
Constant/Intercept	-0.073	0.50**	0.28	0.35	0.52*	-1.93
$\Delta\log(L_{i,t-1})$	0.61***	0.89***	1.05***	1.03***	1.03***	1.05***
Macroeconomic variables						
$\Delta\log(y_{t-1})$	0.990***	0.25***	-0.05	-0.051	-0.11	0.236**
π_{t-1}	0.002	0.001	0.003	0.02*	0.00003	-0.005
$\Delta\log(NPL_{i,t-1})$	-0.048***	-0.037***	-0.057***	-0.043***	-0.025***	-0.055***
Δr_{t-1}	-0.009**	-0.004*	-0.003	-0.003*	-0.007***	0.008
Bank characteristics						
$\Delta Size_{i,t-1}$	0.208***	0.124***	0.02*	0.001**	0.007	0.02
$\Delta Liquidity_{i,t-1}$	0.10*	0.041	0.26***	0.137***	0.13*	0.015
$\Delta Capital_{i,t-1}$	0.04	0.18***	0.18***	0.31*	0.66***	0.132*
Interaction terms						
$(Size * \Delta r_{t-1})$	0.0058***	0.0029***	-0.005*	-0.004	-0.023	-0.0012
$(Liquidity * \Delta r_{t-1})$	-0.04***	-0.036***	0.037***	-0.019**	0.0051	-0.024
$(Capital * \Delta r_{t-1})$	-0.03*	-0.032**	-0.21	-0.012*	-0.096***	-0.002

Number of observations : 260
Number of banks : 10
Estimation procedure: One step
*, **, *** on coefficients indicate the level of significance at 1 % , 5% and 10 % respectively, while *elsewhere stands for multiplication sign

Regarding small banks vs large banks, effect of change in liquidity is more evident in small banks than in large banks, while the impact from change in capital is more pronounced in large banks than in small banks. In fact, for small banks, the increase in liquidity lead to more lending whereas effect from change in capitalization is not statistically significant. For larger banks, it is rather capitalization, which positively influences the loan supply while effect from change in liquidity is not statistically significant.

About less liquid vs more liquid banks, there is no big differences as a change in both capital and size positively affects the lending volume of both less and more liquid banks although the impact from capital is larger when bank is more liquid. On less capitalized banks vs more capitalized banks, lending from the former category of banks is influenced by change in liquidity, while lending from the latter is not sensitive to both liquidity and size.

Moreover, the interaction terms between the policy variable and bank characteristics seem to be more meaningful in the grouped models. The effects of monetary policy changes are likely to be higher in small banks than larger banks, which may mean that larger banks possess a buffer in their balance sheets that enables them to mitigate the effects of monetary policy on their lending. The findings on liquidity and capitalization somehow confirm the insight from the full model as more capitalized banks and more liquid banks respond more to monetary policy change than less capitalized and less liquid banks except in two sub samples namely less liquid and less capitalized banks.

In summary, empirical results explained above show some evidence of bank lending channel in Rwanda, though the effect of monetary policy is still moderate. Considering the realities of the Rwandan economy where financial deepening and banking sector are still developing, these results are somehow consistent with ongoing developments.

6. Conclusion and policy implications

This study provides evidence for the existence of a bank-lending channel in Rwanda using a panel data covering the period 2012Q1 to 2018Q2. Specifically, the study examines the response of bank loans to monetary policy changes and evaluates the effects on loans supply of the following bank specific factors: capitalization, size, liquidity, market power, as well as bank ownership. Moreover, the study investigates potential sources of asymmetrical response of banks to monetary policy shocks, based on the different bank characteristics.

The empirical results obtained in this study show the existence of a bank-lending channel in Rwanda, albeit moderate. The effects of macroeconomic variables, except inflation, are significant and robust across the model. Loan growth is negatively related to policy rate (repo rate), implying that loan supply generally falls following monetary policy tightening. With regard to bank characteristics, the results suggest that bank size and capitalization are also drivers of loan supply and explain the asymmetrical response of banks to monetary policy changes in Rwanda. Larger banks are likely to respond less to monetary policy shocks than smaller banks. When facing a monetary policy shock, well-capitalized and more liquid banks display a stronger response.

By splitting the dataset and grouping banks according to their characteristics (small versus large banks, less liquid versus more liquid banks and less capitalized versus more capitalized banks), results suggest that, both small and large banks respond to monetary policy actions, but the effects of policy rate change to small banks' loans supply is higher than that of large banks.

Moreover, the interaction terms between the policy variable and bank characteristics seem to be more meaningful in the grouped models. The effects of monetary policy changes are likely to be higher in small banks than in larger banks, which may imply that larger banks possess a buffer in their balance sheets that enables them to mitigate the effects of monetary policy on their lending. Regarding liquidity and capitalization, evidences generally confirm that well capitalized and more liquid banks will react more to monetary policy change than less capitalized and less liquid banks.

The policy implications from this paper are: First, the existence of the bank lending channel suggests that the National Bank of Rwanda should take into account the developments in the financial sector when conducting its monetary policy. Besides, as bank capital and liquidity can positively affect monetary transmission mechanism, enforcing financial stability would also facilitate achieving price stability through a more effective monetary policy.

Second, the evidence on heterogeneous reactions of banks to monetary policy actions implies that National Bank of Rwanda need to consider the micro aspect of bank behavior in formulating its policy. Moreover, in assessing the stance of the monetary policy, in addition to other indicators such as short-term interest rates, it is critical for the monetary authority to investigate banks reaction to monetary policy changes as reflected in loan supply to the private sector. Such analysis should also factor in possible asymmetric responses by banks influenced by size as well as capitalization.

Lastly, as the prevalence of bank lending channel is likely to be limited by increase in banks market power, the National Bank of Rwanda with other stakeholders should continue promoting competition in the banking industry to mitigate negative effects from increase in banks market power.

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APPENDIX

Full Model of bank loan supply function in Rwanda, results from Stata 14.1

```
. xtdpdsys log_loans log_GDP l.infl l.Log_NPL l.SIZE l.LIQUIDITY_RATIO l.Capital_ratio l.repo Size_r liqui
> dity_r capital_r Market_power ownership, lags(1) artests(2)
note: ownership dropped from div() because of collinearity

System dynamic panel-data estimation             Number of obs      =        249
Group variable: C_id                             Number of groups   =         10
Time variable: t
                                                 Obs per group:
                                                               min =         24
                                                               avg =       24.9
                                                               max =         25

Number of instruments =    480                   Wald chi2(13)      =   78931.28
                                                 Prob > chi2        =     0.0000
One-step results
```

log_loans	Coef.	Std. Err.	z	P>|z|	[95% Conf.	Interval]
log_loans						
L1.	.8963242	.0277534	32.30	0.000	.8419286	.9507199
log_GDP	.2597235	.0657274	3.95	0.000	.1309001	.3885468
infl						
L1.	.0017603	.0016627	1.06	0.290	-.0014984	.0050191
Log_NPL						
L1.	-.0378082	.0039133	-9.66	0.000	-.045478	-.0301383
SIZE						
L1.	.1247255	.0261264	4.77	0.000	.0735187	.1759323
LIQUIDITY_RATIO						
L1.	.0418518	.0371851	1.13	0.260	-.0310298	.1147333
Capital_ratio						
L1.	.1843796	.0500117	3.69	0.000	.0863585	.2824006
repo						
L1.	-.0042862	.0024224	-1.77	0.077	-.0090339	.0004616
Size_r	.0029712	.0017596	1.69	0.091	-.0004775	.0064199
liquidity_r	-.0365124	.0077481	-4.71	0.000	-.0516984	-.0213264
capital_r	-.0322846	.0134654	-2.40	0.017	-.0586763	-.0058929
Market_power	.132965	.0960117	1.38	0.166	-.0552146	.3211445
ownership	.0038453	.0127847	0.30	0.764	-.0212122	.0289028
_cons	.5035005	.2373654	2.12	0.034	.038273	.9687281

Source: Stata 14.0

ESTIMATING TIME-VARYING VOLATILITY IN CONSUMER PRICES IN RWANDA: APPLICATION OF GARCH MODELS

Maniraguha Faustin[7] Karangwa Mathias[8] Mwenese Bruno[9] Bagabe James[10]

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[7] Economist, Modelling and Forecasting division at National Bank of Rwanda.
[8] Senior Principal Economist, Modelling and Forecasting Division at National Bank of Rwanda.
[9] Principal Economist, Modelling and Forecasting division at National Bank of Rwanda.
[10] Senior Economist, Modelling and Forecasting division at National Bank of Rwanda.

Abstract

For central banks with the objective of maintaining price stability, estimating time-varying volatility in consumer prices helps in monetary policy decision-making. The objective of this study is to assess the magnitude and lifetime of volatility of Consumer price index (CPI) inflation in Rwanda and to use the estimated volatility to assess the quality of in-sample forecasts of inflation. Using quarterly data for selected CPI components and other exogenous variables from 2007 to 2018, an Exponential Generalized Auto-regressive Conditional Heteroscedasticity - EGARCH (1,1) model was used to estimate inflation volatility in four selected CPI components, namely headline, housing, transport and food and non-alcoholic beverage. The findings revealed that inflation volatility in all estimated models was driven by lagged residual. Inflation volatility is also driven by lagged volatility, except for transport.

Volatility in headline and housing inflation is persistent, implying that an impact of shocks dies away slowly. However, the impact of a shock on inflation for food and non-alcoholic beverage dies away very quickly. Besides, negative shocks to food and non-alcoholic inflation have bigger impact than positive shocks. The in-sample forecasts show that forecasts from EGARCH model are closer to the actual inflation than forecasts produced by autoregressive moving average model.

The results from this study shed more light on magnitude and persistence of CPI inflation components volatility and can be used to enhance the accuracy of near term CPI inflation forecasts, which are key input in the quarterly projection models. This is important for the National Bank of Rwanda as it recently adopted a forward-looking monetary policy where the quality of forecast is vital.

Keywords: Inflation volatility, EGARCH models, volatility persistence, Rwanda.

JEL Classification: E31, E37

1. Introduction

Some key macroeconomic variables such as GDP, exports or inflation exhibit varying degree of volatility, raising challenges in estimating and predicting the future path of economies (Cariolle, 2012). For policymakers, the volatility in macroeconomic variables is a challenge because it can weight on the effects of their actions. Specifically, the literature considers volatility in consumer prices as a factor having adverse macroeconomic effects, including the distortion of monetary policy decision-making aiming at price stability (Judson and Orphanides, 1999). Volatility in consumer prices also implies that future consumer prices tend to be uncertain, making policy responses more challenging and complicating economic agent's decision-making process. If the magnitude and persistence of the volatility is not taken into consideration when projecting inflation, the non-robust forecasts produced from volatile series may mislead monetary policy-makers.

This consideration is even more important for a country like Rwanda with relatively lower but highly variably CPI, compared to other countries in the region. The monthly CPI's coefficient of variation (2008M1-2018M10) stands at 0.88 in Rwanda, while this indicator of variability stands at 0.52, 0.51 and 0.73 in Kenya, Tanzania and Uganda, respectively. Acute CPI fluctuations in Rwanda were recorded in years 2016 and 2017 and were mainly reflected in food and energy items. This period was characterized by unpredictable food and local energy supply coming from particularly changing weather conditions, coupled with increased uncertainty in international oil prices and exchange rate developments.

Assessing volatility in consumer price index (CPI) inflation in Rwanda became more important since the adoption of a price-based monetary policy framework in January 2019. The forward-looking approach to monetary policy implementation requires, among other things, enhanced forecasting capacity. During the preparation phase that preceded this adoption, National Bank of Rwanda (NBR) has explored a variety of inflation forecasting tools to guide monetary policy decisions. The tools include near-term forecasting models such as Short-term Inflation Forecasting (STIF) and Autoregressive Moving Average (ARMA), as well as a quarterly projection model (QPM) of the Forecasting and Policy Analysis System (FPAS). Econometric literature shows that short-term forecasting using ARMA-type models becomes limited when price series are volatile due to their restrictive assumptions of linearity and homoscedastic error variance (Lama et al, 2015). Therefore, given the observed the magnitude of price volatility in Rwanda, there is an increasing demand for assessment of volatility to improve the quality and accuracy of short-term forecasts.

Various empirical studies have investigated the volatility in consumer prices (Goudarzi and Ramanarayanan, 2010; Khalafalla, 2010; Awogbemi and Oluwaseyi, 2011; Babatunde and Doguwa, 2012; Alibuhtto, 2015), and have shown that significant and persistent fluctuations in CPI volatility matter for inflation forecasting (Judson and Orphanides, 1999) and monetary policy (Mishkin and Posen, 1998). Such findings imply that understanding the magnitude and persistence of CPI volatility helps to improve the quality of forecasts and facilitates expert judgements for CPI forecasts. In Rwanda, the existing empirical studies focused on estimating and forecasting inflation. However, these studies did not consider the effects of volatility. This is the first study to assess the volatility of CPI inflation in Rwanda and the quality of in-sample forecasts of CPI inflation.

The objective of this study is to estimate the time-varying CPI volatility in Rwanda and assess the quality of in-sample forecasts of CPI inflation. Specifically, the study assesses volatility in three components of CPI in Rwanda. These include housing, food and non-alcoholic beverages, and transport. The choice of the components was guided by their weights and contributions into headline inflation over the considered period. The three components together account for 60 percent in total CPI.

The paper is organized into six sections. The subsequent section provides an overview of the CPI components and their contributions into headline inflation in Rwanda. Section 3 briefly review the literature on modeling price volatility. Section 4 discusses the empirical methodology adopted, while Section 5 focused on data and empirical results discussion. Section 6 concludes with an outline of policy recommendations.

2. Overview on the CPI components and contributions into headline inflation in Rwanda

In Rwanda, CPI weighting schemes have been changing over time, based on the variations in spending habits of the population. Since 1994, CPI weights have been revised four times (in 2000/2001, in 2005/2006, in 2014 and recently 2017). Over that period, three components, comprising food, housing and transport, represented above 60 percent of the total CPI weights (see Table 1).

Table 1: Weights for 12 CPI components: All goods index

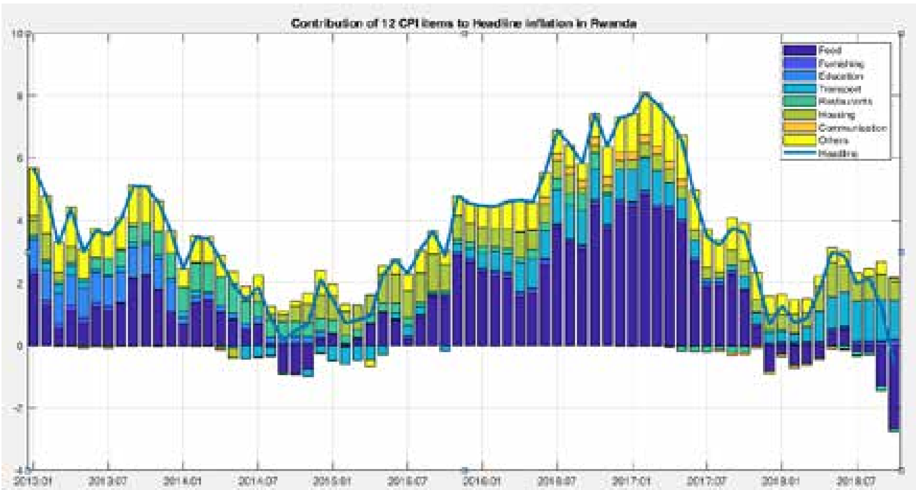
All goods index	Weights for 2000/2001	Weights for 2005/2006	Weights for 2014	Weights for 2017
Food and non-alcoholic beverages	3,709	3,538	2,819	2,738
Alcoholic beverages and tobacco	221	240	276	485
Clothing and footwear	500	377	422	531
Housing, water, electricity, gas and other fuels	1,579	2,204	2,296	2,075
Furnishing, household equipment and routine household maintenance	764	457	408	375
Health	708	163	91	133
Transport	987	1,189	1,774	1,245
Communication	37	288	278	314
Recreation and culture	206	256	213	307
Education	432	331	587	275
Restaurants and hotels	273	558	430	882
Miscellaneous goods and services	584	400	408	639
GENERAL INDEX	10,000	10,000	10,000	10,000

Source: NISR

When measuring the contribution of one components of CPI basket to headline inflation, National Institute of Statistics for Rwanda (NISR) considers its share and the variation in its price index for the period over which inflation is calculated. Any component that has a big share in total CPI and having a high variation in terms of prices index in a specific period, is expected to play a big role to overall average inflation volatility.

