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ESTIMATING DYNAMIC STOCHASTIC GENERAL EQUILIBRIUM MODELS FOR MONETARY POLICY ANALYSIS IN LIBERIA: AN EXTENSION USING BAYESIAN APPROACH

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Abstract

This paper employs the Bayesian Dynamic Stochastic General Equilibrium (DSGE) estimation technique to model the impact of monetary policy, demand, and productivity shocks on key macroeconomic indicators (output gap and inflation) in Liberia from 2007Q1 to 2021Q4. The findings indicate that the impact of monetary policy shock on inflation is negative and short-lived over the eight-quarter horizon, consistent with traditional macroeconomic views and existing literature. Also, the findings reveal that the impact of productivity shock on inflation and output gap in Liberia is positive and transient. This paper further shows that demand shock has a transient positive impact on inflation with a negative transient impact on output. Additionally, the findings show that the central bank is more responsive to productivity shock relative to monetary policy and demand shocks because it has larger effect on inflation.

Keywords: DSGE, Monetary Policy, Output Gap, Inflation, Shock
JEL Codes: C51, E31, E52

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Disclaimer: The views and opinions herein expressed are those of the authors. They do not necessarily represent the views of the Management of the Central Bank of Liberia.

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1.0 INTRODUCTION

Monetary policy is crucial for ensuring macroeconomic and financial stability in any economy. Hence, central banks endeavor to continuously improve the formulation, implementation, and communication of its policy measures, while considering the potential effects of shocks. Whether exogenous or endogenous, shocks can lead to a distortion in the real business cycles, often inducing policymakers to implement policies to avert or minimize the effects that they could have on economic activity. Interestingly, there is abundance of literature on shocks analysis and their impacts on macroeconomic variables. For example, Gambetti et al. (2022) argue that variations in the transmission and propagation of shocks over time are firmly associated with variations in the conduct of monetary policy. Thus, shocks have the propensity to influence the expectation about future economic conditions which tend to affect variations in present economic activity. Hence, investigating the transmission of shocks, especially interest rate, productivity, and monetary policy shocks to macroeconomic variables is paramount to many central banks.

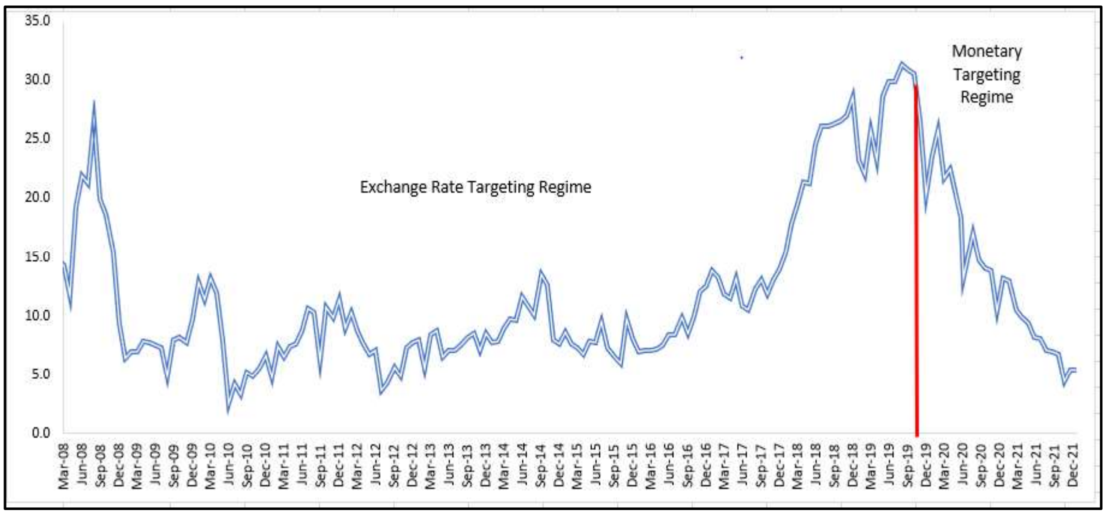
Monetary policy regimes that are operated by central banks vary according to the environment and economic conditions associated with a country. Monetary policy decisions often affect prices and outturn via important financial variables, including lending rate, asset prices, credit, exchange rates, etc. Therefore, analyzing the performance of a particular monetary policy regime and potential shocks requires a thorough assessment employing different advanced econometric techniques.

In Liberia, the implementation of monetary policy had been largely limited in scope since the inception of the Central Bank of Liberia (CBL) in 1999. Prior to the current monetary targeting framework adopted in the fourth quarter of 2019, the CBL utilized an exchange rate targeting regime to ensure price stability and its major tool was the foreign exchange intervention. By this, the Bank basically relied on the sales of foreign exchange, the US dollar, to major importers and vendors to mop up excess Liberian dollar liquidity in the forex market and to also minimize the volatility in the exchange rate.

