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# ESTIMATING DYNAMIC STOCHASTIC GENERAL EQUILIBRIUM MODELS FOR MONETARY POLICY ANALYSIS IN LIBERIA

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***Abstract***

The need to have a structural model which analyzes the dynamic responses of macroeconomic variables to unexpected shocks and provides an idea of what policy reaction should be is of critical importance to policy makers, especially central bankers in their design and implementation of monetary policy. In this regard, this paper estimates a structural model, the Dynamic Stochastic General Equilibrium model, to analyze monetary policy, productivity, and exchange rate shocks on inflation and output gap in Liberia. The findings reveal that monetary policy shock has a transient negative impact on output gap, productivity shock has a persistent positive impact on inflation, while exchange rate shock has a transient negative impact on output gap but a persistent positive impact on inflation. These findings provide evidence that the monetary authority should exert effort in stabilizing the exchange rate and implement monetary policy to support productivity at a level that does not cause the economy to overheat and lead to undesirable inflation.

**Keywords:** Inflation, DSGE, Monetary Policy, Forecasting, Output gap, Shock.
**JEL Codes:** C53, E31, E52

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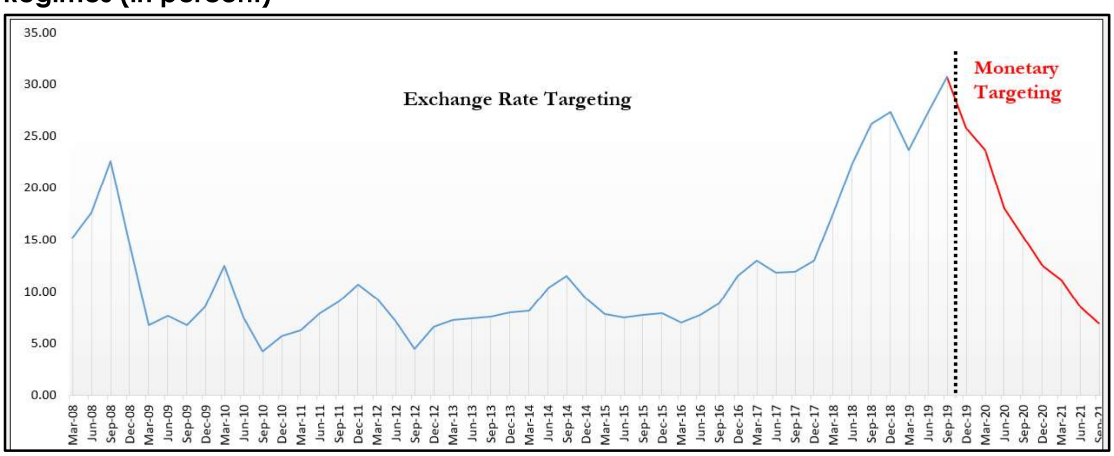
## 1.0 INTRODUCTION

Given the vital role that monetary policy plays in the macroeconomic development of countries, monetary authorities around the world have significantly improved the formulation and implementation of monetary policy as well as communication to their audience.

Over the past years, prior to November 2019, the Central of Liberia (CBL) employed an exchange rate targeting framework and largely relied on foreign exchange intervention as the major tool in implementing its monetary policy. This monetary policy tool allowed the CBL to directly mop up excess Liberian dollar liquidity from the foreign exchange market by auctioning hard currency, the United States (US) dollar, to importers and major vendors with the anticipation of restoring equilibrium to smooth out volatility in the exchange rate and narrow the exchange rate pass-through to inflation since Liberia is a highly dollarized economy as the US dollar is also used as a transaction currency.

To some extent, this approach provided short-term benefits in smoothing out volatility in the exchange rate and lowering inflation. However, the regular intervention by the Bank to sell hard currency exerted significant pressure on Liberia's gross international reserves and exposed the economy to greater risk in responding to external shocks, thereby putting significant pressure on the exchange rate and inflation.

**Figure 1: Inflation Trend Under Exchange Rate Targeting and Monetary Targeting Regimes (in percent)**




**Source**: Authors' calculation using Central Bank of Liberia's data

The limited availability of foreign exchange combined with the high cost associated with the implementation of the exchange rate targeting compelled the monetary authority to abandon this framework in favor of the monetary targeting framework which was adopted in November 2019 with the establishment of the Monetary Policy Advisory Committee (MPAC). The current framework has shown some effectiveness as evidenced by the decline in inflation from higher double digit to mid-single digit (from 30.55 percent in October 2019 to 4.42 in October 2021, Figure 1). However, the Liberian economy is still susceptible to shocks that significantly impact the conduct of monetary policy, and one of such unexpected shocks is the exchange rate shock.

The adoption of any monetary policy framework requires continuous improvements in monetary policy formulation and implementation as well as communication to the public. Like many central banks, the CBL provides an overview of Liberia's macroeconomic outlook and policy strategy to the public. Behind the scenes, this process involves the conduct of advanced macroeconomic analyses, informed by macroeocnometric models (such as Autoregressive Integrated Moving Average and Vector autoregressive models) and analytical tools to forecast and simulate policy responses. However, traditional macroeocnometric models have received strong criticisms, due to the lack of an optimization-based approach to the development of these models, as their parameters are not invariant to policy changes and other structural changes (Lucas, 1976 and Sargent, 1981).