As shown in Figure 1, food, housing, and transport components account for a larger share of the variations in headline inflation for the considered period. Food and non-alcoholic beverages, housing, and transport include the most volatile items such as fresh products and energy. Food items include fresh products whose supply depend on weather and its seasonality. The housing component comprises energy items dominated by products with volatile prices such as charcoal and firewood, water and electricity. The transport component comprises fuel prices and purchases of vehicles among others. Figure 1 further illustrates that the contribution of different components into headline inflation varies across periods. For example, in 2014, the main contributors to headline inflation were food and restaurants, whereas in 2015, headline inflation was mainly reflected in the housing, food & non-alcoholic beverages and transport components.

Figure 1: Contribution of 12 CPI items to headline inflation in Rwanda (Jan 2013-Oct 2018)



Source: Author's calculations

Therefore, this article focuses on the three components of headline CPI (food & non-alcoholic beverages, transport and housing) given that they reflect larger share in fluctuations of headline inflation. The analyses use EGARCH models to estimate the magnitude and lifetime of CPI volatility in each of the components. This information is crucial for the near-term forecasting activities at NBR, as they provide a basis for expert judgements used in improving the quality of forecasts.

3. A brief review of literature on estimation and forecasting of volatile CPI

The literature considers volatility in consumer prices as a factor having an adverse macroeconomic effects for instance distorting decision-making aiming at price stability (Judson and Orphanides, 1999).

Volatility in consumer prices also means that future consumer prices tend to be uncertain, making policy responses more challenging and complicating economic agent's expectations and decision-making.

Modeling and forecasting volatile time series pose significant challenges. In econometric terms, volatile series are heteroscedastic, i.e. have non-constant variance of the error terms/deviations from the predicted ones (Lama et al, 2015). The non-robust forecasts produced from volatile series may mislead the policies once the magnitude of the volatility is not taken into consideration for improving the quality of forecasts.

A number of mathematical and econometric methods have been developed to estimate the volatile components of CPI. Most of them shared the common objective of unveiling the magnitude and the persistence of volatility. Mishkin and Posen (1998) observed a relationship between volatility of CPI components and inflation, noting that in countries where central bank operates under monetary targeting regime, inflation tend to be higher with highly volatile CPI components compared to levels and volatility of CPI under inflation targeting regime.

The relative benefit of ARCH modeling compared to other models (e.g. ARMA) is that ARCH/GARCH provides a non-constant estimate of the volatility of the series (Sparks and Yurova, 2011). The main idea behind the ARCH and GARCH models is that volatility is dependent upon past realizations of the time series data process and related volatility process (Engle, 1982; Bollerslev, 1986)

This is the reason why it is paramount to model consumer price indices and finding out the magnitude as well as the persistence of consumer price index volatility, for better and informed decision-making. In modelling CPI volatility, we may subdivide some models appropriate for modelling volatility in two blocks: (1) The non-ARCH family models and (2) ARCH family models (ARCH, GARCH, EGARCH and TGARCH).

On the first block, previous works related to consumer prices indices adopted different modeling methods in estimating and forecasting CPI volatility. For instance, Fritzer et al (2002) and Hubrich (2005) found that VAR models are accurate in forecasting CPI volatility while (Espasa et al, 2002), pointed out that ARIMA models overtake the VECM and dynamic factor models. A number of other studies (Libert, 1983; Hill and Fildes, 1984; Kelikume and Salami, 2014) also emphasized forecasting strength of ARIMA as a modeling method in forecasting inflation volatility.

Some of these non-ARCH family models were linear and could not well capture some important features of time series especially financial data, which are usually volatile (Brooks, 2008). The use of these models with assumption of constant variances produced biased estimates and forecasts owing to time varying and magnitude of volatility, usually found in time series data.

On the second block, ARCH family models attempted to address that shortcoming as they assumed heteroscedasticity of errors. Engle (1982) introduced the ARCH (Autoregressive Conditional Heteroskedastic) process that allows the conditional variance to change over time as a function of past errors leaving the unconditional variance constant. Afterwards, extension of ARCH model by Bollerslev (1986) included also the effect of past volatility. Bollerslev (1986) generalized the Engle's ARCH model and developed GARCH model, which allow that time-varying volatility to be function of both past innovations and past volatility.

As GARCH models had shown some restrictions especially on assumption of symmetric response of volatility on both positive and negative shocks, Nelson (1991) introduced the EGARCH (exponential GARCH) model, which has among others an advantage of allowing asymmetric response to positive and negative shocks (Brooks, 2008). In the same vein, Glosten et al (1993) introduced a new asymmetric model known as TGARCH (Threshold GARCH), which also allows for asymmetric effects in volatility modeling. They stretched the GARCH model by including an additional term, to capture possible asymmetries in the data.

A number of empirical studies used ARCH family models in attempt to assess volatility in consumer prices and results suggested that these models adequately capture inflation volatility. Nevertheless, depending on study case and which type of CPI components selected, some studies such as Khalafalla (2010) and Alibuhtto (2015) for Sudan and Sri Lanka respectively proposed EGARCH, while Omotosho and Doguwa (2012) suggested TGARCH and GARCH for headline and food price respectively for the case of Nigeria. In fact, country specific characteristics play a role in how volatile consumer prices could be. According to Mishkin and Posen (1998), volatility in consumer prices could also depend on the institutional specific characteristics whether the central bank is operating under monetary targeting or price-based monetary targeting framework.

Looking at some recent studies in developing countries, Khalafalla (2010) employed ARCH family models to assess the relationship between variability of inflation and its uncertainty in Sudan from 1960 to 2005.Using the annual data, the EGARCH (1, 1) model was found to correctly specify and estimate the conditional variance of inflation. Similarly, EGARCH (1, 1) was the most appropriate for modelling CPI for the case of Sri Lanka by Alibuhtto (2015). He analyzed volatility of Colombo Consumer Price Index using GARCH, TGARCH and EGARCH with monthly data from January 2008-April 2014. Results also suggested that there was no evidence of response symmetry to negative and positive shocks.

For the case of Nigeria, Omotosho and Doguwa (2012) used GARCH, EGARCH and TGARCH to assess dynamics of CPI inflation volatility. A set of explanatory variables such as Price of petroleum Motor Spirit per litre, Central Government Expenditure, Broad Money Supply, Official Nominal Naira Exchange rate, Reserve money, Average rainfall, and explained variables namely headline, food and core CPI were selected. The findings suggest that TGARCH is adequate to capture dynamics of headline and core CPI volatility while GARCH is appropriate for food CPI.

Some other studies in African countries adopted ARCH family models for analysis of prices volatility. Worako et al (2011) and Joordan et al (2007) looked at some specific field crops prices (coffee, yellow maize, white maize, wheat, sunflower seed and soybeans) in Ethiopia and South Africa respectively. In both studies, GARCH models performed well in capturing conditional volatility of crop prices.

4. Methodology

In this section, we discuss model specification, choice of variables that are included in the study as well as data description.

4.1 Model specification

This study attempts to model volatility of some key selected components of headline CPI. Previous studies confirmed that the non-linear models namely autoregressive conditional heteroscedastic (ARCH) proposed by Engle (1982) and the Generalized ARCH (GARCH) by Bollerslev in 1986 are appropriate to estimate volatility of consumer price indices. Therefore, our study initially used GARCH because it considers time-varying volatility to be explained by both past deviations and its past volatility, which was disregarded in the ARCH model.

Alternatively, EGARCH models for headline, transport, food & non-alcoholic and housing CPI are estimated to better capture volatility clustering and asymmetric effects. Once the information is known about the magnitude and the lifetime of volatility in the selected CPI equations, it will help to improve the quality of forecasts through the expert judgements in both near term forecasts and quarterly projections models.

Considering the behavior of CPI in Rwanda, we selected three main components namely, housing, food and non-alcoholic and transport CPI in addition to the headline CPI and estimated their mean equations and volatility equations, which measure the ARCH and GARCH coefficients. These equations are specified below:

4.1.1. Headline CPI model specification

$$HCPI_t = co + \sum_{i=0}^{z} \alpha EXCH_{t-1} + \sum_{i=0}^{h} \beta GDPagr\_gap_t + \sum_{i=0}^{k} \varphi CCPI_t + \varepsilon_t$$ Mean equation (1)

$$\log(\delta_t^2) = C0 + \alpha\left(\left|\frac{\varepsilon_{t-1}}{\delta_{t-1}} - \sqrt{\frac{2}{\pi}}\right|\right) + \gamma\left(\frac{\varepsilon_{t-1}}{\delta_{t-1}}\right) + \beta \log(\delta_{t-1}^2)$$ Variance equation (2)

In the equations above, the $HCPI_t$ represents headline CPI inflation at time *t* and is the explained variable. α, β,φ represent the coefficients in the model while lagged EXCH ,GDP agr_gap ,CCPI, are exchange rate(one quarter lag) , agriculture GDP gap, core CPI at time t serve as explanatory variables in the model.

After estimating the mean equation of headline CPI, an EGARCH equation is estimated where $C0, \alpha, \gamma$ *and* β are constant, coefficient of ARCH term, coefficient of asymmetric term effect, coefficient of GARCH term, respectively.

From the equation above, the leverage effect is exponential and it is the reason why the left-hand side of equation is the log of the conditional variance. This implies that the forecasts of the conditional variance should be positive.

The γ term is included in the model as a measure of asymmetric effect of the past shocks. For interpretation, if the asymmetric term is $\gamma \neq 0$, shocks impact is asymmetric and if $\gamma < 0$, there is a leverage effect. The impact of conditional shocks on the conditional variance is measured by α .A positive shock in period t_{-1} has an effect of $\alpha + \gamma$ on the conditional variance whereas a negative shock has an effect of $\alpha - \gamma$.

4.1.2. Food & non-alcoholic beverages CPI model specification

$$FoodCPI_t = co + \sum_{i=0}^{z} \omega frshCPI_t + \sum_{i=0}^{h} \pi GDPnonagr\_gap_t + \sum_{i=0}^{l} \delta EXCH_t + \varepsilon_t$$

Mean equation (3)

$$\log(\delta_t^2) = C0 + \alpha\left(\left|\frac{\varepsilon_{t-1}}{\delta_{t-1}} - \sqrt{\frac{2}{\pi}}\right|\right) + \gamma\left(\frac{\varepsilon_{t-1}}{\delta_{t-1}}\right) + \beta\log(\delta_{t-1}^2)$$

Variance equation (4)

$foodCPI_t$ denotes food & non-alcoholic beverages CPI inflation at time t and is the dependent variable. co is a constant term while ω, π ,δ are the coefficients. Fresh products CPI, non-agriculture GDP gap and Exchange rate at time t are the independents variables in the model. The interpretations of the second equation which is the variance are similar to the equation (2) mentioned above.

4.1.3. Housing CPI model specification

$$HSCPI_t = co + \sum_{i=0}^{v} \mu ENERGYCPI_t + \sum_{i=0}^{n} \rho GDP\_gap_t + \varepsilon_t$$

Mean equation (5)

$$\log(\delta_t^2) = C0 + \alpha\left(\left|\frac{\varepsilon_{t-1}}{\delta_{t-1}} - \sqrt{\frac{2}{\pi}}\right|\right) + \gamma\left(\frac{\varepsilon_{t-1}}{\delta_{t-1}}\right) + \beta\log(\delta_{t-1}^2)$$

Variance equation (6)

From the mean equation, $HSCPI_t$ denotes housing CPI inflation at time t and is the dependent variable. co represents the constant term while μ and ρ represents the coefficient. Energy CPI and GDP agriculture gap are explanatory variables in the model. Equation 6 is the variance equation and is specified as the previous ones (equation 2 and 4).

4.1.4. Transport CPI model specification

$$TRCPI_t = co + \sum_{i=0}^{y} \phi OilCPI_t + \sum_{i=0}^{w} \eta GDPnonagr\_gap_t + \varepsilon_t$$

Mean Equation (7)

$$\log(\delta_t^2) = C0 + \alpha\left(\left|\frac{\varepsilon_{t-1}}{\delta_{t-1}} - \sqrt{\frac{2}{\pi}}\right|\right) + \gamma\left(\frac{\varepsilon_{t-1}}{\delta_{t-1}}\right) + \beta\log(\delta_{t-1}^2)$$

Variance equation (8)

$TRCPI_t$ denotes the transport CPI inflation at time t and is the dependent variable. co represents the constant term while ϕ, η represent the coefficients of explanatory variables namely oil prices and GDP non agriculture gap at time t. The second equation which variance equation is explained in the previous equation (2, 4 &6).

4.2. Choice of variables

Variables selected include headline CPI inflation, food & non-alcoholic CPI inflation, housing CPI inflation, transport CPI inflation, fresh products CPI inflation, energy CPI inflation, core CPI inflation, non-agriculture GDP gap, and exchange rate and oil prices. The choice of the components was guided by their weights and contributions into headline CPI inflation over the considered period. The three components together account for 60 percent in total CPI.

Looking at the drivers of inflation, theory suggests demand-pull inflation (due to demand shock), cost-push inflation and external factors such as exchange rate shocks, oil prices shocks. Hence, some variables such as exchange rate, oil prices and GDP non-agriculture gap (as a proxy of demand pressures) were selected in the models. In addition, variables such core inflation, energy inflation and fresh products inflation were added following Omotosho and Doguwa (2012) who conducted a similar study in Nigeria. Overall, selection of exogenous variables included in the mean models specified above, was based on theoretical, empirical and situational relevance.

4.3. Data

This study uses quarterly data spanning from 2007Q1 to 2018Q3. Data on headline CPI inflation and components are from the National Institute of Statistics of Rwanda while data on other variables are from National Bank of Rwanda.

5. Empirical results

5.1. Stationarity test results

In ARCH models estimation, it is paramount to test for stationarity of the time series to avoid risk of spurious estimation. Results from Augmented Dickey-Fuller (ADF) test showed that headline inflation, core inflation, exchange rate inflation, food and non-alcoholic beverages inflation were stationary at level while other variables (oil prices, energy and transport inflation) were stationary after first difference except different measures of output gap used. (Results of stationarity tests are given in table 1 indicated in the Appendix-1). After stationarity analysis, regressions analyses allowed us to check whether ARCH family models are appropriate for estimating both mean and volatility equations. On this, heteroscedasticity analysis on residuals as well as ARCH test are used in order to confirm the presence of ARCH estimation. Results confirmed that all equations are appropriate for ARCH estimation.