Although the exchange rate targeting framework, on the overall, proved somewhat effective and provided short-term benefits in smoothing out variations in the exchange rate and lowering inflation, it came with a hard price-depletion of international reserves. The regular sales of foreign exchange by the CBL placed significant pressure on the country's international reserves, thereby exposing the economy to higher risk in countering external shocks, notable the deadly Ebola virus epidemic that struck the economy in 2014.

Consequently, the CBL switched from its previous monetary policy framework to the current monetary targeting framework. The present framework was adopted in November 2019 and the Monetary Policy Advisory Committee (MPAC) was established in the same period. Since its adoption, the current framework has delivered some effectiveness in combating inflation, proven by the significant decline in inflation from high double digit to single digit (from 30.55 percent in October 2019 to 5.46 percent in December 2021). Despite this gain, the domestic economy remains vulnerable to shocks that significantly influence the conduct of monetary policy.

Figure 1: Inflation Trend under Exchange Rate Targeting and Monetary Targeting Regimes



Note: Figure 1 displays the trend in year-on-year monthly inflation (consumer price index) during the previous exchange rate regime and the current monetary targeting regime.

In the conduct of its monetary policy, the CBL places premium on the enhancement of policy formulation, implementation, and communication to its audience. As part of the process of transmitting its policy to the public, the Bank provides an overview of the macroeconomic performance of the economy. In the background, advanced macroeconomic analyses of the real, monetary, fiscal, and external sectors of the economy are conducted using various advanced traditional macroeconometric models such as Autoregressive Integrated Moving Average (ARIMA) and Vector autoregressive (VAR) models to forecast and simulate policy responses. Even so, the parameters of traditional macroeconometric models are variant to policy changes and other structural variations because they lack optimization-based approach to their development. Hence, these models have been heavily criticized because of such limitations (Lucas, 1976 and Sargent, 1981).

To address the shortcomings, structural models have been developed to complement traditional macroeconometric models. The development of structural models gives policymakers, particularly the monetary authority, the latitude to have a collection of models for policy simulation, analysis, and forecasting. Prominent amongst the so-called structural models is the DSGE model that has been mainly popularized in the literature, namely: the Real Business Cycle framework (Kydland and Prescott, 1982, 1990) and the New-Keynesian framework (Rotemberg and Woodford, 1997). It is worth emphasizing that the former assumes price flexibility whilst the latter assumes price rigidities and offers microeconomic foundations for Keynesian concepts (Gali and Gertler, 2007).

DSGE models are appealing to policy makers due to their potential and robustness in policy analysis (Sbordone et al. 2010). They are relevant for monetary policy analysis because they can aid in identifying sources of fluctuations, address issues of structural changes and predict the effect of policy changes (Coletti and Murchison, 2002). In DSGE models, current choices are dependent on future uncertainties and this dependence makes the models dynamic. The interactions between economic agents reflect the general equilibrium nature of DSGE models.

Given the attractions of DSGE models in terms of monetary policy analysis, this paper estimates the New Keynesian variant of the DSGE model using Bayesian approach to analyze the impacts of monetary policy, demand, and productivity shocks on inflation and output gap in Liberia for the period spanning 2007Q1 to 2021Q4. The Bayesian estimation approach is used as it allows for setting priors for parameters to obtain more efficient posterior estimates. Additionally, the Bayesian approach is useful in the case of small sample size.

This paper is motivated by the gap in the empirical literature on shock analysis of monetary policy in Liberia using Bayesian DSGE estimation approach. To the best of our knowledge, this paper is the first paper that uses the Bayesian DSGE approach to analyze monetary policy shock in Liberia and its findings are expected to lay down the platform for wider policy discussions amongst policymakers and academics. Thus, an attempt is made in this study to contribute to the literature with key interest in analyzing the impacts of monetary policy, demand, and productivity shocks on key macroeconomic variables and how the CBL should respond to such shocks. Compared to the classical DSGE method, the Bayesian estimation method has gained traction following the works of Sims and Zha (1999), Schorfheide (2000) and Smets and Wouters (2003), among others.

The Bayesian estimation technique uses both prior and posterior distributions. The density of the observed data is described by the likelihood function. Given the prior density p(ג) and a likelihood function p(K_T/ג), the posterior density p(ג/K_T) parameters can be obtained using the Bayes' theorem. The posterior density combined with the marginal density of the data conditional on the model allows researcher to update all posterior moments of interest by estimating the likelihood function using the Kalman filter algorithm. The posterior kernel using the posterior density is then simulated using Monte Carlo method such as Metropolis-Hastings. Therefore, a Bayesian estimation uses both prior knowledge and information from the data to generate posterior estimates, as prior knowledge is normally expressed in the form of independent probability distributions that are associated with each of the structural parameters.