Given this criticism, several structural models have been developed to address this shortcoming of relying on just traditional macroeconometric models for policy analysis and forecasting. This development has ensured that central banks have a suite of models at their disposal for policy analysis and forecasting. One of such structural models is the Dynamic Stochastic General Equilibrium (DSGE) model which has been mainly popularized in two strands of the literature: the Real Business Cycle framework which assumes flexible prices (Kydland and Prescott, 1982 and 1990) and the New-Keynesian framework which assumes price rigidities (Rotemberg and Woodford, 1997) and provides microeconomic foundations for Keynesian concepts (Gali and Gertler, 2007).

DSGE models are backed by fundamental macroeconomic and microeconomic theories, emphasizing the intertemporal choice for economic agents. In DSGE models, current choices are dependent on future uncertainties. The outcome of this dependence renders the models dynamic, thereby, assigning a key role to agents' expectations in determining current macroeconomic outcomes. The general equilibrium nature of DSGE models captures the interaction between agents' behavior and policy actions. The potential and robustness of DSGE models in analyzing policy make them appealing to policymakers (Sbordone et al. 2010). According to Coletti and Murchison (2002), DSGE models are useful for monetary policy practices in that they can help to identify sources of fluctuations, answer questions about structural changes, generate forecasts, predict the effects of policy changes, and perform counterfactual experiments. DSGE models offer a concise framework for policy analysis and forecasting. Additionally, the models can be used to effectively conduct business cycle analysis, and they help to identify sources of variations while forecasting the impact of policy changes.

Considering the plausible features of DSGE models and the additional benefits they offer in terms of accounting for shocks in policy analysis and forecasting, this paper estimates New Keynesian DSGE models for Liberia to inform monetary policy formulation and implementation by the CBL. In the baseline model, the impacts of monetary policy and productivity shocks on key macroeconomic variables are analyzed. In order to analyze the impacts of exchange rate shock on the macroeconomy and how the CBL should respond, another model is estimated considering exchange rate shock in addition to the two shocks previously mentioned. Quarterly data on output, consumer price index, monetary policy rate and exchange rate for the period 2007Q1 to 2021Q2 are used.

The rest of the paper is structured as follows: section two provides the methodology and data used; section three presents the empirical results and analysis; while section four concludes the papers and presents policy recommendations.

## 2.0 METHODOLOGY AND DATA

### 2.1 Model

To assess the impacts of monetary policy and productivity shocks on inflation and output gap, this paper utilizes, as its theoretical foundation, the linearized version of the DSGE model presented by Woodford (2003, Chapter 4). The DSGE model consists of a suite of equations derived from economic theories, and therefore, has directly interpretable parameters. The model utilized in this paper consists of three equations that describe the behavior of households, firms, and central bank as specified in equations 1, 2 and 3, respectively. Details on the nonlinear DSGE model and the derivation of the equations are reported in the Appendix.

Equation 1 presents a Phillips Curve generated from optimization by firms (linearized form of eq. A1 in the appendix). The equation is in fact referred to as the New Keynesian Phillips Curve (NKPC) based on the Calvo (1983) and Taylor (1980) staggered-contracts models (see Roberts, 1995). The equation specifies inflation ($p_t$) as a linear combination of future inflation ($p_{t+1}$) and the output gap ($x_t$). The parameter kappa ($k$) measures how responsive inflation is to excess demand in the economy and should have a positive sign. The parameter $\beta$ captures inflation expectations.

$$p_t = \beta E_t p_{t+1} + k x_t \tag{1}$$

Household optimization gives rise to the Euler equation in 2 (linearized form of eq. A2 in the Appendix) which specifies output gap as a linear combination of future output gap ($x_{t+1}$), nominal interest rate ($r_t$), and a state variable ($g_t$) which captures changes in the natural level of output (see Appendix for derivation of $g_t$)

$$x_t = E_{t+1} x_{t+1} - (r_t - E_t p_{t+1} - g_t) \tag{2}$$

The central bank's monetary policy rule is presented in equation (3) (linearized form of eq. A3 in the Appendix) which specifies interest rate as a linear combination of inflation and a state variable ($u_t$) that captures movements in the interest rate that are not driven by inflation. The parameter $\frac{1}{\beta}$ captures the degree to which the central bank responds to movements in inflation.

$$r_t = \frac{1}{\beta} p + u_t \tag{3}$$

To complete the model, both state variables, $u_t$ and $g_t$ are modeled as first-order autoregressive processes in equations 4 and 5, respectively

$$\mu_{t+1} = \rho_u \mu_t + \epsilon_{t+1} \tag{4}$$

$$g_{t+1} = \rho_g g_t + \varepsilon_{t+1} \tag{5}$$

where $\epsilon_{t+1}$ is the shock to the state variable $u_t$ (monetary policy shock); and $\varepsilon_{t+1}$ is the shock to the state variable $g_t$ (productivity shock).