5.2. Conditional Mean equations

Table 2: Mean Equation for headline CPI inflation (EGARCH estimation)

Variable	Coefficient	Std. Error	z-Statistic	Prob.
YAG_GAP	-0.19	0.073	-2.691	0.007
EXCH(-1)	0.18	0.044	4.077	0.000
CORE	0.92	0.036	25.104	0.000
C	-0.19	0.373	-0.517	0.604

The results suggest that headline CPI inflation at current period is explained by agriculture output gap, exchange rate with one-quarter lag and core CPI inflation. In fact, one percent increase in agriculture output gap (improvement in agriculture production) would lead to a decline of 0.19 percent in headline CPI inflation ceteris paribus whereas one percent exchange rate depreciation would lead to an increase of 0.18 percent in headline CPI inflation.

Results from food & non-alcoholic mean equation, are also well in line as demand pressures proxied by non-agriculture GDP gap lead to higher food & non-alcoholic CPI inflation while the impact of exchange rate depreciation on food& non-alcoholic CPI inflation increase is also more evident as elasticities (1.8 and 0.59 respectively) are relatively larger. The next table gives detailed results.

Table 3: Mean equation for food & non-alcoholic CPI inflation (EGARCH estimation)

Variable	Coefficient	Std. Error	z-Statistic	Prob.
YNAGR_GAP	1.80	0.340	5.302	0.000
EXCH	0.59	0.153	3.918	0.000
FLSH_CPI	0.54	0.036	15.196	0.000
C	-0.13	0.763	-0.170	0.864

Table 4: Mean equation for housing CPI inflation (EGARCH estimation)

Variable	Coefficient	Std. Error	z-Statistic	Prob.
ENERGY	0.37	0.054	6.924	0.000
Y_GAP	0.48	0.174	2.762	0.005
C	1.36	0.397	3.435	0.000

The findings in the mean equation of housing CPI inflation show that energy CPI inflation and output gap (both agriculture and non-agriculture) drive variation in housing CPI inflation. As in the previous equations, demand pressures (output gap) influence the changes in housing CPI inflation as the elasticity is 0.48 implying that positive demand pressures will significantly drive up housing CPI inflation.

Table 5: Mean equation for transport CPI inflation (EGARCH estimation)

Variable	Coefficient	Std. Error	z-Statistic	Prob.
YNAGR_GAP	0.972	0.490	1.984	0.047
OILP	0.025	0.021	1.218	0.223
C	-5.797	9.159	-0.633	0.527

Regarding the mean equation of transport CPI, only the coefficient of non-agriculture output gap was found to be statistically significant at 5 percent level. As in previous equations, demand pressures drive transport CPI inflation up and the elasticity is not trivial (0.97). Recall that the main components of transport CPI are purchases of vehicles, transport in services and operational of personal transport.

5.3. Results of the volatility models

The volatility models were analyzed using GARCH and EGARCH following the specification done in methodology. Each model was selected basing on the lowest value of AIC for each model between GARCH, EGARCH and TGARCH. Detailed results are in the tables below:

Table 6: Headline CPI volatility equation

Variables	GARCH	EGARCH	TGARCH
C	0.248^{ns}	-1.17**	0.182^{ns}
ARCH	0.919**	1.48*	0.729^{ns}
GARCH	0.133^{ns}	0.590**	0.174^{ns}
γ(Asymmetry)	-	-0.09^{ns}	0.473^{ns}
Persistence($\alpha+\beta$)	2.052	2.07	0.903

*=significant at 5 percent level; **=Significant at 10 percent level; ns=Not significant

From the results above, EGARCH model was found to be the most appropriate model to estimate headline CPI equation. The results indicate that both ARCH and GARCH terms are statistically significant at 5 percent and 10 percent level respectively. The persistence parameter is about 2.07 and this is above one unit, implying that the impact of shocks to headline CPI inflation die away very slowly. The asymmetric term is negative but not significant.

Table 7: Food & non-alcoholic volatility equation

Variables	GARCH	EGARCH	TGARCH
C	1.77^{ns}	1.53*	1.91^{ns}
ARCH	1.28**	1.43*	0.37^{ns}
GARCH	0.01^{ns}	-0.61*	0.251^{ns}
Asymmetry		1.42*	0.726^{ns}
Persistence($\alpha+\beta$)	2.29	0.82	0.62

*=significant at 5 percent level; **=Significant at 10 percent level; ns=Not significant

Regarding to the volatility model for food & non-alcoholic CPI, still EGARCH (1, 1) model was the one appropriate for volatility estimation. The results show that both ARCH and GARCH terms are statistically significant at 5 percent level. The persistence parameter is about 0.82 and is below one unit (i.e. the condition of stationarity). This means that the impacts of shocks to food and non-alcoholic inflation die away very quickly. The asymmetric term is positive and significant. This explains that negative shocks to food & non-alcoholic CPI inflation have big impact than positive shocks.

Table 8: Housing volatility equation

Variables	GARCH	EGARCH	TGARCH
C	0.71^{ns}	-1.128^{ns}	0.95**
ARCH	0.87**	1.76*	0.84^{ns}
GARCH	-0.01	0.70*	-0.01^{ns}
Asymmetry	-	0.15^{ns}	-0.89^{ns}
Persistence($\alpha+\beta$)		2.46	0.83

*=significant at 5 percent level; **=Significant at 10 percent level; ns=Not significant

On the results of housing equation, EGARCH (1,1) is again the best model compared to the rest due to its lowest AIC value. Both ARCH and GARCH terms are significant at 5 percent, and on volatility persistence, the coefficient is 2.46 indicating that the impact of shocks to housing CPI inflation die away slowly.

Table 9: Transport volatility model

Variables	GARCH	EGARCH	TGARCH
C	19.13*	0.90^{ns}	17.7*
ARCH	0.66*	1.60*	0.72*
GARCH	-0.23**	0.27ns	-0.20^{ns}
Asymmetry	-	-0.10^{ns}	-0.39^{ns}
Persistence($\alpha+\beta$)	0.43	1.87	0.52

*=significant at 5 percent level; **=Significant at 10 percent level; ns=Not significant

Regarding transport CPI, AIC test suggests that EGARCH (1,1) model better captures transport CPI inflation volatility than GARCH and TGARCH. The results also indicate that only ARCH term is significant at 5 percent significance level, implying that the current volatility in transport CPI inflation is influenced by the past deviations but not its past volatility, and this volatility is not persistent.

5.4. In-sample forecasting for the models (ARMA & EGARCH)

This section compares the one-step ahead forecasts using EAGRCH (1,1) to forecasts using ARMA. The results are summarized in table 10 and table 11. The RMSE (Root Mean Squared Error) was used to check the accuracy of the model and generally supports that EGARCH models are better than ARMA models.

Table 10 and table 11 show that EGARCH (1,1) model outperformed ARMA in all the estimated equations for the period under consideration except for the first two quarters indicating that shocks observed in those two periods were not significant. In Table 10, the RMSE of headline and food & non-alcoholic beverages inflation forecasts yield lower RMSEs under EGARCH, compared to ARMA. In table 11, the RMSE of housing and transport inflation forecasts also have lower RMSEs under EGARCH, compared to ARMA.

These results are in line with the different shocks to inflation observed in the second half of 2016 onwards. Since 2016Q3, inflation recorded acute fluctuations suggesting increased volatility.

Table 10: Summary of the forecasts for headline, food & non-alcoholic beverages inflation

	Headline				Food & non-alcoholic beverage			
	ARMA (2,3)		EGARCH (1,1)		ARMA (3,3)		EGARCH(1,1)	
	Actual	**Forecast**	**Actual**	**Forecast**	**Actual**	**Forecast**	**Actual**	**Forecast**
2016Q1	4.5	4.4	4.5	3.8	8.2	9.2	8.2	13.5
2016Q	4.9	4.3	4.9	5.4	7.0	7.4	7.0	11.5
2016Q	6.4	3.8	6.4	6.4	12.3	6.5	12.3	13.1
2016Q	7.0	3.3	7.0	7.1	15.4	5.9	15.4	12.1
2017Q1	7.7	2.9	7.7	7.3	16.6	5.2	16.6	12.4
2017Q2	6.2	2.8	6.2	5.9	13.3	4.2	13.3	9.9
2017Q3	3.5	2.8	3.5	4.1	7.4	3.1	7.4	6.5
2017Q4	2.2	2.9	2.2	2.7	1.9	2.2	1.9	3.1
2018Q1	0.9	3.0	0.9	2.0	-1.8	1.7	-1.8	-0.5
2018Q	2.5	3.0	2.5	2.3	0.6	1.7	0.6	0.9
2018Q	1.8	3.0	1.8	0.8	-2.1	1.8	-2.1	-0.2
RMSE	2.38		0.58		5.59		2.96	

Table 11: Summary of the forecasts for housing and transport inflation

	Housing				Transport			
	ARMA (3,3)		EGARCH(1,1)		ARMA (3,3)		EGARCH(1,1)	
	Actual	**Forecast**	**Actual**	**Forecast**	**Actual**	**Forecast**	**Actual**	**Forecast**
2016Q1	2.9	2.2	2.9	3.4	4.7	-0.1	4.7	6.7
2016Q2	3.2	2.8	3.2	3.7	7.3	3.7	7.3	7.9
2016Q	2.2	3.2	2.2	2.2	8.7	8.6	8.7	8.4
2016Q	1.2	3.7	1.2	0.9	7.7	6.9	7.7	9.6
2017Q1	2.0	4.0	2.0	1.8	8.5	7.0	8.5	8.0
2017Q2	1.8	4.3	1.8	2.7	5.4	5.9	5.4	8.0
2017Q3	1.7	4.6	1.7	2.6	1.3	5.5	1.3	7.7
2017Q4	2.3	4.8	2.3	4.1	3.0	4.9	3.0	7.0
2018Q1	2.4	4.9	2.4	4.1	3.0	4.6	3.0	7.9
2018Q2	4.4	5.1	4.4	5.5	8.2	4.3	8.2	7.1
2018Q3	3.6	5.2	3.6	5.8	10.3	4.0	10.3	6.0
RMSE	1.94		0.91		3.27		3.25	

5.5 Discussion

Empirical evidence outlined in the previous section suggest that headline CPI inflation volatility is persistent and the impact of shock die away slowly. Compared to other studies on CPI volatility in Africa, Omotosho and Doguwa (2012) found that volatility of headline CPI in Nigeria is persistent but the effect of shock die away quickly while for food and core CPI, it dies away slowly contrary to the case of Rwanda where impact of shock on food CPI die quickly.

These results are an important input in near term forecasts headline inflation as it informs the expert judgement. In the new framework (price-based monetary policy framework) recently adopted by the National Bank of Rwanda (NBR), headline CPI inflation forecasts serve a primary role in guiding the policy makers as well as the economic agents. One key lesson for forecasting exercise is to pay keen attention on food CPI dynamics as it contributes much to overall CPI dynamics and the shock effect on it die away quickly, which is a challenge in forecasting exercise.

Better estimates of volatility magnitude and persistence would improve on forecast from currently used models such as ARMA, exponential smoothing and STIF, which do not take into consideration the variance of deviations of headline. Hence, improved near term forecast of headline CPI inflation and its key components (food & non-alcoholic beverages, housing and transport) will ultimately enhance forecasts accuracy.

Some of the previous studies such as the work done by Lama et al (2015) as highlighted in the literature review of this study showed that EGARCH model was the best among ARMA and GARCH and justified that the performance of EGARCH resulted from its capacity to capture asymmetric volatility that are normally found in the volatile time series data.

6. Conclusion and policy implications

The study estimates the persistence and the magnitude of inflation volatility in consumer price indices in Rwanda by considering headline, food & non-alcoholic, housing and transport CPI in order to understand the dynamics of inflation volatility between 2005 and 2018. The study used quarterly data from the National Institute of Statistics of Rwanda and the National Bank of Rwanda.

In line with the literature on modeling CPI inflation volatility, the present study used EGARCH (1, 1) model. First, by estimating conditional mean of headline, food & non-alcoholic, housing and transport CPI inflation, the residuals from the models were tested for ARCH effects so that to confirm the presence of volatility. Second, by estimating the volatility models, the findings revealed the current volatility in headline, food & non-alcoholic, housing and transport CPI inflation are influenced by the past deviations as well as past volatility. Furthermore, the results suggest that volatility in the estimated models is persistent for headline, food and non-alcoholic as well as housing except transport inflation. Looking at the coefficients/magnitude of persistence, the impacts of shocks on food and non-alcoholic inflation dies away quickly while it dies away slowly on headline and housing inflation. Once the volatility is persistent, it may lead to non-robust forecasts due to these unexpected deviations.

The in-sample forecasts produced by both ARMA and EGARCH (1 ,1) illustrated that the forecasts from EGARCH model were closer to the actuals inflation in comparison with the forecasts produced by ARMA. The advantage of EGARCH against ARMA in modelling and forecasting the volatile time series data stems from its ability to capture asymmetric shocks.

Findings from this study shed more light on magnitude and persistence of CPI inflation components volatility. The findings also suggest that using EGARCH in addition to the existing NTFs models at NBR will contribute to enhancing the accuracy of near term CPI forecast. This is important for the National Bank of Rwanda as it recently adopted a forward-looking monetary policy where the quality of forecast is vital.

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Appendix

Table 1: Stationarity test results

	ADF-test		
Variables	t-stat	P.value	Level
Hcpi	-3.178269	0.0279	I(0)
housing cpi	-5.871370	0.0001	I(1)
trans cpi	-6.123444	0.0000	I(1)
food cpi	-6.473198	0.0000	I(0)
core cpi	-3.867932	0.0210	I(0)
exch	-3.549015	0.0452	I(0)
oil	-5.0134197	0.0001	I(1)
energy cpi	-8.174127	0.0000	I(1)
fresh products cpi	-7.463820	0.0000	I(1)

EXCHANGE RATE PASS-THROUGH TO CONSUMER PRICES IN RWANDA: A RE-EXAMINATION

Patrick HITAYEZU[11]   Christian NYALIHAMA[12]

[11] Director, Research Department, National Bank of Rwanda
[12] Senior Principal Economist, Research Department, National Bank of Rwanda

Abstract

Global empirical evidence suggests that exchange rate pass-through (ERPT) to consumer prices is more pronounced among developing economies such as Rwanda, especially following the adoption of market-based exchange rate regimes. Recently, the National Bank of Rwanda has re-affirmed its commitment to maintain a lower and stable inflation through the adoption of a price-based monetary policy framework, renewing its interest in understanding the magnitude and speed of transmission of exchange rates to consumer prices. This article re-examines ERPT in Rwanda in light of the two stages of transmission, from exchange rate to aggregate import prices and ultimately to aggregate consumer prices. Time series data spanning from 2006Q1 to 2018Q3 are employed in a structural vector auto-regressive (VAR) framework to estimate the exchange rate elasticity of various price indices.