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 with policy recommendations.

2.0 METHODOLOGY AND DATA

2.1 Model

To analyze the impacts of monetary policy, productivity and demand shocks on inflation and output gap, this paper adopts the linearized version of the Dynamic Stochastic General Equilibrium (DSGE) model presented by Woodford (2003). The DSGE model is a suite of equations based on economic theories, and thus, has parameters which are directly interpretable. The model used in this paper comprises three equations characterizing the optimization behavior of household, firms, and central bank as specified in equations 1, 2 and 3, respectively.

2.1.1 Firms

Equation 1 describes a Phillips Curve obtained from firms' optimization. The equation is an augmented New Keynesian Phillips Curve (NKPC), following the Calvo (1983) and Taylor (1980) staggered-contracts models (see Roberts, 1995). It specifies inflation (p_t) as a linear combination of past inflation (p_{t-1}), expected inflation (p_{t+1}), the output gap (x_t), and a state variable capturing movements in inflation not driven by exchange rate (es_t). The parameter kappa (k) measures how responsive inflation is to excess demand (positive output gap) in the economy and should a priori have a positive sign. The parameter β captures inflation expectations.

$$p_t = \rho_p p_{t-1} + (1-\rho_p)[\beta E_t(p_{t+1}) + \kappa x_t + \phi es_t] \qquad (1)$$

To ensure that the model is solvable, another equation is specified to link the unobserved state variable es_t to the growth rate of exchange rate, e_t, which is an observed exogenous variable:

$$e_t = es_t \qquad (2)$$

2.1.2 Households

Optimization by households is given by the Euler equation in (3), specifying output gap as a linear combination of future output gap (x_{t+1}), nominal interest rate (r_t), and a state variable (g_t) that captures changes in the natural level of output.

$$x_t = E_t(x_{t+1}) - (r_t - E_t p_{t+1} - g_t) \qquad (3)$$

2.1.3 Central Bank

The monetary policy rule of the central bank is given by the Taylor's rule in equation (4) that specifies interest rate as a linear combination of previous period interest rate, inflation, and a state variable (u_t) which captures movements in the interest rate that are not caused by inflation. The lag of interest rate in the Taylor's rule accounts for interest rate smoothing (inertia), as the CBL is cautious in changing policy rate. The parameter ρ_r is the interest rate smoothening parameter while $\frac{1-\rho_r}{\psi}$ captures the central bank's response to movements in inflation.

$$r_t = \rho_r r_{t-1} + \frac{1-\rho_r}{\psi} p_t + u_t \qquad (4)$$

2.1.4 Shocks

In order to complete the model, the three state variables, u_t, g_t and es_t are modeled as first-order autoregressive processes in equations 5, 6 and 7, respectively.

$$\mu_{t+1} = \rho_u \mu_t + \epsilon_{t+1} \qquad (5)$$

$$g_{t+1} = \rho_g g_t + \varepsilon_{t+1} \qquad (6)$$

$$es_{t+1} = \rho_{es} es_t + v_{t+1} \qquad (7)$$

where ϵ_{t+1} is the shock to state variable u_t (monetary policy shock); ε_{t+1} is the shock to state variable g_t (productivity shock); and v_{t+1} represents shock to state variable es_t (demand shock).

2.2 Data

This paper uses quarterly series of monetary policy rate, inflation rate, and exchange rate spanning 2007Q1 to 2021Q4. Inflation rate is measured as the year-on-year change in consumer price index (CPI). The exchange rate variable is measured as units of local currency per United States dollar; hence, an appreciation of the domestic currency would imply a negative rate of change and vice versa. Data on these variables are sourced from the Central Bank of Liberia.

2.3 Priors for Distributions

Table 1 below shows priors of the parameters and their respective density functions. These priors reflect external information about model parameters based on expert knowledge of their behavior and in some case, based on empirical evidence from the literature.