To estimate the model specified above, a Maximum Likelihood estimator is employed using Stata 16.

### 2.2 Data

The paper utilizes quarterly data on monetary policy rate, inflation, and exchange rates for the period 2007Q1 to 2021Q2. Inflation is measured by the change in consumer price index (CPI). The exchange rate variable is measured as units of local currency per a unit of foreign currency, the US dollars, thus, a negative rate of change would imply an appreciation of the domestic currency. Data on these variables were obtained from the Central Bank of Liberia.

## 3.0 EMPIRICAL RESULTS AND ANALYSIS

This section presents the empirical results and analyzes the dynamic responses of macroeconomic variables to unexpected shocks to monetary policy, productivity, and exchange rate. It also provides suggestions on what should be the appropriate responses by policymakers at the central bank. Additionally, the section reports short-term forecasts for both inflation and monetary policy rates.

As a preliminary exercise, two models (one unrestricted and the other restricted) are estimated to select the best fit model for the data. In the restricted model, the value for the parameter beta is constrained at 0.5, implying that about 50 percent of agents set prices considering future prices. The preferred model is chosen based on the root mean squares error (RMSE) and forecast performance. Based on these criteria, the unrestricted model is chosen as the preferred model because it has lower RMSE and better projections for the forecast period. Hence, the analysis that follows is based on results from the unrestricted model.

In the structural matrix reported in Table 1, beta is statistically significant and has a value of 0.55, implying that about 55 percent of the economic agents in the Liberian economy set their prices considering future inflation. Thus, it is possible for the CBL to reduce the inflation rate by an appropriate monetary policy stance. The inverse of beta shows that for a percent increase in inflation, the CBL should adjust its policy rate by about 1.8 percentage points.

The policy matrix of the unrestricted model reports the initial impulse responses and is presented in Table 2 column 2. The result shows no significant impact of a unit shock to the state variable $u_t$ (monetary policy shock) on inflation. This finding is in line with Leeper et al. (1996) assumption that price is not affected in the impact period of monetary policy shock. However, a unit shock to the state variable $u_t$ increases monetary policy rate (MPR) by about 0.92 percent. These findings possibly imply a weak transmission mechanism that is likely due to the underdeveloped nature of the financial markets in Liberia. The results also show that a unit shock to the state variable $g_t$ (productivity shock) has no significant impact on output gap and inflation in the initial period.

Additionally, the findings show an inverse and significant relationship between monetary policy shock and output gap. That is, a unit shock to the state variable ($u_t$) reduces output gap by an estimated 2.29 percent. This inverse relationship aligns with arguments in the macroeconomic literature that an increase in the rate of interest resulting from the monetary policy shock as discussed earlier reduces output (see for example, Christiano, Eichenbaum and Evans, 1999). It is important to note that monetary policy shock significantly impacts output and not inflation, thus, suggesting the structural nature of inflation in Liberia.

The results of the impulse response functions (IRFs) further reveal that the response of output gap to monetary policy shock is transient, thus, indicating that the effect of unexpected changes in monetary policy on output is short-lived. Conversely, the impact of productivity shock on inflation seems to be persistent over time, highlighting the structural nature of inflation in Liberia.

The forecast values for inflation and monetary policy rate are reported in Table 3. The forecasts are realistic and supported by previous univariate time series models forecast produced. According to the forecast, inflation is expected to remain in single digit up to the last half of 2021 but is expected to marginally rise to about 8.9 percent in the fourth quarter of 2021. In contrast, the forecast for the monetary policy rate shows a downward trend but remains in double-digit.

**Table 1: Structural Matrices**

| Variables | Unrestricted | Restricted |
|---|---|---|
| beta | 0.551*** | 0.500 |
| | (0.0788) | (0) |
| kappa | 0.0133 | 0.0358 |
| | (0.0403) | (0.0337) |
| rhou | 0.587*** | 0.601*** |
| | (0.115) | (0.113) |
| rhog | 0.897*** | 0.895*** |
| | (0.0535) | (0.0538) |
| 1/beta | 1.8143*** | |
| | (0.2593) | |
| sd (e.u) | 3.847*** | 3.919*** |
| | (0.373) | (0.377) |
| sd (e.g) | 11.86 | 6.542 |
| | (28.35) | (4.294) |
| Obs. | 54 | 54 |

**Source**: Authors' calculation using Central Bank of Liberia's data

Note: a) *** indicates that parameter estimates are statistically significant at 10%, 5% and 1% level of significance. b) The structural matrix presents results of the estimated structural model which specifies the theoretical relationship among the set of variables.