The estimation results unveil several interesting insights. They show that a 1 percent nominal depreciation in exchange rate affects headline and core CPI inflation (overall ERPT) with maximum elasticities of 0.21 and 0.25, respectively. A deeper investigation into the transmission mechanism suggests that a maximum exchange rate elasticity of imported goods CPI inflation (stage-1 ERPT) of 0.28 is achieved in the second quarter. Results further show that shock to nominal exchange rate accounts for (i) 17 percent of headline CPI inflation variability and 12 percent of local goods CPI inflation variability from the third quarter on; (ii) 22 percent of imported goods CPI inflation from the fourth quarter on; and around 25 percent of core goods CPI inflation variability from the third quarter on. Historical decomposition suggests that shocks to exchange rate during key episodes of high or low inflation have had a bigger impact on imported goods inflation compared to other price indices. The findings point to the importance of taking into account exchange rate movements when forecasting the future path of inflation in Rwanda.

Keywords: Exchange rate pass-through, inflation, Rwanda

JEL classification: F31, E31.

1. Introduction

Exchange rate volatility and persistent imbalances in global and regional trade are increasingly stirring up the interest in understanding the role of exchange rate pass-through (ERTP) in monetary policy. Since the widespread adoption of market-based exchange rate regimes among developing countries and emerging market economies, monetary policy makers have been challenged with increasing inflationary pressures and exchange rate volatility, rising the need for understanding the channels through which exchange rate movements are transmitted into domestic prices. Understanding the extent and timing of import price adjustments to exchange rates movements and their implications for consumer prices is important for forecasting future path of inflation and appropriate monetary policy response. Moreover, through the phenomenon of expenditure switching, exchange rate elasticity of domestic prices determines the effectiveness of trade balance adjustment (Aron et al., 2014a).

Unlike most developing countries where ERPT is generally lower and decreasing (Taylor, 2000), global empirical evidence suggests that ERPT was more pronounced among developing economies (Aron et al., 2014a) such as Rwanda. Since the 1994 genocide, the Rwandan economy underwent several structural reforms that enhanced the potential link between movements in exchange rate and inflation. Amongst other reforms, Rwanda exchange rate regime was liberalized *de jure* since 1995. The liberalization of financial and monetary policies in Rwanda has left exchange rates largely floating to serve as an efficient shock absorption mechanism to align the local economic conditions with external sector in an equilibrium manner. Since then, foreign exchange market has been marked with a considerable variability. Developments in nominal effective exchange rate (NEER) suggest that the Rwandan Franc (FRW) has consistently but steadily depreciated against most trading partners' currencies, reflecting the dynamism in the country trade balance position.

The past developments in currency depreciation in Rwanda occurred within the context of dynamic monetary policy framework. Since 1995, when the floating exchange regime was adopted, the monetary policy authorities adopted a monetary targeting framework that use quantity of money as an operating target. Since early 2010, however, the central bank of Rwanda (NBR) embarked on a journey to modernize the monetary policy framework in line with positive developments in the financial sector. In 2019, a price-based monetary policy framework was officially adopted, reflecting a firm commitment to keeping inflation low and stable.

The advent of flexible exchange rate regime and a price-based monetary policy framework called for the importance of examining of domestic price responsiveness to exchange rate depreciation. The magnitude and speed of transmission of exchange rates to consumer prices in Rwanda has been a long-standing policy question, as the focus on ERPT in the empirical literature on Rwanda remains scarce and limited. An early attempt by Nuwagira (2015) (and the only one in the empirical literature on Rwanda) revealed a relatively smaller but persistent exchange rate pass-through to consumer prices with a dynamic elasticity of 0.28 that dies after four quarters. Notwithstanding the importance for understanding *overall ERPT* in Rwanda, Nuwagira's (2015) findings the findings of mask important insights into the mechanism of transmission that operates through import prices. The study overlooks the transmission mechanism from exchange rate to domestic prices, and uses a single measure of inflation rate (namely headline inflation) to investigate the responsiveness of domestic prices.

Inspired by a recent study by Kabundi and Mbelu (2018), this article uses time series data spanning from 2006Q1 to 2018Q3 to re-examine the magnitude and duration of ERPT in Rwanda in light with two major stages of transmission. The first stage consists of the impact of exchange rate on aggregate prices of imported goods and services, and the second stages refers to the eventual reaction of aggregate domestic consumer prices to changes in import prices. Quantifying each impact separately is in line with the empirical expectation that the sensitivity of prices to changes in exchange rate typically subside going down the price distribution chain, as an incomplete transmission mechanism along the chain may portrays different theoretical expectations that causes deviations from the law of one price (Aron et al., 2014a). In addition, this empirical investigation disaggregates headline inflation into core and non-core inflation to expounds the understanding of ERPT in Rwanda.

The remainder of this article is organized into five sections. Section 2 presents some recent developments in key monetary policy variables in Rwanda. Section 3 reviews the theoretical and empirical literature on ERPT. Section 4 outlines the methodology used to examine ERPT in Rwanda. Section 5 presents the results and discusses the main findings. The last section summarizes the findings and outlines key implications for monetary policy in Rwanda.

2. Recent developments in exchange rate and inflation in Rwanda

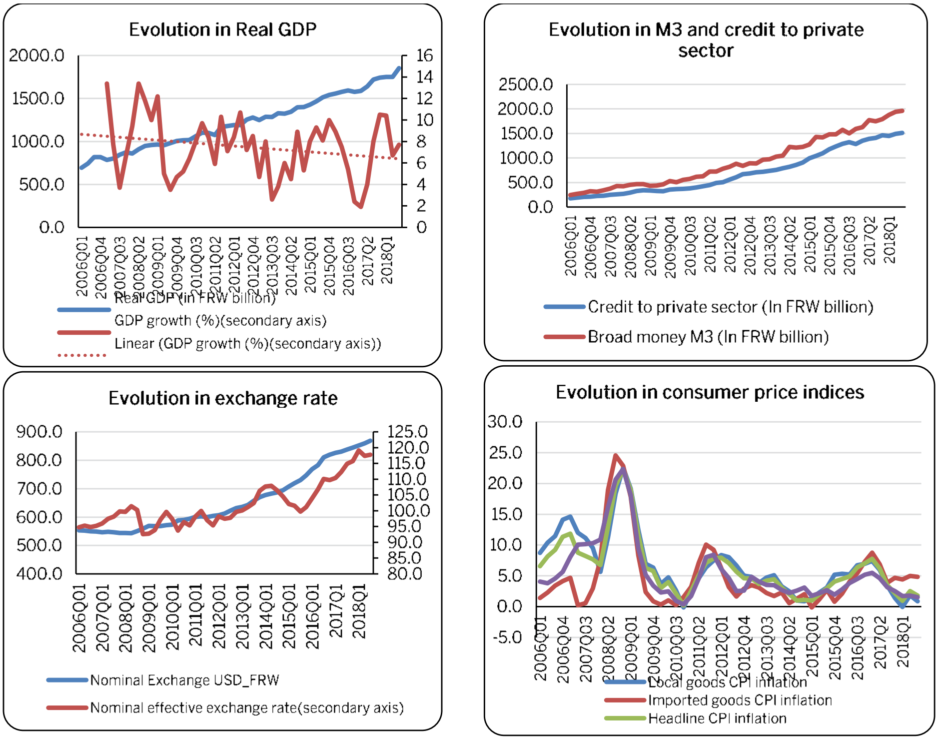
With financial liberalization introduced in mid-1990, the exchange rate of the Rwandan Francs (FRW) vis a vis foreign currencies have been flexible and market determined contrary to the period prior the 90s where it was strongly managed. Since financial liberalization, FRW exchange rate has generally been on depreciating trend amid unfavorable external imbalances characterized by higher imports and lower exports.

One of the next charts exhibits how nominal FRW exchange rate against the US dollar has been depreciating since 2006. The chart also depicts the nominal effective exchange rate evolution that has generally been on depreciating trend except in few episodes such as in 2014 and first half of 2015 when it was appreciating. Recall that nominal exchange rate is geometric mean of bilateral nominal exchange rate between the Rwandan francs and currencies of 10 main trade partners weighted with their share in external trade (Import and exports).

Since 2017, the speed of depreciation has declined amid ongoing improvement in current account balance following increase in exports in line with current Government policy of boosting and diversifying Rwanda exports.

Meanwhile inflation has been on a downward trend especially since 2010 just after a supply shock of 2008, which drove prices abnormally higher. Nevertheless, movement in core CPI and imported CPI have diverged in some few episodes. Besides, imported goods inflation seems to be a leading indication of headline inflation especially in episodes where price inflation were substantial. Another important fact to highlight is that for the last 5 years, CPI inflation has been relatively more stable and lower than nominal exchange rate depreciation. The next charts portray evolution of exchange rates and different consumer price indices, in addition to other key macro-economic variables such as real GDP and money supply and credit to private sector.

Figure 1. Overview of developments in GDP and monetary variables



Source: BNR and NISR.

Looking briefly on real GDP, the chart above shows how expansion in economic activities has been sustained overtime. Real GDP growth has been consistently high and averaged around 7.4 percent since 2006, except in some episodes (e.g. from 2016 Q2 to 2017 Q2) where expansion was subdued, In the same vein, growth in money supply and credit to private sector have been in line with expansion of economic activities and ongoing financial deepening and inclusion in Rwandan economy. The broad money to GDP ratio and credit to GDP ratio continued to grow, reaching 23.6 percent and 19.3 percent respectively by end 2017, implying that despite noteworthy development, there is still a room to continue improving.

3. Literature review

3.1. Theoretical underpinning

The literature on ERPT suggests a changing focus of analysis of ERPT. As documented by Aron et al. (2014a), early attempts to analyze ERPT can be traced in the industrial organization literature, where the focus was on the micro-economics of firm pricing strategies. Studies in this strand were concerned by the pricing strategy of monopolist, from ERPT to aggregate trade prices. By early 2000s, a renewed focus on ERPT was observed, this time in the monetary economics literature. Aron et al. (2014a) argue that this new macroeconomic focus resulted from insights of the so-called 'new open economy macroeconomics' and the famous Taylor's (2000) pricing model.

The original definition of the term ERPT (currently known as stage-1 ERPT) was the percentage change in import prices resulting from a one percentage change in exchange rate. With an increasing focus on the macro-economics of exchange rate, the original definition was extended to take into account the effect of exchange rate movements on a broader spectrum of prices, including consumer and producer prices (currently referred to as overall ERPT). To portray the transmission mechanism of the overall ERPT, a stage-2 ERPT is often included in the analyses, referring to the responsiveness of consumer and/or producer prices to changes in import prices.

The theoretical relationship between international prices and exchange rates can be understood from both normative and positive economic perspectives (Burstein and Gopinath, 2014). The point of departure in the theoretical literature around ERPT is based on the cross-country notion of relative purchasing power parity (PPP) that posits that changes in goods prices should be the same across all locations when converted into a single currency, and if markets are efficient, changes in the cost of production should equate the changes in market prices. Inefficiencies result from deviations that accrues from the cost of supplying the goods to different locations and/or price discrimination among firms. Within a single country, the magnitude of ERPT (often referred to as complete or incomplete ERPT) helps to understand the structure of an economy and the channels through which exchange rate movements stimulate or dampen the economy.

Why would ERPT be incomplete or at least delayed? The theoretical expectation of incomplete ERPT is based on the hypotheses of producer currency pricing (PCP) and local currency pricing (LCP) of the new open-economy macroeconomics (Aron et al., 2014a). Under the PCP system, prices in the exporter's currency remain unchanged, and importer's prices vary closely with changes in exchange rate. In this case, the ERPT to import prices would be complete. Whenever exchange rate depreciates, import goods would become more expensive, and a flexible exchange rate regime will adjust the trade balance through expenditure switching towards domestically produced substitutes.

With an LCP system, local prices remain fairly stable, while exporter's price varies closely with exchange rate. Under the LCP, therefore, ERPT is incomplete. The magnitude of responsiveness of local prices to exchange-rate driven cost shocks is informative of the market structure, the nature of demand faced by firms, and market segmentation across countries, while the speed of adjustment of firms to cost shocks is an indicator of the so-called "real rigidities" that propagate money non-neutralities (Burstein and Gopinath, 2014). Aron et al (2014a) outlines three channels through which ERPT becomes incomplete. In Channel 1 and Channel 2, exporter's prices vary with changes in mark-up and changes in marginal cost, respectively. Changes in mark-up (Channel 1) are negatively related to ease of substitution between foreign and domestic goods (i.e. product differentiation) and positively depends on degree of market segmentation (i.e. potential arbitrage). In Channel 2, exchange rate increases exporter's marginal cost (and hence price) due to factors such as decreasing returns to scale and/or imported goods in production of exporter's goods. Channel 2 is also triggered by transaction and marketing costs in the importing country (such as the costs of transport, taxes, insurance, advertising, etc). Channel 3 explains delayed responsiveness of import prices (i.e. delayed ERPT) as a result of short-term nominal rigidities.

3.2. Empirical evidence

The theories outlined in the previous subsection have considerably been backed by interesting insights from empirical evidence. A review of empirical findings from major advanced economies (Canada, France, Germany, United Kingdom, Italy, Japan, Switzerland, and the U.S.) by Burstein and Gopinath (2014) suggested that stage-2 ERPT is generally lower than stage-1 ERPT, and stage-1 ERPT is typically incomplete in the long run, displays dynamics, and varies considerably across countries. A similar phenomenon is observed developing and emerging economies. In South Africa, estimation results of Kabundi and Mbelu's (2018) indicated that ERPT is complete (of about 80%) and rapid in the first stage, but incomplete and slow in the second stage.

As stated in the previous subsection, incomplete pass-through can originate from rigidity in local prices for a period of time or from partial adjustments to exchange rate movements. This means ERPT estimated using aggregated data mask considerably the two phenomena. To unpack the incompleteness of ERPT, therefore, empirical studies have used micro price data underlying the construction of most price indices. This method has been widely explored in the empirical literature. In South Africa, for example, Aron et al. (2014b) reported maximum elasticities of 30% and 44.5% reached after two years, respectively, when micro-price and aggregate data are used.

Economists have argued that changes in long-run ERPT may largely depend on the source of exchange rate movement. In the United Kingdom, Forbes et al, (2018) showed that exchange rates movements driven by negative global shocks and domestic supply shock during the 2007-2009 global financial crisis corresponded to greater ERPT, compared to the ERPT that was observed after the 1996-1997 exchange rate movements caused by negative shocks in local demand. In South Africa, Kabundi and Mbelu (2018) showed a decline in first-stage ERPT from 80% in 2000-2009 to 63% in 2011 after the global financial crisis, before recovering to 68% in 2014.

Another insight from the empirical literature is that ERPT is asymmetric, especially over business cycles. Delatte and López-Villavicencio (2012) argued that the assumption of a uniform price-setting reaction to exchange rate variations of the pricing-to-market and mark-up models may not be empirically valid, given that the decision to pass exchange rate shocks onto prices has different implications for the firm's markup hence different incentive, depending on whether it is an appreciation of depreciation shock. The authors, using an autoregressive distributed lag (ARDL) model, showed that domestic prices in four major economies (Japan, Germany, the United Kingdom and the United States) rise more as a result of domestic currency depreciation compared with how they fall as a result of a domestic currency appreciation. In South Africa Kabundi and Mbelu (2018), using a rolling-window regression, showed that ERPT tends to rise (to around 62%) in the expansion phase of business cycle and decline (to about 46%) during contractionary phase.

4. Methodology

4.1. Estimation technique

A number of studies (e.g. Stulz, 2007; Ito and Sato, 2006; McCarthy, 2000; Choudhri et al 2005) have used VAR system in order to better address the endogeneity between exchange rate and domestic prices and capture the dynamic impact which are likely to characterize the pass-through. In an attempt to assess the extent and speed of pass through to various domestic prices, the present study adopts the same methodology and identifies exogenous shock to exchange rate in structural VAR framework. This is the main advantage structural VAR (SVAR) over the single equation approach.