Table 1: Priors for Distributions

Parameter	Interpretation	Range	Density Function	Para (1)	Para (2)
ρ_r	Interest rate smoothening parameter	(0,1)	Beta	0.30	0.70
ψ	The weight placed on inflation by policy maker	(0, 1)	Beta	0.50	0.50
ρ_p	Backward-looking price setting	(0,1)	Beta	0.30	0.70
β	Inflation expectation parameter	(0,1)	Beta	0.95	0.05
κ	Slope of Phillips curve	(0,+∞)	Beta	0.30	0.70
ϕ	Exchange rate parameter	(0, 1)	Beta	0.30	0.70
ρ_u	AR(1) for monetary policy shock	(0,1)	Beta	0.75	0.25
ρ_g	AR(1) for productivity shock	(0,1)	Beta	0.75	0.25
ρ_e	AR(1) for demand shock	(0,1)	Beta	0.75	0.25

σ_u	Standard deviation of monetary policy shock	(0,+∞)	Inverse gamma	0.01	0.01
σ_g	Standard deviation of productivity shock	(0,+∞)	Inverse gamma	0.01	0.01
σ_{es}	Standard deviation of demand shock	(0,+∞)	Inverse gamma	0.01	0.01

Note: Priors are based on findings from previous studies in the empirical literature.

3.0 EMPIRICAL RESULTS AND ANALYSIS

In this section, the dynamic responses of macroeconomic variables to shocks are presented and analyzed. Initially, the model is estimated with a Markov Chain Monte Carlo (MCMC) size of 25,000 but fails to achieve convergence as shown by the model without block option reported in the results in the appendix. Thus, to ensure convergence, the model is re-estimated using the block option. The posterior means of the parameters in the model without block option and with block option are reported in Table 2

Table 2: Posterior Means of Parameters

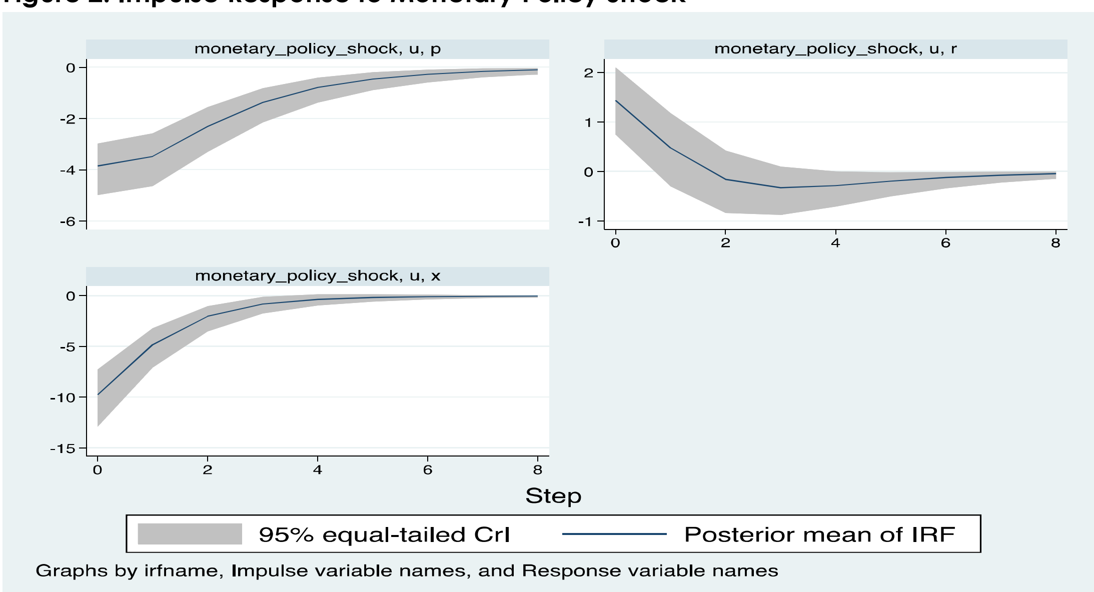
	Model (without block)		Model (with block)	
Parameters	Mean	95% interval	Mean	95% interval
ρ_r	0.5540	[0.4930 0.6136]	0.5810	[0.5016 0.6552]
ψ	0.4720	[0.3966 0.5484]	0.3988	[0.3110 0.4925]
ρ_p	0.2534	[0.1862 0.3209]	0.3129	[0.2321 0.3955]
β	0.9471	[0.8928 0.9825]	0.9444	[0.8885 0.9815]
κ	0.2622	[0.1939 0.3352]	0.2435	[0.1657 0.3326]
ϕ	0.3224	[0.2337 0.4085]	0.3152	[0.2290 0.4081]
ρ_u	0.5022	[0.4401 0.5619]	0.6000	[0.5165 0.6853]
ρ_g	0.8364	[0.7830 0.8800]	0.7220	[0.6367 0.8023]
ρ_e	0.7353	[0.6287 0.8074]	0.7041	[0.6179 0.7850]
σ_u	4.4969	[3.9148 5.1383]	5.5223	[4.4909 7.0241]
σ_g	4.2483	[3.8288 4.7013]	8.2295	[6.0465 11.1595]
σ_{es}	5.9273	[4.9975 6.9066]	4.4941	[3.7441 5.3923]

Source: authors' construction

Note: We use MCMC size of 25,000, resulting into 30,000 MCMC iterations, and discard the first 5,000 iterations as burn-in.