**Table 2: Policy Matrices**

| Variables | | Unrestricted | Restricted |
|---|---|---|---|
| **Inflation** | | | |
| | u | -0.0449 | -0.1090 |
| | | (0.1248) | (0.0794) |
| | g | 0.2058 | 0.3678 |
| | | (0.4896) | (0.2379) |
| **Output Gap** | | | |
| | u | -2.2890*** | -2.1265*** |
| | | (0.7673) | (0.6944) |
| | g | 7.8436 | 5.6679*** |
| | | (5.7448) | (2.83118 |
| **MPR** | | | |
| | u | 0.9185*** | 0.7820*** |
| | | (0.2353) | (0.1589) |
| | g | 0.3734 | 0.7355 |
| | | (0.9272) | (0.4758) |
| **Obs.** | | **54** | **54** |

**Source**: Authors' calculation using Central Bank of Liberia's data
Note: a) *** indicates that parameter estimates are statistically significant at 1% level of significance.
b) The policy matrix is part of the state-space form of the DSGE model. It specifies the model's control variables as a function of the model's state variables.

**Table 3: Two-Period Ahead Quarterly Forecast for Monetary Policy Rate and Inflation**

| | 2021Q3 | 2021Q4 | Confidence Interval |
|---|---|---|---|
| MPR | 21.76 | 20.04 | [16.0160 28.5192] |
| Inflation | 8.55 | 8.92 | |

**Source**: Authors' calculation using CBL's data
Note: Inflation does not have confidence interval for its forecast because of zero standard deviation

### 3.1 Additional Analysis

This section provides additional analysis to support the findings from the baseline estimation by incorporating exchange rate shock in the unrestricted model. To do this, the Phillips curve in Equation 1 is modified as follows:

$$p_t = \beta E_t p_{t+1} + kx_t + \psi es_t \tag{6}$$

where $es_t$ is a state variable capturing movements in inflation not driven by the exchange rate. To ensure that the model is solvable, another equation is specified linking the unobserved state variable $es_t$ to the growth rate of the exchange rate, $e_t$, which is an observed exogenous variable:

$$e_t = es_t \tag{7}$$

To complete the model, a first-order autoregressive process for the unobserved state variable $es_t$ is specified:

$$es_{t+1} = \rho_e es_t + \eta_{t+1} \tag{8}$$

where $\eta_{t+1}$ is the shock to state variable $es_t$ (exchange rate shock).

The results of the structural and policy matrices of the estimated model are reported below in Tables 4 & 5, respectively. The results of the structural matrix of this model with exchange rate shock is similar to those of the baseline unrestricted model in terms of the sign and magnitude of the estimated parameters, excluding the estimates of the new parameter and standard deviation characterizing the exchange rate shock.

The results of the policy matrix in Table 5 show that the impacts of monetary policy and productivity shocks on inflation are not significant in the initial period. However, a unit shock to the state variable $es_t$ (exchange rate shock) is found to increase inflation by 0.27 percent, thus, implying that $es_t$ has greater passthrough to inflation compared to shocks to $u_t$ and $g_t$. This result of exchange rate shock increasing inflation corroborates the findings of Billmeier and Bonato (2004) on the impact of exchange rate shock on inflation in Croatia.

Additionally, all the state variables ($u_t, g_t$ & $es_t$) are found to have significant impacts on output gap. While a unit shock to the state variables $u_t$ reduces output by 2.44 percent, a unit shock to state variable $g_t$ increases output gap by about 7.5 percent. A shock to state variable $es_t$ reduces output by 3.35 percent. Interestingly, it is worth highlighting that the significant negative impact of exchange rate shock on output gap signals the high degree of import dependence of the Liberian economy. Depreciation of the Liberian dollars as a result of the exchange rate shock makes imports expensive for individuals and businesses mainly transacting in Liberian dollars in the economy. The negative impact of depreciation on output gap is consistent with findings from previous studies (see, for example, Ahmed, 2003; Kandil, 2004).

In terms of the impacts of shocks on the monetary policy rate, exchange rate shock is found to positively impact monetary policy rate in the initial period, implying that exchange rate depreciation occasions monetary tightness by increasing policy rate. A unit shock to state variable $es_t$ causes a 0.47 percent increase in the monetary policy rate. Also, the impact of monetary shock on the monetary policy rate is higher (at about 0.99 percent for a one-unit monetary policy shock).

**Table 4**: **Structural Matrix with Exchange Rate Shock**

| **Variables** | **Coefficients (Standard Errors)** |
|---|---|
| beta | 0.5735*** |
| | (0.0564) |
| kappa | 0.0000 |
| | (0.0001) |
| psi | 0.1245*** |
| | (0.0369) |
| rhou | 0.5907*** |
| | (0.1147) |
| rhog | 0.8663*** |
| | (0.0637) |
| rho_e | 0.9353*** |
| | (0.0492) |
| $1/beta$ | 1.7438*** |
| | (0.2593) |
| sd (e.u) | 3.8406*** |
| | (0.3696) |
| sd (e.g) | 5954.22 |
| | (32713.59) |
| sd(e.es) | 4.0964 |
| | (0.3952) |
| Obs. | 54 |

**Source**: Authors' calculation using Central Bank of Liberia's data
Note: a) *** indicates that parameter estimates are statistically significant at 10%, 5% and 1% level of significance. b) The structural matrix presents results of the estimated

structural model which specifies the theoretical relationship among the set of variables.