Given the structure of the Rwanda's small open economy, VAR analysis allows to take into consideration interactions between exchange rate and other domestic macro-economic variables when investigating the pass-through to inflation. VAR as a system also helps to examine the impact of other shocks on key macro variables such as monetary policy stance and economic activities on inflation.

In the previous study on exchange rate pass through in Rwanda by Nuwagira (2015), the price variable included in estimated SVAR was headline CPI. Following McCarthy (2000) and in line with other studies such as Hahn (2003) and Hájek and Horváth (2015), the analysis of ERPT in this study is improved by incorporating the stages of the distribution chain in the VAR system in order to evaluate the pass-through to different types of prices indices, from imported inflation to headline, domestic and core inflations.

The VAR model estimated is of the following form:

$$AY_t = C(L)Y_t + Bu_t \tag{1}$$

Where Y_t is a vector of endogenous variables (details are in the next section), L is the lag operator, A, B and C are matrices and u_t is a vector of normally distributed errors ($U_t \sim N(O, I)$).

4.2. Identification strategy

A number of empirical studies reviewed (McCarthy, 2000; Bhundia, 2002, etc.), adopted Cholesky decomposition to identify the structural shocks. However, all of them did use the same ordering of variables, due to different context and case studies. For instance, Hajek and Hovrath (2015) for Czech Republic, in line with McCarthy (2000), used Cholesky decomposition by ordering supply and demand factors before distribution chain, whereas other studies checked the robustness of results using alternatives ordering (e.g Hahn, 2003).

This identification strategy involves imposing a structure on matrices *A* and *B*. In practice, equation 1 is multiplied through by the inverse of matrix *A* as follows:

$$Y_t = A^{-1}C(L)Y_t + A^{-1}Bu_t \tag{2}$$

Given et as residuals from unrestricted:

$$A^{-1}Bu_t = e_t \tag{3}$$

Which is equivalent to:

$$Bu_t = Ae_t \tag{4}$$

To impose a structure on matrices *A* and *B* (subsequently to structural VAR represented in equation 1), we follow Cholesky decomposition, which implies that zero restrictions on upper triangle of *A* (*A* is lower triangular) and structural shocks are uncorrelated as follows:

$$A = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 \\ a_{21} & 1 & 0 & 0 & 0 \\ a_{31} & a_{32} & 1 & 0 & 0 \\ a_{41} & a_{42} & a_{43} & 1 & 0 \\ a_{51} & a_{52} & a_{53} & a_{54} & 1 \end{bmatrix}, \qquad B = \begin{bmatrix} b_{11} & 0 & 0 & 0 & 0 \\ 0 & b_{22} & 0 & 0 & 0 \\ 0 & 0 & b_{33} & 0 & 0 \\ 0 & 0 & 0 & b_{44} & 0 \\ 0 & 0 & 0 & 0 & b_{55} \end{bmatrix}$$

Variables order is key for identification of structural shock through Cholesky decomposition. Therefore, we order variables in our VAR basing on local realities and assume that exchange rate (nominal effective exchange rate) does not contemporaneously react to demand shock, monetary policy shock and price shock. Then we assume that real GDP does not contemporaneously respond to monetary policy shock and price shock while it contemporaneously respond to exchange rate shocks. Lastly, we assume that prices react contemporaneously to other endogenous variables included in our models (exchange rate, output, money supply) and distribution chain goes from imported goods CPI to core, local goods and headline CPI. Hence, in our various model specifications, imported goods CPI is ordered ahead of local goods, core and headline CPIs. This distribution chain also allow us to evaluate “second round” effects.

Hence, variables are initially ordered as follows: nominal effective exchange rate, output gap, broad money, imported goods CPI and headline CPI in model 1. In alternative models, local goods CPI (model 2) and core CPI (model 3) replace headline CPI. Alternatives ordering allow to check for results robustness.

4.3. Variables selection

The choice of endogenous variables is guided by the theory and local realities. Nominal effective exchange rate and various consumer price indices (local, imported, core and headline) are key variables of the model. Additionally, other variables included are output gap (as a measure of demand pressures), broad money M3 (as an indicator of monetary policy stance), global oil prices (as a proxy of global economy or supply shock). The latter is included as an exogenous variable.

First, exchange rate indicator for this study is the nominal effective exchange rate, calculated as geometric mean of bilateral nominal exchange rate between the Rwandan francs and currencies of 10 main trade partners, weighted with their share in external trade (import and exports). Some studies used bilateral exchange rate with the US Dollar. However, given that Rwanda has various trade partners, we opted for the nominal effective exchange rate. This is would allow us to measure the total effect of Rwandan Francs depreciation or appreciation.

Second, output is proxied by output gap derived from real GDP series and Kalman filtering. We opted for the latter given that it is well in line with demand pressure observed in Rwandan economy, better than gaps derived from other alternatives such as HP filtering.

Third, monetary policy is proxied by broad money (M3). We opted for M3 because other alternative indicators such as the interbank rate or repo rate could not well capture the policy stance especially in years prior to 2013 where the National Bank of Rwanda was operating in a pure monetary targeting framework. Even though repo rates and other money market rates could capture well the stance of policy in recent years, the alternative of shortening the sample period in a VAR framework would arise degrees of freedom issues.

Regarding prices, we include headline CPI, local goods CPI, core CPI and imported goods CPI. These are price indices of different basket of goods classified according to international standards and are used to measure inflation in Rwanda. We consider these different baskets to investigate and compare the degree of pass through into different prices in Rwanda and evaluate pricing chain as earlier mentioned.

Lastly, we include global oil prices, which can capture supply shocks but also global economic situation. This is important given that Rwanda is small open economy. In contrast with other studies (Ito and Sato, 2006; Hahn, 2003, etc.) which included oil prices as an endogenous variable, it enters our VAR model as an exogenous variable given that domestic variables do not affect it and also its inclusion as an endogenous variable would reduce the degrees of freedom.

Data on prices, exchange rate and monetary aggregates are seasonally adjusted and their rates of growth are quarter on quarter annualized.

Data sources are National Institute of Statistics of Rwanda (for GDP and price indices), National Bank of Rwanda (for nominal effective exchange rate and broad money M3) and St Louis Federal Reserve (for oil prices).

5. Results and discussion

5.1. Stationarity test

Usually, for time series data analysis, it is of paramount importance to test for stationarity before proceeding with estimation. All variables were transformed in logs (except oil prices that were already transformed in log form) and results from Augmented Dickey Fuller (ADF) unit root test indicate that no variable was stationary in their log level. Nevertheless, deriving the quarter on quarter (henceforth Q on Q) annualized percentage changes of seasonally adjusted series (except real GDP) made all variables stationary and appropriate to use in VAR framework. A number of studies on pass through estimated VARs with series transformed in rate of changes. The next table shows stationarity test for selected variables.

5.2. Empirical estimation results

We estimated six different VARs models each including exchange rate, output gap, imported goods CPI and alternatively measures of domestic prices namely core CPI, local goods CPI and headline CPI to assess distribution chain. On monetary policy indicator, broad money and credit to private sector were included alternatively and results were almost similar. Here, we will present results obtained using broad money (the one with credit to private sector may be availed on request).

Table 1. Unit root test

Variable	ADF	Results
Q on Q annualized percentage change in nominal effective exchange	0.0000	Stationary
Output gap	0.0000	Stationary
Q on Q annualized percentage change in broad money	0.0001	Stationary
Q on Q annualized percentage change in imported goods CPI	0.0150	Stationary
Q on Q annualized percentage change in local goods CPI	0.0006	Stationary
Q on Q annualized percentage change in core CPI	0.0010	Stationary
Q on Q annualized percentage change in headline CPI	0.0054	Stationary

Source: authors' calculation

For each VAR, various criteria to determine the lag length (Akaike Information Criterion, Hannan-Quinn and Schwarz Criterion) suggested one lag for most of models. However, when estimated, there was an issue of autocorrelation and normality in some cases. We opted for two lags to solve that issue and keep our model as parsimonious as possible to allow more degrees of freedom.

Regarding diagnostic test for all three VARs models estimated, results were generally satisfactory. On stability, all models are stable as inverted roots lie in the unit circle. On serial correlation, results from LM autocorrelation test suggest that all three VARs have no issue of autocorrelation. Normality tests confirm that residuals are multivariate normal for all three models. Lastly, all models had no heteroscedasticity issues.

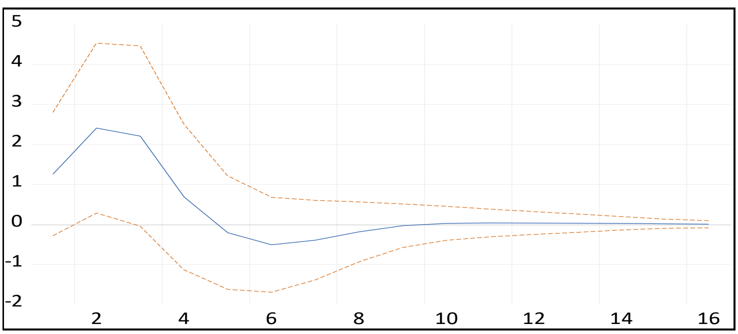
5.2.1. Impulse response analysis

Impulse response analysis allowed to assess the response of different prices to exchange rates shock and how the former react along the distribution chain. Overall, results from the three VARs models indicate the presence of exchange rate pass through in Rwanda though it is incomplete. Model 1 evaluates transmission to headline inflation, while model 2 and 3 investigate transmission to local goods inflation and core inflation respectively. All three models include imported goods inflation as the first stage of transmission.

With regard to the first stage of transmission from exchange rate change to imported goods inflation, impulse response analysis shows that an exchange rate depreciation will lead to an increase in imported goods inflation in the first quarter and the maximum impact on imported goods inflation occurs in the second quarter with an elasticity of around 0.28. This first stage of transmission lasts for only three quarters, as beyond that period, the effect of depreciation on imported goods inflation is no longer different significant.

Figure 2 displays the response of imported goods inflation to Cholesky one standard deviation shock to nominal exchange rate (from model 1 estimation). The solid blue line in the middle exhibits the estimated response and the two dashed lines represent a two standard error confidence band around the estimate at 5 percent level. Regarding the impact on the first quarter, calculations suggest that it is also statistically significant at 10 percent level. (All impulse response are in appendix).

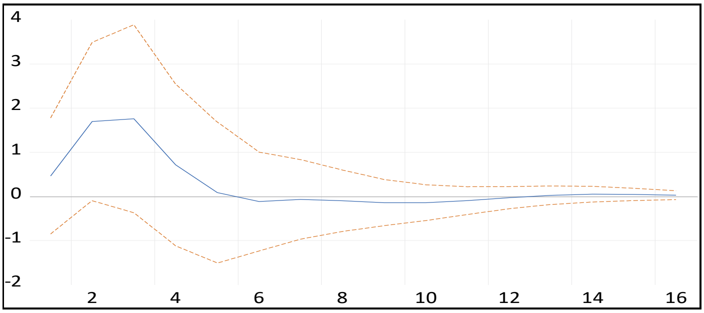
Figure 2. Response of imported goods CPI inflation to exchange rate shock



Source: Authors' estimation

Regarding the second stage of transmission, starting with the effect on local goods inflation (see Figure 3), impulse responses analysis would suggest a relatively mild and short-lived transmission compared to the case of imported prices inflation. However, a closer look at standard deviation indicate that impulse response are not statistically significant at 5% level. This limited pass through to local goods inflation can be linked to a number of factors including the composition of the local goods index, which exclude imported products. Besides, empirical evidences (for example Ito and Sato in 2006) have highlighted this low pass through to domestic prices.

Figure 3. Response of local goods CPI inflation to exchange rate shock

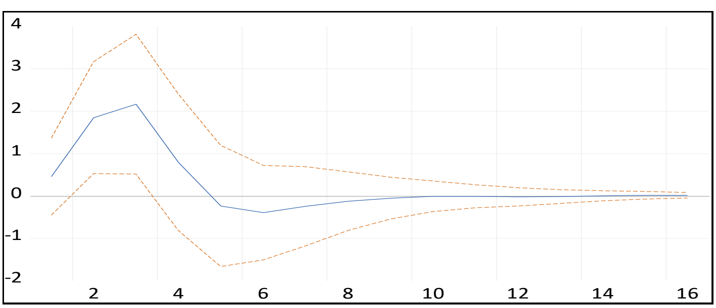


Source: Authors' estimation

On the transmission to core inflation, results also indicate that the degree of exchange rate pass through is slightly lower (elasticity estimated at around 0.25) compared to the case of imported goods inflation (elasticity estimated at around 0.28. The fact that a number of imported goods are included in core inflation is likely influencing this result.

In addition, impulse response analysis in Figure 4 suggests that response of core inflation last for only two quarters, beginning in the second quarter following the effect on imported goods inflation in the first quarter and reach its maximum in the third quarter. The next chart depicts the response of core inflation on exchange rate depreciation. (All impulse response are in appendix).

Figure 4. Response of core CPI inflation to exchange rate shock

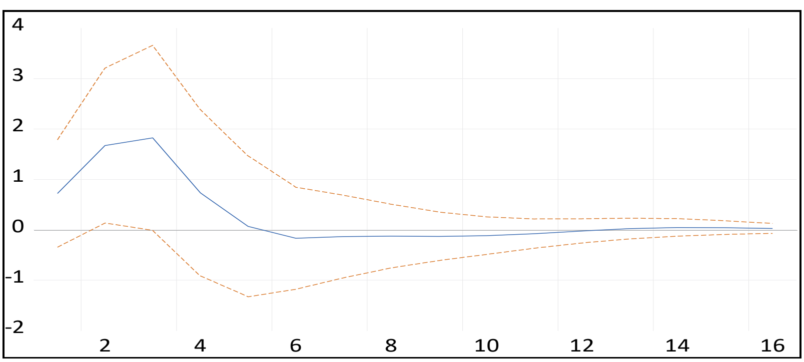


Source: Authors' estimation

Regarding the transmission to headline CPI, there are many similarities with the case of core inflation discussed in the previous section. The magnitude of pass through is relatively weaker (elasticity estimated at around 0.21 in third quarter) compared to imported good inflation as expected, given that headline CPI include some products on which impact from exchange rate may likely be mild. This is almost similar to results from previous study on Rwanda by Nuwagira (2015) who found a pass through elasticity of 0.22 for headline inflation. This result is in line with what is usually expected on pass through to different domestic prices namely a higher pass through to imported goods inflation compared to other domestic price indices. Ito and Sato (2006) had found similar result for Asian countries as the degree of exchange rate pass through was higher for imported prices than for general CPI.

In addition, similar to core inflation, the response of headline inflation starts in the second quarter and ends in the third quarter as beyond that period, the impact is no longer different from zero. The next figure exhibits the response of headline inflation to Cholesky one standard deviation shock to nominal exchange rate (from model 1 estimation. All impulse responses are in appendix).

Figure 5. Response of Headline CPI inflation to exchange rate shock



Source: Authors' estimation

About how other key macro variables react to shocks in the models, there are various insights worthy to mention. First, shock on nominal exchange rate has no significant impact on output gap and money supply. With regard to output gap, nominal depreciation seems to have a slightly positive effect but it is not statistically significant. One of the explanation would be that for a big part of the sample periods, exports from Rwanda where mostly commodities where Rwanda is a price taker, and the effect from nominal depreciation might not have been positive as suggested by the theory. Of recent, Rwanda exports are becoming more diversified and further studies in the future can investigate this issue using more recent data.