Figure 2 shows the responses of inflation (p), monetary policy rate (r) and output gap (x), to monetary policy shock in the Liberian economy. As shown in the figure, a monetary policy shock occasions an initial rise in the monetary policy rate which causes inflation and output to decline in the initial period. However, as the tightness in the monetary policy rate reduces over the horizon and goes to its steady state, inflation tends to rise and approaches its steady state after six periods. Output, on the other hand, declines markedly in the initial period. This is because the monetary authority's primary objective is price stability and is willing to accept the loss of output in order to gain price stability, consistent with the sacrifice ratio phenomenon. In addition, output tends to increase and approaches its steady state beginning the fourth quarter. Over the eight-period horizon, the impact of monetary policy shock is short lived and pronounced in the first two quarters, after which the variables tend to converge to their steady states.

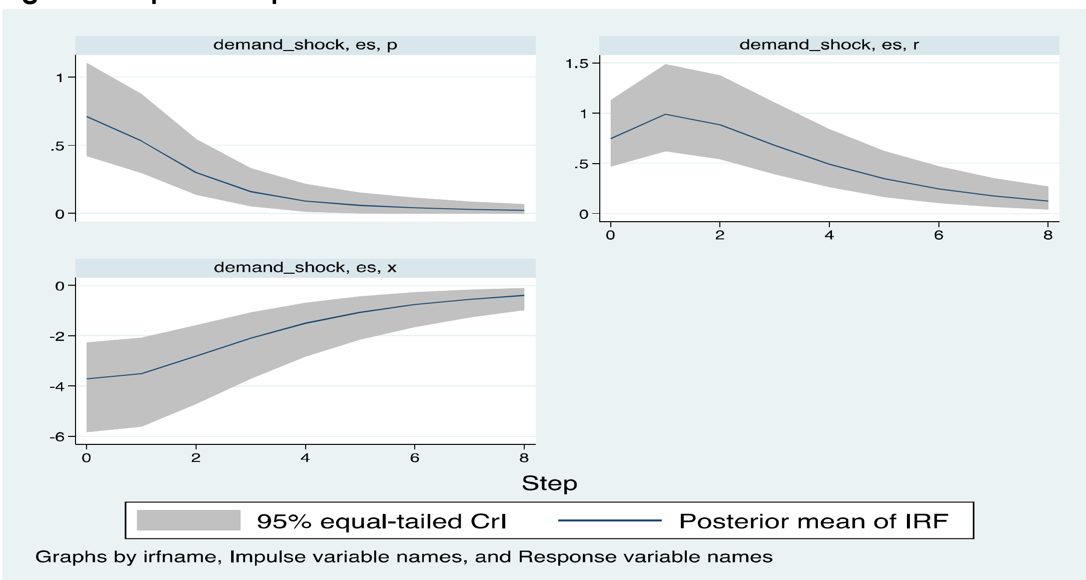
Figure 2: Impulse Response to Monetary Policy Shock



Note: The graphs reflect the impulse responses of inflation (p), monetary policy rate (r) and output gap (x) to monetary policy shock (u) in the Liberian economy over 8-quarter horizon within 95% credible interval.

As displayed in Figure 3, given a demand shock (sharp depreciation of the exchange rate) in the initial period, price is elevated, prompting an increase in the policy rate. The rise in the policy rate translates into higher borrowing cost for producers, thus constraining production. As a result, output declines as reflected by the negative output gap. Despite inflation declining on account of the initial rise in the monetary policy rate, the monetary authority further increases the policy rate in the first quarter-reflecting interest rate inertia- and then reduces the policy rate in the second quarter. The reduction in the tightness of the monetary policy stance causes the negative output gap to close as the exchange rate returns to its steady state and price pressure dissipates.