**Table 5**: **Policy Matrix with Exchange Rate Shock**

| Variables | | Coefficients (Standard Errors) |
|---|---|---|
| **Inflation** | | |
| | u | -0.0001 |
| | | (0.0005) |
| | g | 0.0004 |
| | | (0.0020) |
| | es | 0.2684*** |
| | | (0.0715) |
| **Output Gap** | | |
| | u | -2.4429*** |
| | | (0.6848) |
| | g | 7.4768** |
| | | (3.5602) |
| | es | -3.3554** |
| | | (2.6104) |
| **MPR** | | |
| | u | 0.9998*** |
| | | (0.0009) |
| | g | 0.0006 |
| | | (0.0035) |
| | es | 0.4681*** |
| | | (0.1330) |
| **Obs.** | | **54** |

**Source**: Authors' calculation using Central Bank of Liberia's data
Note: a) *** indicates that parameter estimates are statistically significant at 1% level of significance.
b) The policy matrix is part of the state-space form of the DSGE model. It specifies the model's control variables as a function of the model's state variables.

Results of the impulse response functions show that the impact of monetary policy shock on output gap is transient and significant up to three quarters whereas the impact of monetary policy shock on monetary policy rate persists up to the fifth quarter. The impacts of productivity shock on inflation and monetary policy rate are positive and persistent over the 8-quarter horizon. Exchange rate shock has persistent positive impacts on price and monetary policy rate over the 8-quarter horizon but negative impact on output gap up to the fifth quarter.

## 4.0 CONCLUSION AND POLICY RECOMMENDATIONS

This paper is focused on estimating DSGE models for analyzing the impacts of monetary policy, productivity, and exchange rate shocks on key macroeconomic variables: inflation, output, and monetary policy rate. In the baseline model, the impacts of monetary policy and productivity shocks are analyzed. The findings show that, in the initial period, monetary policy shock impacts monetary policy rate but does not impact inflation and output gap. However, over the horizon (eight quarters), monetary policy shock is found to have a short-lived negative impact on output gap (up to the third quarter). Also, productivity shock is found to have a persistent positive impact on inflation over the full horizon, implying the structural nature of inflation in Liberia.

In the extended model which incorporates exchange rate shock, in the initial period, a shock to exchange rate is found to have a positive impact on inflation, whereas monetary policy and productivity shocks have no impact on inflation. However, results from impulse response functions show that the positive impact of productivity shock on inflation is permanent and lasts over the eight quarters. In terms of the impacts of shocks on output gap in the initial period, both monetary policy and exchange rate shocks have negative impacts while productivity shock has a positive impact. Over the horizon, monetary policy and exchange rate shocks have short-lived negative impacts on output gap (three quarters and four quarters, respectively). Additionally, monetary policy and exchange rate shocks positively impact MPR in the initial period whereas productivity shock has no impact. Over the horizon, productivity and exchange rate shocks have positive impacts on MPR for the entire eight quarters, while monetary policy shock positively impacts MPR up to the fifth quarter.

The finding that monetary policy shock induces monetary policy tightness through increase in the policy rate but does not impact inflation implies a weak monetary policy transmission mechanism possibly resulting from underdeveloped financial markets in Liberia. Thus, this paper recommends that that CBL works with relevant stakeholders (mainly the national government through the Ministry of Finance and Development Planning) to develop the financial markets which will enhance the monetary policy transmission mechanism.

In addition, given the finding that exchange rate shock negatively impacts output gap while productivity shock increases the gap, the paper recommends that the CBL should endeavor to stabilize the exchange rate in a tolerable range and implement conducive monetary policy to support productivity (development finance) at a level that does not cause the economy to overheat and lead to undesirable inflation which undermines its main objective (price stability).

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## Appendix

### Derivation of Non-Linear DSGE Model

The following non-linear DSGE model capturing the behaviors of firms, households and the central bank is based on the work by Woodford (2003).

*Optimization by firms* generates equation (A1) linking current deviation of inflation from its steady state, $\pi_t - \pi$, to the expected value of the deviation of inflation from its steady state in the future, $E_t(\pi_{t+1} - \pi)$, and to the ratio of actual output, $Y_t$, to the natural level of output, $Z_t$.

$$(\pi_t - \pi) + \frac{1}{\phi} = \phi\left(\frac{Y_t}{Z_t}\right) + \beta E_t(\pi_{t+1} - \pi) \qquad \text{(A1)}$$

*Optimization by households* results into equation (A2) which links current output $Y_t$ to future output, $Y_{t+1}$, expected inflation $\pi_{t+1}$ and current nominal interest rate $R_t$.

$$\frac{1}{Y_t} = \beta E_t\left(\frac{1}{Y_{t+1}}\frac{R_t}{\pi_{t+1}}\right) \qquad \text{(A2)}$$

Equation (A3) describes the *central bank monetary policy rule* which shows how the central bank adjusts the interest rate in response to inflation and other factors not modeled.

$$\frac{R_t}{R} = \left(\frac{\pi_t}{\pi}\right)^{1/\beta} U_t \qquad \text{(A3)}$$

The state variables $U_t$ captures all movements in interest rate not occasioned by inflation, while $R$ is the steady-state value of interest rate.