Second, positive shock on output lead to an increase in imported goods, local goods and headline inflation. Here, it is important to note that the effect on local goods prices is stronger as expected given that headline CPI include also some goods produced in foreign economies and which change costs of production and prices are insulated from effects of business cycles in Rwanda.

Third, positive shock to broad money supply affect only headline inflation, local goods inflation and output but this impact is not persistent (only 2 quarters) whereas the impact on imported goods inflation is not statistically different from zero. As broad money in the models is a proxy of monetary policy, the results suggest that monetary policy shock in accommodative direction will positively affect output in the third and fourth quarter in Rwanda.

Lastly, the effect of shock to imported goods inflation on domestic goods inflation is smaller and short lived compared to the effect on core inflation and headline inflation. The pass-through on the latter is moderate (elasticity of around 0.5) and last for 2 quarters. This can be explained by the fact that in a imported products are part of components of core CPI and headline CPI.

5.2.2. Variance decomposition

Analysis of variance decomposition (see tables in appendix) give additional evidence on exchange rate pass through to domestic prices in Rwanda as it shows to what extent exchange rate shock affect domestic prices versus shock to other variables. The following sections highlights key insights from variance decompositions, which are very similar to evidences from impulse response above.

Looking at imported goods CPI inflation, the effect from nominal exchange rate shock is relatively stronger (accounting for 22 percent from the fourth quarter on) as expected. Nominal exchange rate shock impact remains stronger over 10 quarter's horizons almost at the same level as the impact of output gap shock (around 22 percent).

Similarly, variance decomposition of core goods CPI inflation at 10 quarters horizons indicates that the impact of nominal exchange rate shocks (around 25 percent from the third quarter on) is almost similar to the one from output gap shock (around 27 percent) and both have the highest impact (excluding shock from CPI components whose impact is naturally large). The effect of money supply shock on core CPI inflation is also relatively stronger than for the case of imported goods and headline inflation.

On local goods inflation, the effect of exchange rate shock over 10 quarters horizons is relatively lower (accounting for around 12 percent from the third quarter on) and the impact form a shock on money supply strengthens (around 13 percent) at the expenses of the former as expected. Shock to output gap are the main driver of local goods inflation variability (accounting for around 36 percent).

About headline inflation, shock to nominal exchange rate have a moderate effect on headline CPI inflation variability (accounting for 17 percent from the third quarter on). The highest impact on headline CPI inflation variability is from the output gap (around 33 percent). The impact form a shock on money supply is relatively moderate (around 9 percent) compared to the case of local goods and core inflation.

Regarding the variance decomposition for other variables included in our models, key evidences to highlights are the following:

- Apart from its own shock, nominal exchange rate is mostly affected by shock on money supply (around 7 percent) and imported good CPI inflation (around 10 percent);
- With regard to output gap, monetary policy shock has a non-trivial effect on its variability. It is mostly shock to money supply (around 19 percent) in addition to its own shock;
- On money supply, it is mainly its own shock while effect from output gap and nominal exchange rate is rather low.

5.2.3. Historical decomposition

Considering the influence of exchange rate on prices dynamics in Rwanda for the recent periods, historical decomposition evaluates the impact of exchange rates shocks in some key episodes of high/low inflation and contrast it with the impact from other shocks from variables included in the model. The main observation is that shocks to exchange rate have had a bigger impact on imported goods inflation compared to other price indices.

Since 2015, the impact of exchange rate shock is the strongest on imported goods inflation and core inflation while on local goods inflation and headline inflation, it is rather the shock to output gap.

For recent years, shocks to exchange rate have exerted both inflationary and deflationary pressures to prices in Rwanda and the effect weakened over the distribution chain (see chart in annex). From 2014 to 2015, exchange rate shocks exerted deflationary pressures on CPI inflation in Rwanda, notably on imported goods inflation. Since then, exchange rate pressures have been moderately inflationary.

Recent historical decomposition also highlights the importance of business cycle in influencing the magnitude of exchange rate pass through. In fact, looking at the last four years, the effect of depreciation on headline inflation was stronger during “booms” than during “downturn” in line with Kabundi and Mbelu (2018). Besides, Burstein and Gopinath (2014) had suggested that the magnitude of responsiveness to exchange rate could be informative on market structure and nature of demand faced by firms. In line with this, the results may imply that market structure in Rwanda is competitive as firms or sellers are less reactive to exchange rate depreciation when demand is subdued.

Whether there is asymmetric response in case of depreciation versus appreciation as suggested by Delatte and López-Villavicencio (2012), historical decomposition seem to confirm that in Rwanda, exchange rates depreciation have had stronger effect on headline CPI than in case of appreciation especially since 2009.

5.2.4. Robustness check

Given that variables ordering is key in our identification strategy, we checked the sensitivity of our results using an alternative ordering. This is also because ordering of some variables can be highly debatable as they can be affecting each other contemporaneously. In the alternative ordering, we based on theory on monetary policy reaction where monetary policy authorities would react to movement on key macro variables notably output gap and inflation. Secondly, we assume again that nominal exchange rate contemporaneously affect prices and not vice versa, given that the nominal effective exchange rate include other countries exchange rate which are at a higher extent insulated from development in our domestic prices, while the latter can be contemporaneously affected via a non-negligible share of imported goods in CPI basket. Hence, the new ordering is output gap, nominal effective exchange rate, imported goods CPI, headline CPI (alternatively core CPI and local goods CPI) and lastly broad money M3.

Looking at both impulse response and variance decomposition, the results are almost similar to the previous one (available on request) except a slight increase of the degree of the exchange rate pass through. In summary, we can conclude that the pass through of nominal exchange rate shock to domestic prices in Rwanda is evident although it is incomplete and die out after 3 quarters.

5.2.5. Discussion

Empirical results explained in the previous sections point out to a partial pass through of nominal exchange rate to domestic prices in Rwanda. Comparing this with evidence from other studies on developing countries, these results are somehow in line with a study by Razafimaheva (2012) on pass through in Sub Saharan African (SSA) Economies and Nuwagira (2015) on pass through in Rwanda, suggesting that the pass through in SSA economies was partial and incomplete. The maximum effect occurs within four quarters in SSA case against three quarters in Rwanda.

Regarding the distribution chain, the pass through varies across different prices in line with the theory. The pass through is faster and immediate on imported goods prices in first place and transmission to other domestic prices takes effect in the next quarter at a decreasing rate along the distribution chain. According to Taylor (2000), difference in pass through along distribution chain can be attributed to a number of factors notably the share of prices in the price index that are affected by the shock. On this, it is normal that imported goods inflation and core inflation are most affected given than local goods inflation as the former include a bigger share of prices of imported goods. With regard to policy implications, the fact that "second round effect" from imports prices to domestic prices is partial and short lived is an advantage for NBR as the policy potency is rather limited especially in a situation where shock to import prices reflects external factors beyond NBR control.

Again, the fact that exchange rate pass through is partial and not persistent in Rwanda can be an advantage to monetary policy formulation. Actually, this would give a room to a more independent monetary policy as the effect of external shock on cost of production and domestic inflation is somehow limited. Mishkin (2008) pointed out that low pass through would make it easier for monetary policy to stabilize inflation and output.

Besides, a lower exchange rate pass through would allow more room to correct for any exchange rate misalignment without jeopardizing domestic product competitiveness, given that the exchange rate movement will have a limited effect on price of tradable goods.

Lastly, as domestic prices react with one-quarter lag after imported goods prices; this evidence is an additional contribution in monetary policy formulation at National Bank of Rwanda especially on CPI near term forecast, which is very important input for medium term projection in a forward-looking monetary policy framework.

6. Conclusion and policy recommendations

Global empirical evidence suggests that exchange rate pass-through (ERPT) to consumer prices is more pronounced among developing economies such as Rwanda, especially following the adoption of more market based exchange rate regime. This article re-examines ERPT in Rwanda in light with the two stages of transmission, from exchange rate to aggregate import prices and from import prices to aggregate consumer prices. Time series data spanning from 2006Q1 to 2018Q3 are employed in a structural vector auto-regressive (VAR) framework to estimate the exchange rate elasticity of various price indices.

The estimation results unveil several interesting insights. They show that a 1 percent nominal depreciation in exchange rate affects headline and core CPI inflation (overall ERPT) in the third quarter with elasticity of 0.21 and 0.25, respectively. A deeper analysis of the transmission mechanism suggests that a maximum exchange rate elasticity of imported goods CPI inflation (stage-1 ERPT) of 0.28 is found in the second quarter.

The results further show that shock to nominal exchange rate accounts for (i) 17 percent of headline CPI inflation variability and 12 percent of local goods CPI inflation variability from the third quarter on; (ii) 22 percent of imported goods CPI inflation from the fourth quarter on; and around 25 percent of core goods CPI inflation variability from the third quarter on. Historical decomposition suggests that shocks to exchange rate during key episodes of high/low inflation have had a bigger impact on imported goods inflation compared to other price indices.

The finding that elasticities of stage-2 ERPT are considerably lower compared to stage-1 ERPT elasticity could suggests a success of past monetary policy in anchoring price expectations, which partially reversed the effects of inflationary shocks in exchange rates.

A key implication from these findings is that, since nominal exchange rate depreciation can be inflationary, National Bank of Rwanda should proactively take it into account when forecasting the future path of inflation. Given that exchange rate itself is endogenous to monetary policy, the central bank reaction function should be modelled together with the ERPT system.

Although this article has help to improve the understanding of how exchange rate movements affect price stability in Rwanda, it does not capture the complexity of the phenomenon. One noticeable shortfall of this analysis pertains to the use of price aggregates. Given the importance of volatile prices in the inflation process in Rwanda, it is advisable to supplement the analyses with micro-level investigations to spur the understanding of underlying drivers of inflation in Rwanda. Moreover, there is need to understand the sources of exchange rate movements, as these determine how exchange rate movements affect prices. When estimating the effect of exchange rate on inflation, future studies should model and forecast shocks that influence exchange rate movement in order to explicitly take into account the fact that ERPT is state-dependent.

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APPENDIX

1. Diagnostic tests

a. Stability test

Model 1		Model 2		Model 3	
Root	Modulus	Root	Modulus	Root	Modulus
0.636336 - 0.402085i	0.7527	0.618654 - 0.397885i	0.7356	0.471892 - 0.559234i	0.7317
0.636336 + 0.402085i	0.7527	0.618654 + 0.397885i	0.7356	0.471892 + 0.559234i	0.7317
0.387719 - 0.523012i	0.6511	0.391962 - 0.529127i	0.6585	0.555483 - 0.340174i	0.6514
0.387719 + 0.523012i	0.6511	0.391962 + 0.529127i	0.6585	0.555483 + 0.340174i	0.6514
-0.083445 - 0.502110i	0.5090	-0.071641 - 0.499783i	0.5049	-0.051081 - 0.598932i	0.6011
-0.083445 + 0.502110i	0.5090	-0.071641 + 0.499783i	0.5049	-0.051081 + 0.598932i	0.6011
0.419332	0.4193	0.3965	0.3965	0.532812	0.5328
-0.308323 - 0.110314i	0.3275	-0.374053 - 0.067068i	0.3800	-0.266076 - 0.372839i	0.4580
-0.308323 + 0.110314i	0.3275	-0.374053 + 0.067068i	0.3800	-0.266076 + 0.372839i	0.4580
-0.305672	0.3057	-0.242947	0.2429	-0.26208	0.2621
No root lies outside the unit circle. VAR satisfies the stability condition.		No root lies outside the unit circle. VAR satisfies the stability condition.		No root lies outside the unit circle. VAR satisfies the stability condition.	

b. Autocorrrelation test

VAR Residual Serial Correlation LM Tests						
Null Hypothesis: no serial correlation at lag order h						
	Model 1		**Model 2**		**Model 3**	
Lags	LM-Stat	Prob	LM-Stat	Prob	LM-Stat	Prob
1	20.16	0.74	19.13	0.79	23.18	0.57
2	22.16	0.63	21.52	0.66	25.67	0.43
3	26.14	0.40	26.94	0.36	16.70	0.89
4	40.91	0.02	42.79	0.01	37.18	0.06
5	16.01	0.91	15.58	0.93	16.62	0.90
6	27.55	0.33	26.74	0.37	32.65	0.14
Probs from chi-square with 25 df.						

c. Normality test

VAR Residual Normality Tests

Orthogonalization: Cholesky (Lutkepohl)

Null Hypothesis: residuals are multivariate normal

	Model 1				Model 2				Model 3			
Component	Skewness	Chi-sq	df	Prob.	Skewness	Chi-sq	df	Prob.	Skewness	Chi-sq	df	Prob.
1	-0.32	0.84	1	0.36	-0.33	0.88	1	0.35	-0.22	0.40	1	0.53
2	-0.29	0.69	1	0.41	-0.23	0.44	1	0.51	-0.16	0.20	1	0.66
3	-0.22	0.40	1	0.53	-0.25	0.49	1	0.48	-0.36	1.03	1	0.31
4	-0.42	1.41	1	0.24	-0.29	0.67	1	0.41	-0.29	0.69	1	0.41
5	-0.18	0.27	1	0.60	-0.02	0.00	1	0.95	-0.46	1.70	1	0.19
Joint		3.60	5	0.61		2.48	5	0.78		4.01	5	0.55
Component	Kurtosis	Chi-sq	df	Prob.	Kurtosis	Chi-sq	df	Prob.	Kurtosis	Chi-sq	df	Prob.
1	2.47	0.57	1	0.450	2.47	0.57	1	0.45	2.35	0.86	1	0.35
2	3.39	0.31	1	0.580	3.34	0.23	1	0.63	3.63	0.79	1	0.37
3	2.34	0.87	1	0.350	2.30	0.97	1	0.32	2.31	0.95	1	0.33
4	2.88	0.03	1	0.870	2.80	0.08	1	0.78	3.25	0.12	1	0.72
5	3.46	0.42	1	0.517	3.43	0.36	1	0.55	3.30	0.18	1	0.67
Joint		2.20	5	0.821		2.21	5	0.82		2.91	5	0.71
Component	Jarque-Bera	df	Prob.		Jarque-Bera	df	Prob.		Jarque-Bera	df	Prob.	
1	1.41	2.00	0.49		1.44	2.00	0.49		1.25	2.00	0.53	
2	1.00	2.00	0.61		0.67	2.00	0.72		0.99	2.00	0.61	
3	1.27	2.00	0.53		1.47	2.00	0.48		1.98	2.00	0.37	
4	1.43	2.00	0.49		0.75	2.00	0.69		0.81	2.00	0.67	
5	0.69	2.00	0.71		0.37	2.00	0.83		1.88	2.00	0.39	
Joint	5.80	10.00	0.83		4.69	10.00	0.91		6.91	10.00	0.73	