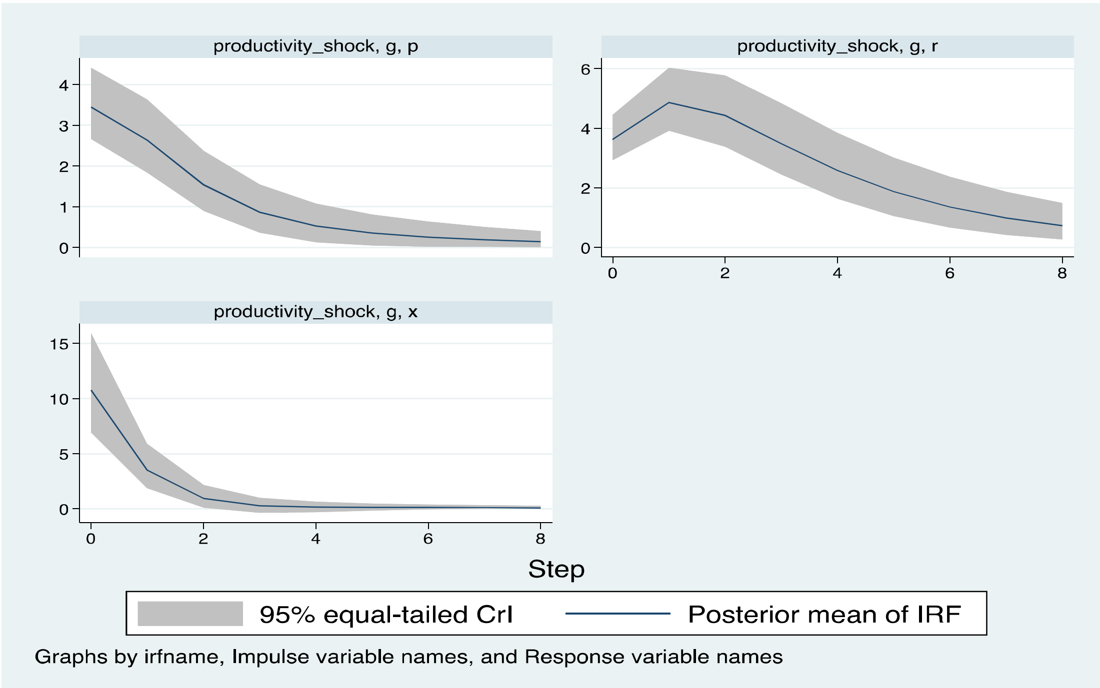
Figure 3: Impulse Response to Demand shock



Note: The graphs reflect the impulse responses of inflation (p), monetary policy rate (r) and output gap (x) to demand shock (es) in the Liberian economy over 8-quarter horizon within 95% credible interval.

As shown in Figure 4, productivity (technology) shock occasions an initial rise in output and inflation. As a response to this initial shock, the monetary authority raises the policy rate to counter the rise in prices consistent with its primary objective of price stability. Additionally, due to interest rate inertia and the need to aggressively tackle the high level of inflation occasioned by the large output gap, the monetary authority further tightens its policy stance in the next quarter, triggering declines in inflation and output. As a result, price declines over the horizon (declining faster up to the second quarter) before approaching steady state beginning the sixth quarter. Accordingly, the monetary authority reduces the policy rate.

Figure 4: Impulse Response to Productivity shock



Note: The graphs reflect the impulse responses of inflation (p), monetary policy rate (r) and output gap (x) to productivity shock (g) in the Liberian economy over 8-quarter horizon within 95% credible interval.

4.0 CONCLUSION AND POLICY RECOMMENDATIONS

This paper employed the Bayesian DSGE estimation method to analyze the effects of monetary policy, demand and productivity shocks on output gap and inflation in the Liberian economy from 2007Q1 to 2021Q4. The model was based on the standard new Keynesian framework that comprised three rational economic agents-household, firms, and the central bank of Liberia.

The findings reveal that the data is informative as the posterior mean is different from the prior mean. The results also show that over the eight-quarter horizon, monetary policy shock has a transient negative impact on inflation and output gap, implying that the central bank is more inclined to achieving its primary objective of price stability, and would tolerate some losses of output in the short-run by raising the policy rate. This finding is in line with traditional macroeconomic fundamentals and corroborates with Aruoba and Drechsel (2022) who argue that monetary tightening causes the inflation to moderate. Also, the posterior estimate on the lag of interest rate parameter is higher than the prior indicating a smoothing path for the short-term interest rate.

Furthermore, productivity shock has a transient positive impact on both output gap and inflation, while demand shock has a transient positive impact on inflation but a transient negative impact on output gap. This result implies that productivity shock produces short-term effects, while demand shock generates a long-term effect. Of the three shocks, the finding reveals that the central bank is more aggressive in responding to productivity shock as it induces the highest increase in inflation.

Given the findings that productivity shock has pronounced effect on output gap relative to demand and monetary policy shocks, this paper recommends that the central bank implement policies that would stimulate the real sector in coordination with the fiscal authority. Additionally, the central bank should remain proactive in the implementation of its monetary policy to maintain price stability.