Following Woodford (2003), the model in (A1) to (A3) is respecified by defining $X_t = Y_t/Z_t$ as the output gap.

$$(\pi_t - \pi) + \frac{1}{\phi} = \phi(X_t) + \beta E_t(\pi_{t+1} - \pi) \qquad \text{(A4)}$$

$$1 = \beta E_t\left(\frac{X_t}{X_{t+1}}\frac{1}{G_t}\frac{R_t}{\pi_{t+1}}\right) \qquad \text{(A5)}$$

$$\frac{R_t}{R} = \left(\frac{\pi_t}{\pi}\right)^{1/\beta} U_t \qquad \text{(A6)}$$

where $G_t = Z_{t+1}/Z_t$ is a state variable capturing changes in the natural level of output, $Z_t$.

**Table A1. Impulse Response Function**

| | **1** | | | **2** | | |
|---|---|---|---|---|---|---|
| **Step** | **irf** | **Lower** | **Upper** | **irf** | **Lower** | **Upper** |
| 0 | -8.8056 | -11.8048 | -5.8064 | -0.1728 | -0.6519 | 0.3063 |
| 1 | -5.1708 | -7.8275 | -2.5140 | -0.1015 | -0.3830 | 0.1800 |
| 2 | -3.0363 | -5.1560 | -0.9166 | -0.0596 | -0.2258 | 0.1066 |
| 3 | -1.7830 | -3.3638 | -0.2022 | -0.0350 | -0.1336 | 0.0636 |
| 4 | -1.0470 | -2.1747 | 0.0807 | -0.0205 | -0.0793 | 0.0382 |
| 5 | -0.6148 | -1.3948 | 0.1652 | -0.0121 | -0.0472 | 0.0231 |
| 6 | -0.3610 | -0.8884 | 0.1664 | -0.0071 | -0.0282 | 0.0140 |
| 7 | -0.2120 | -0.5626 | 0.1386 | -0.0042 | -0.0169 | 0.0085 |
| 8 | -0.1245 | -0.3544 | 0.1054 | -0.0024 | -0.0101 | 0.0052 |
| | **3** | | | **4** | | |
| **Step** | **irf** | **Lower** | **Upper** | **irf** | **Lower** | **Upper** |
| 0 | 93.0163 | -178.9620 | 364.9940 | 2.4407 | 2.2052 | 2.6762 |
| 1 | 83.3972 | -160.4720 | 327.2670 | 2.1883 | 1.9455 | 2.4311 |
| 2 | 74.7729 | -143.9830 | 293.5290 | 1.9620 | 1.6686 | 2.2554 |
| 3 | 67.0405 | -129.2690 | 263.3500 | 1.7591 | 1.4097 | 2.1085 |
| 4 | 60.1077 | -116.1300 | 236.3460 | 1.5772 | 1.1794 | 1.9750 |
| 5 | 53.8918 | -104.3910 | 212.1750 | 1.4141 | 0.9787 | 1.8495 |
| 6 | 48.3187 | -93.8953 | 190.5330 | 1.2679 | 0.8054 | 1.7303 |
| 7 | 43.3219 | -84.5052 | 171.1490 | 1.1367 | 0.6567 | 1.6168 |
| 8 | 38.8419 | -76.0985 | 153.7820 | 1.0192 | 0.5297 | 1.5087 |

68% lower and upper bounds reported

(1) irfname = model1, impulse = u, and response = x

(2) irfname = model1, impulse = u, and response = p

(3) irfname = model1, impulse = g, and response = x

(4) irfname = model1, impulse = g, and response = p

**Source**: Authors' calculation using CBL's data

**Table A2: Robustness Check for Interval Estimate for MPR. One-Sample t-test**

| | Obs. | Mean | Std. Err | Std. Dev | [68% Conf. Interval] | |
|---|---|---|---|---|---|---|
| X | 3 | 22.26762 | 1.452966 | 2.516611 | 16.01601 | 28.51923 |

| | |
|---|---|
| Mean = mean (x) | t = 4.3027 |

Ho: mean = 16.01601 degrees of freedom = 2

| | | |
|---|---|---|
| Ha: mean < 16.01601 | Ha: mean! = 16.01601 | Ha: mean > 16.01601 |
| Pr (T<t) = 0.9750 | Pr (\|T\| >\|t\|) = 0.0500 | Pr (T>t) = 0.0250 |