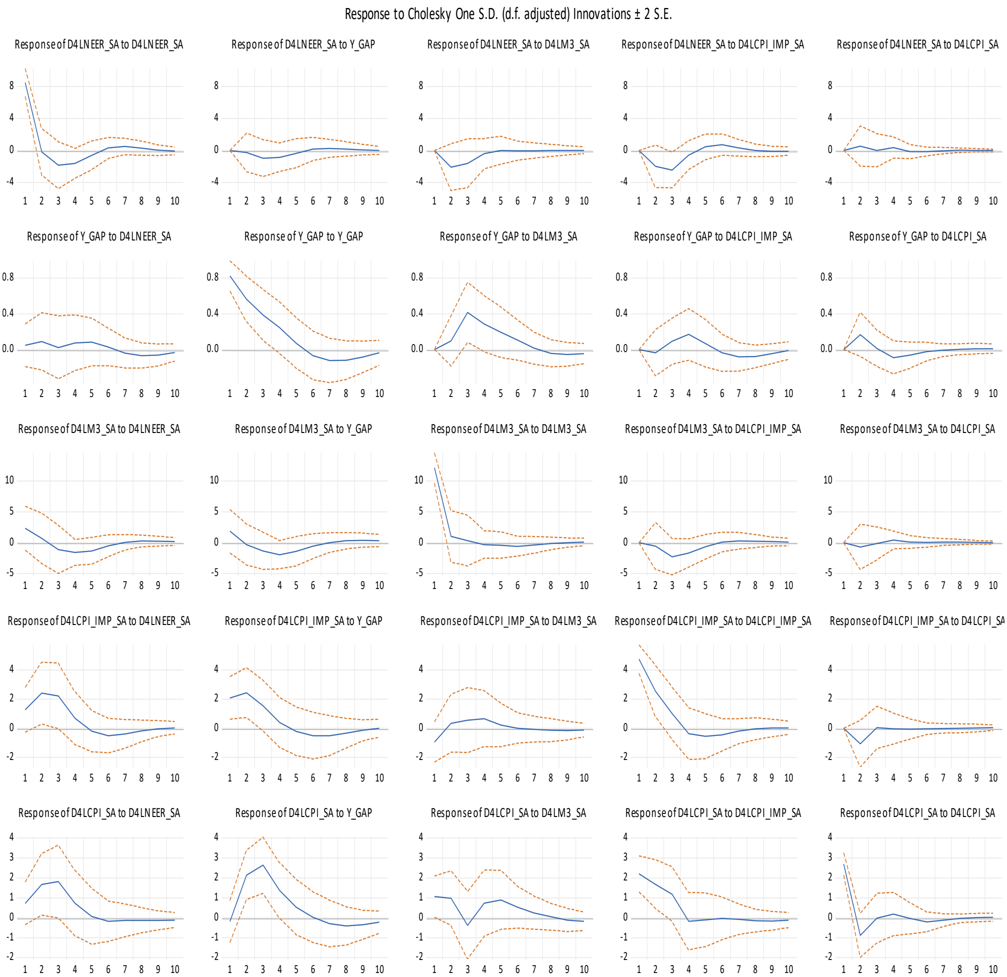
d. Heteroskedasticity test

VAR Residual Heteroskedasticity Tests: No Cross Terms (only levels and squares)

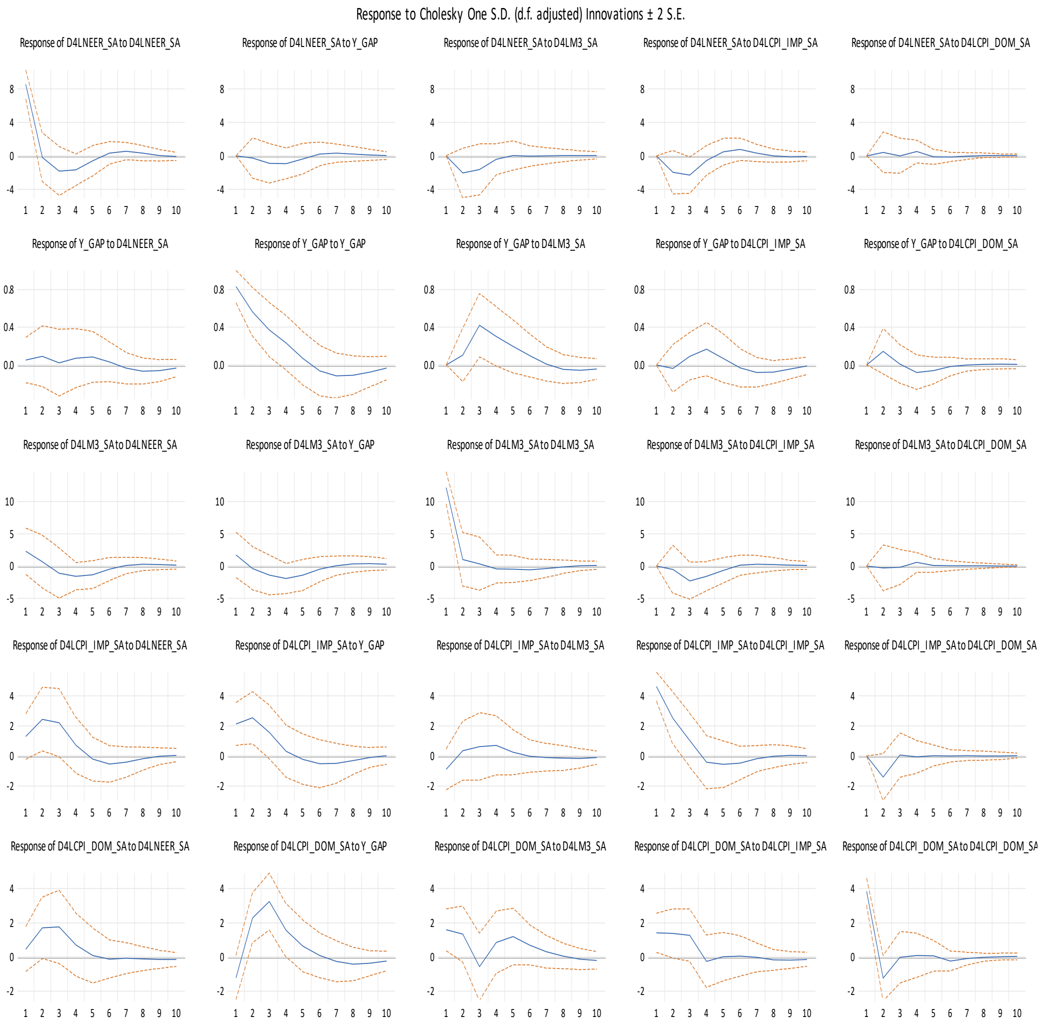
Included observations: 48

Joint test								
Model 1			Model 2			Model 3		
Chi-sq	df	Prob.	Chi-sq	df	Prob.	Chi-sq	df	Prob.
358.56	330	0.1342	357.885	330	0.1396	348.211	330	0.2351

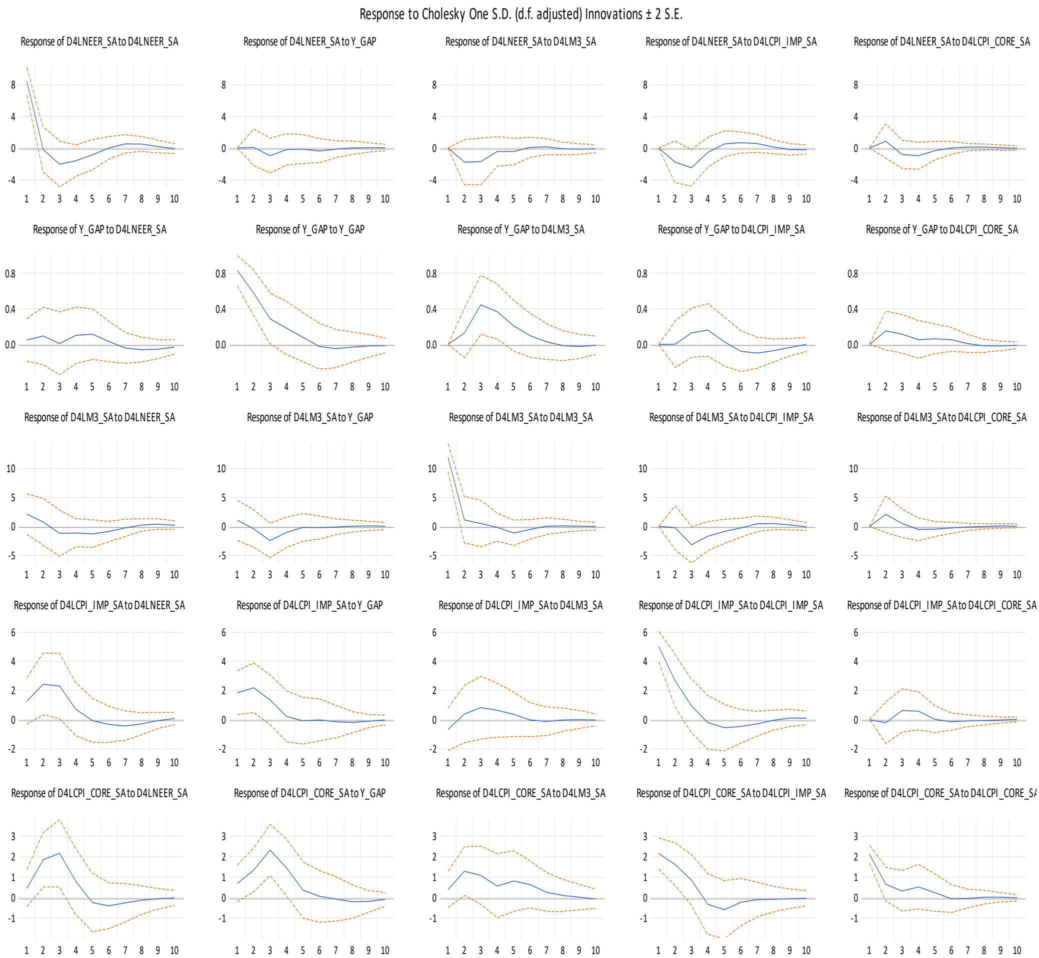
2. Impulse response model 1



3. Impulse response model 2



4. Impulse response model 3



5. Variance decomposition model 1

Variance Decomposition of D4LNEER_SA:

Period	S.E.	D4LNEER_SA	Y_GAP	D4LM3_SA	D4LCPI_IMP_SA	D4LCPI_SA
1	8.529229	100	0	0	0	0
2	9.019989	89.449	0.069744	5.292336	4.812188	0.376728
3	9.699232	80.92604	1.014311	7.301929	10.43103	0.326687
4	9.899843	80.36577	1.680517	7.165261	10.33453	0.453918
5	9.935859	80.15038	1.776631	7.114242	10.48718	0.471562
6	9.97046	79.70152	1.79858	7.065763	10.94843	0.485708
7	9.993064	79.60785	1.867507	7.033922	11.00702	0.483701
8	9.999719	79.59067	1.907556	7.024775	10.99242	0.484581
9	10.00092	79.57332	1.9179	7.023286	11.0005	0.484994
10	10.00151	79.56884	1.918256	7.023336	11.00462	0.484945

Variance Decomposition of Y_GAP:

Period	S.E.	D4LNEER_SA	Y_GAP	D4LM3_SA	D4LCPI_IMP_SA	D4LCPI_SA
1	0.827232	0.353108	99.64689	0	0	0
2	1.025193	1.02524	95.27463	0.871541	0.113741	2.714851
3	1.175453	0.819857	83.21806	13.15564	0.728593	2.077853
4	1.251546	1.086868	77.1922	16.90196	2.468529	2.350449
5	1.274574	1.480463	74.74714	18.59134	2.670963	2.510095
6	1.281733	1.515348	74.18908	19.05745	2.721675	2.516453
7	1.291024	1.580602	74.04834	18.79656	3.090371	2.484125
8	1.30141	1.830629	73.71763	18.60786	3.398344	2.445541
9	1.30753	2.028826	73.43613	18.61332	3.492404	2.429322
10	1.309308	2.087374	73.31544	18.67883	3.490105	2.428251

Variance Decomposition of D4LM3_SA:

Period	S.E.	D4LNEER_SA	Y_GAP	D4LM3_SA	D4LCPI_IMP_SA	D4LCPI_SA
1	12.48687	3.488805	2.175269	94.33593	0	0
2	12.58037	3.719552	2.210119	93.57133	0.190794	0.308208
3	12.91867	4.280901	3.200317	88.795	3.419874	0.303907
4	13.28418	5.484452	5.232205	84.03336	4.872718	0.377261
5	13.4516	6.363931	6.204461	82.04973	5.011324	0.370552
6	13.48725	6.480658	6.351204	81.81132	4.988023	0.368794
7	13.49535	6.474075	6.343591	81.79246	5.018485	0.37139
8	13.50428	6.501926	6.383849	81.6969	5.04376	0.373569
9	13.5128	6.525115	6.455176	81.59386	5.05228	0.373564
10	13.51789	6.533274	6.502919	81.53725	5.053277	0.373284

Variance Decomposition of D4LCPI_IMP_SA:

Period	S.E.	D4LNEER_SA	Y_GAP	D4LM3_SA	D4LCPI_IMP_SA	D4LCPI_SA
1	5.41921	5.400594	14.5818	3.050115	76.96749	0
2	6.984571	15.15406	21.0023	2.070253	59.42556	2.347837
3	7.574025	21.38908	22.02555	2.289909	52.29458	2.000873
4	7.651722	21.76124	21.83722	2.968169	51.47149	1.961882
5	7.681002	21.66782	21.74884	3.026516	51.60405	1.952782
6	7.728049	21.83964	21.92833	2.989873	51.31065	1.931506
7	7.758047	21.9301	22.1951	2.97523	50.98281	1.916759
8	7.768956	21.92585	22.32107	2.999634	50.84205	1.911385
9	7.772074	21.91012	22.33623	3.041545	50.80172	1.910385
10	7.773221	21.90488	22.32966	3.066613	50.78737	1.911477

Variance Decomposition of D4LCPI_SA:

Period	S.E.	D4LNEER_SA	Y_GAP	D4LM3_SA	D4LCPI_IMP_SA	D4LCPI_SA
1	3.725768	3.736831	0.271234	8.115083	35.0149	52.86195
2	5.082852	12.82377	17.93657	8.081042	29.76105	31.39756
3	6.139966	17.62139	30.84155	5.930406	24.08869	21.51796
4	6.379732	17.64661	33.14382	6.814143	22.38496	20.01046
5	6.465229	17.19405	32.94852	8.549221	21.82188	19.48633
6	6.492231	17.11873	32.67737	9.134431	21.64317	19.4263
7	6.506199	17.08801	32.73374	9.239869	21.56452	19.37386
8	6.522363	17.0403	32.97136	9.199974	21.50798	19.28039
9	6.536145	17.00833	33.12549	9.193541	21.4734	19.19924
10	6.544661	16.99612	33.15532	9.247156	21.44983	19.15157