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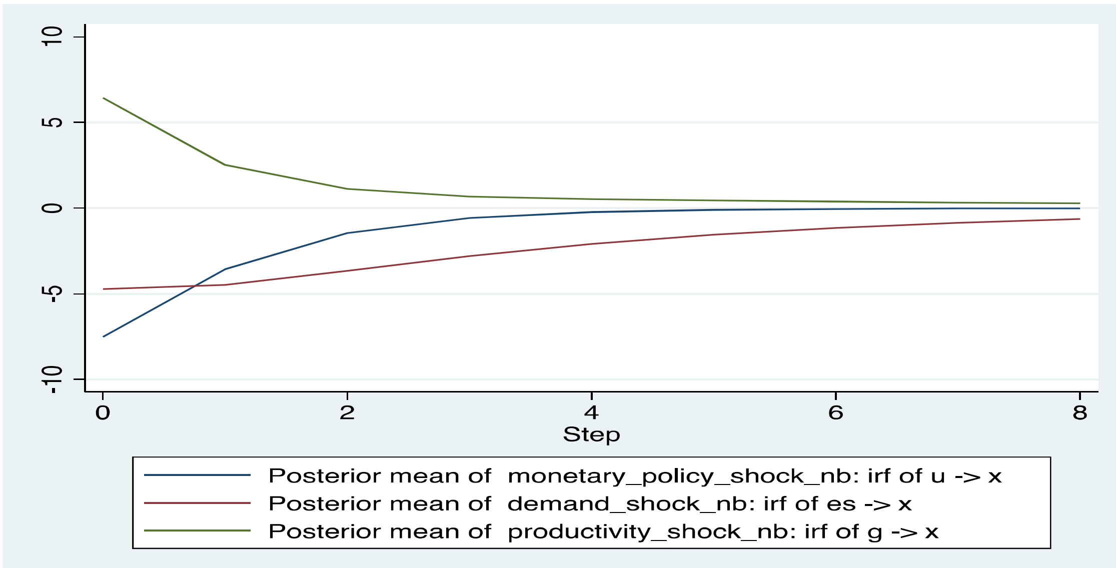
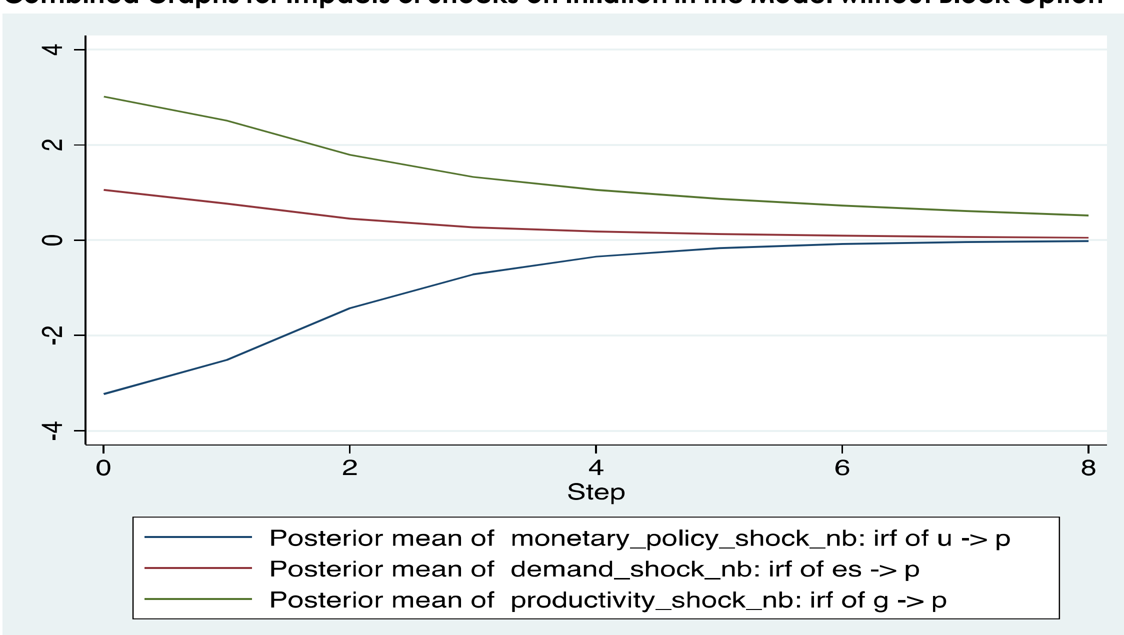
Appendix