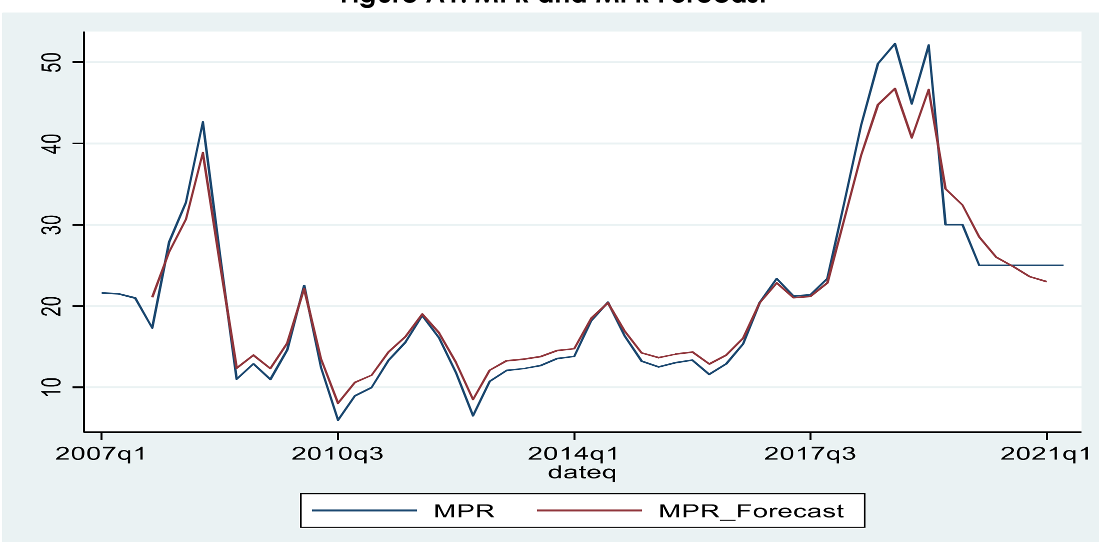
**Source**: Authors' calculation using Central Bank of Liberia's data

**Table A3: Quarterly Forecast for Monetary Policy Rate, Inflation & Exchange Rate of Change**

| | 2021Q3 | 2021 Q4 | Confidence Interval |
|---|---|---|---|
| MPR | 21.08 | 18.86 | |
| Inflation | 8.11 | 8.16 | |
| Rate of Change in Exchange Rate appreciation (-)/depreciation (+) | - 13.0096 | - 11.7237 | |

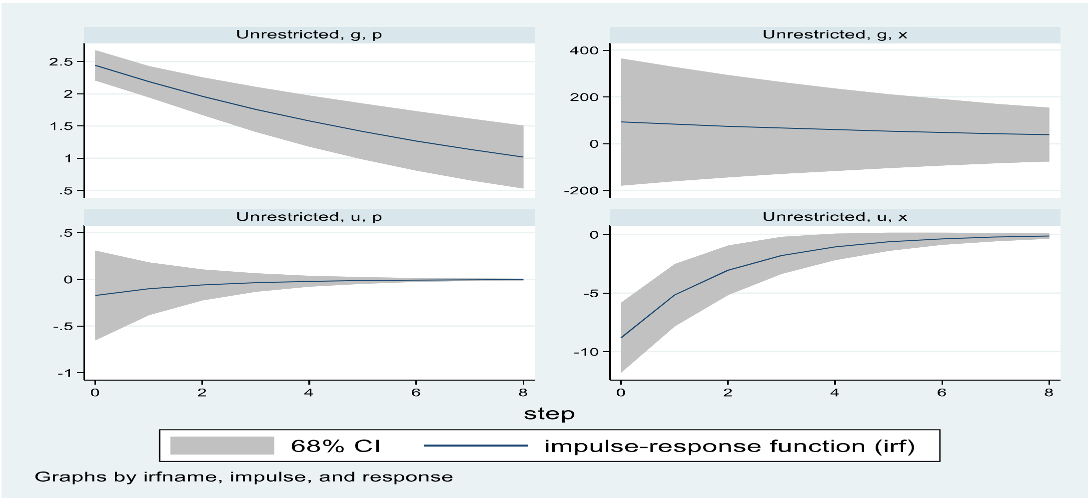
**Source**: Authors' calculation using Central Bank of Liberia's data

**Figure A1: MPR and MPR Forecast**




**Source:** Authors' construction using CBL's data

**Figure A2: Impulse Response Functions**




**Source:** Authors' construction using CBL's data

**Table A4: Impulse Response Functions**

| | 1 | | | 2 | | |
|---|---|---|---|---|---|---|
| **Step** | **irf** | **Lower** | **Upper** | **irf** | **Lower** | **Upper** |
| 0 | -9.3821 | -12.1303 | -6.6339 | -0.0004 | -0.0023 | 0.0016 |
| 1 | -5.5419 | -8.2003 | -2.8836 | -0.0002 | -0.0013 | 0.0009 |
| 2 | -3.2736 | -5.4672 | -1.0800 | -0.0001 | -0.0008 | 0.0006 |
| 3 | -1.9337 | -3.6000 | -0.2674 | -0.0001 | -0.0005 | 0.0003 |
| 4 | -1.1422 | -2.3460 | 0.0616 | 0.0000 | -0.0003 | 0.0002 |
| 5 | -0.6747 | -1.5157 | 0.1663 | 0.0000 | -0.0002 | 0.0001 |
| 6 | -0.3985 | -0.9721 | 0.1750 | 0.0000 | -0.0001 | 0.0001 |
| 7 | -0.2354 | -0.6196 | 0.1488 | 0.0000 | -0.0001 | 0.0000 |
| 8 | -0.1391 | -0.3928 | 0.1147 | 0.0000 | 0.0000 | 0.0000 |
| | **3** | | | **4** | | |
| **Step** | **irf** | **Lower** | **Upper** | **irf** | **Lower** | **Upper** |
| 0 | 3.8400 | 3.4724 | 4.2075 | 44518.3000 | -198640.0000 | 287676.0000 |
| 1 | 2.2682 | 1.7833 | 2.7532 | 38566.0000 | -172201.0000 | 249333.0000 |
| 2 | 1.3398 | 0.8091 | 1.8706 | 33409.5000 | -149313.0000 | 216132.0000 |
| 3 | 0.7914 | 0.3281 | 1.2548 | 28942.5000 | -129496.0000 | 187381.0000 |
| 4 | 0.4675 | 0.1044 | 0.8306 | 25072.8000 | -112333.0000 | 162479.0000 |
| 5 | 0.2761 | 0.0086 | 0.5436 | 21720.4000 | -97465.6000 | 140906.0000 |
| 6 | 0.1631 | -0.0263 | 0.3525 | 18816.3000 | -84583.9000 | 122216.0000 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 7 | 0.0964 | -0.0341 | 0.2268 | 16300.5000 | -73420.1000 | 106021.0000 |
| 8 | 0.0569 | -0.0311 | 0.1449 | 14121.0000 | -63742.9000 | 91985.0000 |