Cholesky Ordering: D4LNEER_SA Y_GAP D4LM3_SA D4LCPI_IMP_SA D4LCPI_SA

6. Variance decomposition model 2

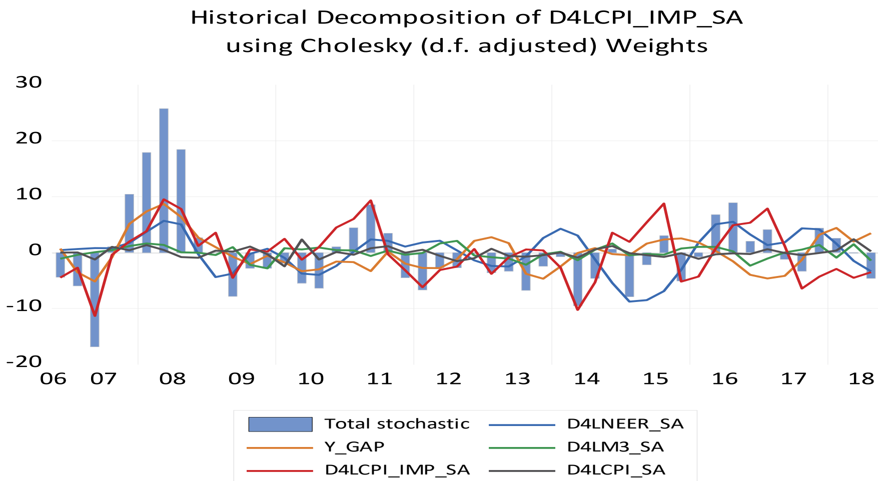
Period	S.E.	D4LNEER_SA	Y_GAP	D4LM3_SA	D4LCPI_IMP_SA	D4LCPI_DOM_SA
Variance Decomposition of D4LNEER_SA:						
Period	S.E.	D4LNEER_SA	Y_GAP	D4LM3_SA	D4LCPI_IMP_SA	D4LCPI_DOM_SA
1	8.522603	100	0	0	0	0
2	9.004096	89.63491	0.090606	5.259334	4.813401	0.201746
3	9.66271	81.4542	0.959522	7.487941	9.923148	0.175185
4	9.88683	80.67701	1.779273	7.332088	9.799858	0.41177
5	9.924707	80.43779	1.90963	7.276518	9.947512	0.428545
6	9.962932	79.93851	1.94223	7.223307	10.44918	0.446776
7	9.988348	79.83301	2.025691	7.187357	10.50615	0.447793
8	9.995895	79.8137	2.071049	7.177057	10.4903	0.447898
9	9.997192	79.79458	2.080167	7.175891	10.50111	0.448251
10	9.997937	79.78945	2.080026	7.176102	10.50615	0.44827
Variance Decomposition of Y_GAP:						
Period	S.E.	D4LNEER_SA	Y_GAP	D4LM3_SA	D4LCPI_IMP_SA	D4LCPI_DOM_SA
1	0.83251	0.410255	99.58974	0	0	0
2	1.025471	1.099237	95.68005	1.07431	0.104715	2.041688
3	1.173931	0.886399	83.13011	13.69179	0.726219	1.565485
4	1.250539	1.126565	76.78127	17.90156	2.442021	1.748579
5	1.273966	1.53296	74.27965	19.63406	2.670998	1.88233
6	1.280215	1.590434	73.7774	20.05424	2.699301	1.878619
7	1.287968	1.634014	73.65304	19.82018	3.036696	1.856073
8	1.296863	1.859233	73.32414	19.66183	3.319031	1.835771
9	1.302084	2.046606	73.05191	19.67261	3.400038	1.828843
10	1.30352	2.100617	72.94665	19.72758	3.396722	1.828434
Variance Decomposition of D4LM3_SA:						
Period	S.E.	D4LNEER_SA	Y_GAP	D4LM3_SA	D4LCPI_IMP_SA	D4LCPI_DOM_SA
1	12.5072	3.340256	1.88346	94.77628	0	0
2	12.58563	3.571316	1.953454	94.2353	0.184045	0.055885
3	12.93032	4.149929	3.021143	89.34781	3.404722	0.076398
4	13.29006	5.396683	4.991722	84.69951	4.662761	0.249326
5	13.4605	6.281852	5.960664	82.69372	4.815441	0.248323
6	13.49438	6.395893	6.076405	82.48059	4.799133	0.247983
7	13.50283	6.390134	6.069299	82.45829	4.834456	0.247817
8	13.51217	6.424037	6.111997	82.3543	4.861682	0.247988
9	13.51974	6.449281	6.172812	82.26229	4.867903	0.247713
10	13.52367	6.456549	6.208193	82.21991	4.867745	0.247599
Variance Decomposition of D4LCPI_IMP_SA:						
Period	S.E.	D4LNEER_SA	Y_GAP	D4LM3_SA	D4LCPI_IMP_SA	D4LCPI_DOM_SA
1	5.306025	5.901257	16.0324	2.79507	75.27127	0
2	6.985221	15.59431	22.38312	1.867453	56.21303	3.942093
3	7.590046	21.67239	23.24117	2.250556	49.49178	3.344099
4	7.674149	22.07451	22.90196	3.040124	48.70425	3.279154
5	7.703995	21.97881	22.81058	3.113977	48.84213	3.254505
6	7.753954	22.17031	22.96655	3.074921	48.57552	3.212706
7	7.782695	22.28258	23.18351	3.066851	48.27666	3.190398
8	7.791854	22.28435	23.2738	3.095261	48.16366	3.182928
9	7.794111	22.27176	23.27645	3.131955	48.13865	3.181191
10	7.795116	22.26956	23.27118	3.150543	48.12793	3.180785
Variance Decomposition of D4LCPI_DOM_SA:						
Period	S.E.	D4LNEER_SA	Y_GAP	D4LM3_SA	D4LCPI_IMP_SA	D4LCPI_DOM_SA
1	4.568556	1.018897	6.962107	12.04404	9.526203	70.44875
2	5.845398	9.041223	19.57479	12.55975	11.32662	47.49761
3	7.047827	12.45184	34.51829	9.293185	11.06302	32.67367
4	7.30911	12.53132	36.64809	10.02701	10.3993	30.39429
5	7.435459	12.12229	36.15636	12.29302	10.05007	29.37826
6	7.47336	12.02467	35.80426	13.03927	9.954352	29.17745
7	7.484757	11.99686	35.80585	13.16627	9.925227	29.10579
8	7.499387	11.96777	35.98142	13.1203	9.937874	28.99263
9	7.513305	11.95933	36.0896	13.10103	9.963727	28.88632
10	7.522485	11.96704	36.1	13.14075	9.974223	28.81799

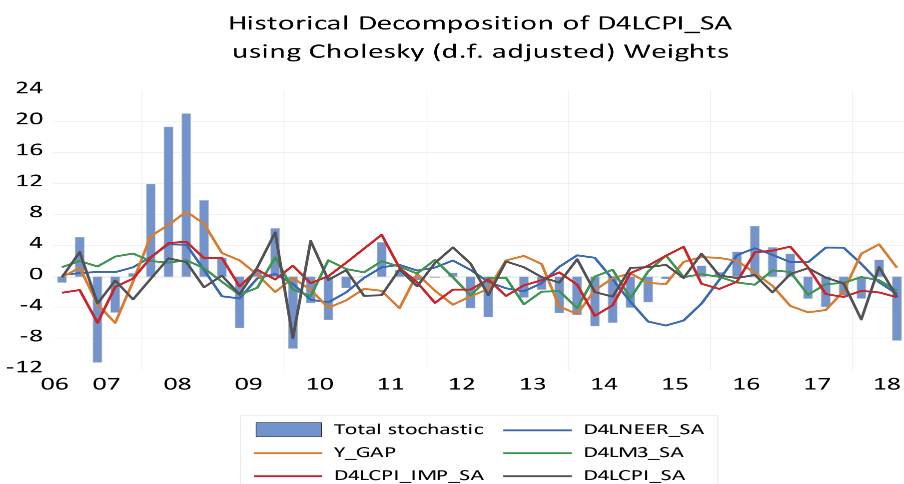
Cholesky Ordering: D4LNEER_SA Y_GAP D4LM3_SA D4LCPI_IMP_SA D4LCPI_DOM_SA

7. Variance decomposition model 3

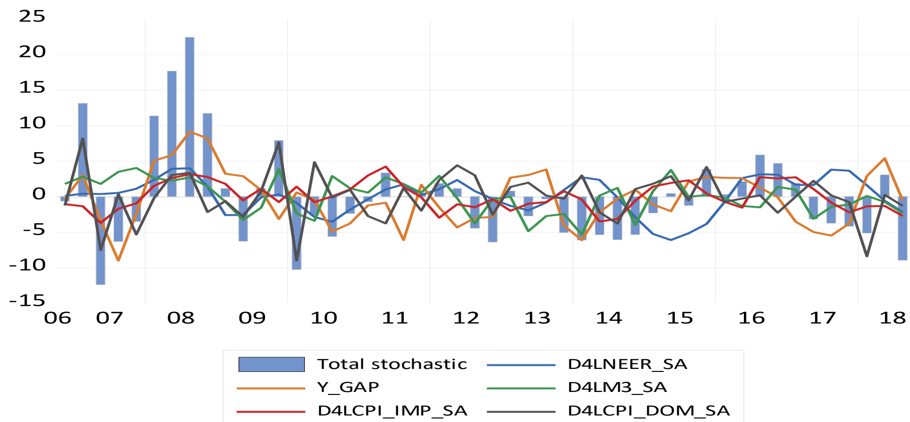
Variance Decomposition of D4LNEER_SA:						
Period	S.E.	D4LNEER_SA	Y_GAP	D4LM3_SA	D4LCPI_IMP_SA	D4LCPI_CORE_SA
1	8.453541	100	0	0	0	0
2	8.856776	91.14286	0.011058	3.933187	3.925609	0.987287
3	9.654746	81.06167	0.967994	6.443454	10.00581	1.521071
4	9.855053	80.36371	0.956999	6.378534	9.888022	2.412739
5	9.919553	80.03337	0.960555	6.492086	10.03661	2.477379
6	9.949423	79.55377	1.073982	6.463058	10.44634	2.462849
7	9.983741	79.29562	1.087933	6.445153	10.71163	2.459661
8	9.998525	79.31533	1.085863	6.431971	10.70017	2.466666
9	10.0034	79.27557	1.089345	6.446233	10.72149	2.467366
10	10.00635	79.23433	1.092514	6.452291	10.75443	2.466428
Variance Decomposition of Y_GAP:						
Period	S.E.	D4LNEER_SA	Y_GAP	D4LM3_SA	D4LCPI_IMP_SA	D4LCPI_CORE_SA
1	0.831487	0.353682	99.64632	0	0	0
2	1.036539	1.081345	95.19168	1.525265	0.000477	2.20123
3	1.177401	0.847205	79.84623	15.38192	1.225942	2.698704
4	1.262724	1.386132	71.51701	21.83086	2.731505	2.53449
5	1.28935	2.122585	68.96552	23.56536	2.675568	2.670971
6	1.297316	2.15968	68.14886	23.88508	2.991011	2.815371
7	1.302665	2.22977	67.72424	23.74626	3.500551	2.799178
8	1.306323	2.427905	67.39583	23.62487	3.751685	2.799701
9	1.308158	2.580571	67.22362	23.5896	3.79905	2.807165
10	1.308618	2.629918	67.18542	23.57909	3.796424	2.809144
Variance Decomposition of D4LM3_SA:						
Period	S.E.	D4LNEER_SA	Y_GAP	D4LM3_SA	D4LCPI_IMP_SA	D4LCPI_CORE_SA
1	12.18732	3.095197	0.784934	96.11987	0	0
2	12.457	3.373701	0.842222	92.88052	0.023956	2.879601
3	13.14718	3.809447	4.156523	83.54178	5.736787	2.755466
4	13.34368	4.365911	4.583168	81.10776	7.133738	2.809424
5	13.48161	5.118004	4.502668	80.13183	7.388713	2.858788
6	13.52395	5.491005	4.49501	79.76899	7.371972	2.873028
7	13.53444	5.511156	4.490417	79.6471	7.478351	2.872971
8	13.549	5.540331	4.484631	79.48313	7.624515	2.86739
9	13.55862	5.622958	4.48395	79.37403	7.648856	2.870205
10	13.56142	5.653816	4.484582	79.34191	7.645716	2.873974
Variance Decomposition of D4LCPI_IMP_SA:						
Period	S.E.	D4LNEER_SA	Y_GAP	D4LM3_SA	D4LCPI_IMP_SA	D4LCPI_CORE_SA
1	5.533681	5.239014	11.0307	1.506243	82.22404	0
2	6.970366	15.45718	16.76735	1.248544	66.43308	0.093837
3	7.590535	22.17862	17.28094	2.211952	57.57943	0.749066
4	7.677531	22.51259	16.96596	2.842775	56.3556	1.323079
5	7.706737	22.34823	16.85024	3.034892	56.45309	1.313555
6	7.729815	22.39747	16.7509	3.017455	56.49064	1.343533
7	7.75008	22.58323	16.69757	3.025897	56.34345	1.349848
8	7.758269	22.67567	16.72389	3.020006	56.22711	1.353321
9	7.760162	22.67008	16.73351	3.018533	56.2231	1.354781
10	7.761308	22.6736	16.72994	3.019015	56.22297	1.35448
Variance Decomposition of D4LCPI_CORE_SA:						
Period	S.E.	D4LNEER_SA	Y_GAP	D4LM3_SA	D4LCPI_IMP_SA	D4LCPI_CORE_SA
1	3.166316	2.079549	4.988979	1.622294	46.14736	45.16182
2	4.472759	18.07651	11.67986	9.089925	36.36147	24.79223
3	5.673712	25.79955	24.17781	9.36558	24.91005	15.747
4	5.967738	25.07592	27.70191	9.391998	22.79409	15.03608
5	6.071122	24.38462	27.1354	10.86245	22.94074	14.67679
6	6.122493	24.39346	26.69304	11.78717	22.68887	14.43746
7	6.134618	24.45582	26.59869	11.94185	22.619	14.38463
8	6.140469	24.45072	26.64612	11.95242	22.59144	14.3593
9	6.143581	24.43336	26.70489	11.94194	22.5741	14.34571
10	6.144491	24.42637	26.71469	11.94643	22.57082	14.34169
Cholesky Ordering: D4LNEER_SA Y_GAP D4LM3_SA D4LCPI_IMP_SA D4LCPI_CORE_SA						

8. Historical decomposition

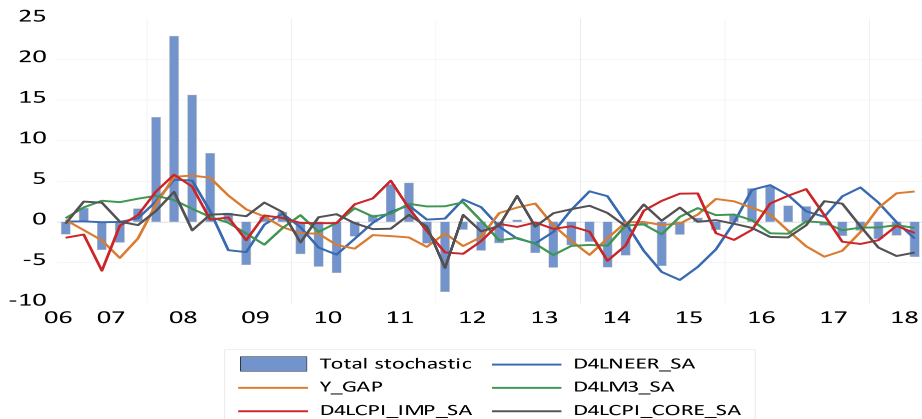




Historical Decomposition of D4LCPI_DOM_SA using Cholesky (d.f. adjusted) Weights



Historical Decomposition of D4LCPI_CORE_SA using Cholesky (d.f. adjusted) Weights



National Bank of Rwanda
KN 6 AV. 4
P.O. Box: 531 Kigali, Rwanda
Tel: (+250) 788 199 000
Email: info@bnr.rw
Swiftcode: BNRWRWRW
Twitter: @CentralBankRw
Website: www.bnr.rw