| | **5** | | | **6** | | |
|---|---|---|---|---|---|---|
| **Step** | **irf** | **Lower** | **Upper** | **irf** | **Lower** | **Upper** |
| 0 | 2.1878 | 1.9783 | 2.3973 | 3.8151 | 3.2927 | 4.3374 |
| 1 | 1.8953 | 1.6716 | 2.1189 | 3.3050 | 2.7984 | 3.8116 |
| 2 | 1.6418 | 1.3605 | 1.9232 | 2.8631 | 2.2981 | 3.4281 |
| 3 | 1.4223 | 1.0873 | 1.7574 | 2.4803 | 1.8476 | 3.1129 |
| 4 | 1.2322 | 0.8578 | 1.6065 | 2.1487 | 1.4629 | 2.8345 |
| 5 | 1.0674 | 0.6683 | 1.4665 | 1.8614 | 1.1420 | 2.5808 |
| 6 | 0.9247 | 0.5133 | 1.3361 | 1.6125 | 0.8779 | 2.3471 |
| 7 | 0.8011 | 0.3873 | 1.2149 | 1.3969 | 0.6625 | 2.1313 |
| 8 | 0.6940 | 0.2855 | 1.1024 | 1.2101 | 0.4881 | 1.9321 |

| | **7** | | | **8** | | |
|---|---|---|---|---|---|---|
| **Step** | **irf** | **Lower** | **Upper** | **irf** | **Lower** | **Upper** |
| 0 | -13.7452 | -24.3773 | -3.1132 | 1.0995 | 0.7896 | 1.4094 |
| 1 | -12.8563 | -23.4036 | -2.3090 | 1.0284 | 0.7349 | 1.3219 |
| 2 | -12.0248 | -22.4613 | -1.5884 | 0.9619 | 0.6750 | 1.2488 |
| 3 | -11.2472 | -21.5488 | -0.9456 | 0.8997 | 0.6125 | 1.1869 |
| 4 | -10.5198 | -20.6650 | -0.3746 | 0.8415 | 0.5496 | 1.1334 |
| 5 | -9.8394 | -19.8091 | 0.1303 | 0.7871 | 0.4882 | 1.0860 |
| 6 | -9.2031 | -18.9806 | 0.5744 | 0.7362 | 0.4295 | 1.0429 |
| 7 | -8.6079 | -18.1787 | 0.9629 | 0.6886 | 0.3743 | 1.0029 |
| 8 | -8.0512 | -17.4032 | 1.3008 | 0.6440 | 0.3229 | 0.9652 |

| | **9** | | |
|---|---|---|---|
| **Step** | **irf** | **Lower** | **Upper** |
| 0 | 1.9173 | 1.3453 | 2.4894 |
| 1 | 1.7933 | 1.2523 | 2.3344 |
| 2 | 1.6774 | 1.1509 | 2.2039 |
| 3 | 1.5689 | 1.0451 | 2.0927 |
| 4 | 1.4674 | 0.9385 | 1.9963 |
| 5 | 1.3725 | 0.8343 | 1.9107 |
| 6 | 1.2838 | 0.7344 | 1.8331 |
| 7 | 1.2007 | 0.6402 | 1.7613 |
| 8 | 1.1231 | 0.5524 | 1.6938 |

68% lower and upper bounds reported

(1) irfname = model2, impulse = u, and response = x
(2) irfname = model2, impulse = u, and response = p
(3) irfname = model2, impulse = u, and response = r
(4) irfname = model2, impulse = g, and response = x
(5) irfname = model2, impulse = g, and response = p
(6) irfname = model2, impulse = g, and response = r
(7) irfname = model2, impulse = e, and response = x
(8) irfname = model2, impulse = e, and response = p
(9) irfname = model2, impulse = e, and response = r

**Figure A3: Impulse Response Functions (Model with Exchange Rate Shock)**