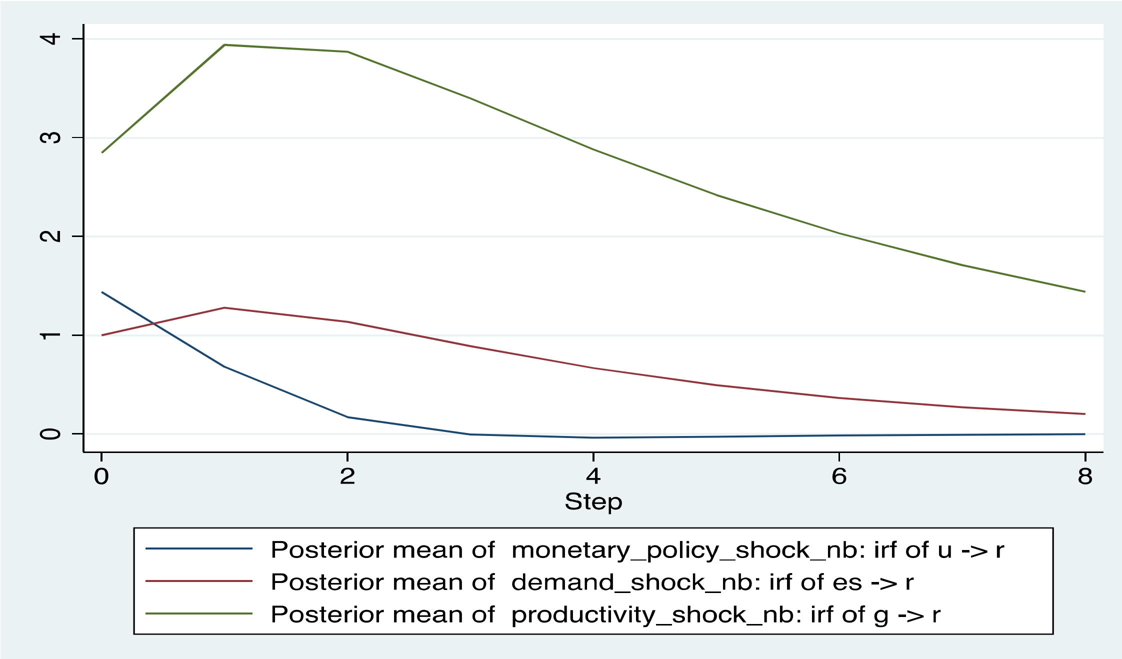
Combined Graphs for Impacts of Shocks on Output Gap in the Model without Block Option



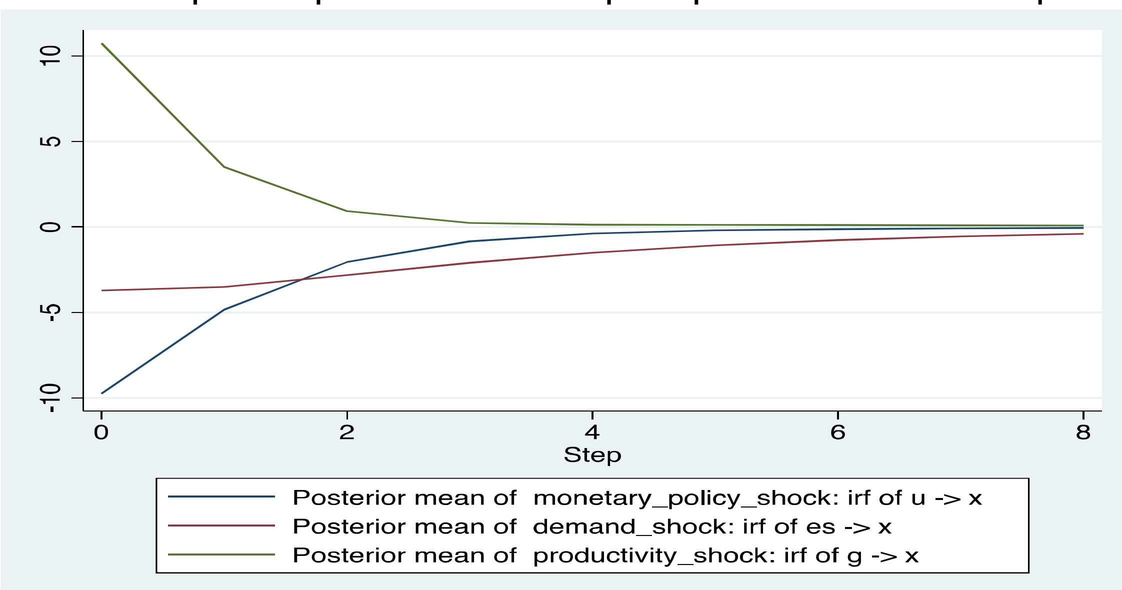
Combined Graphs for Impacts of Shocks on Inflation in the Model without Block Option



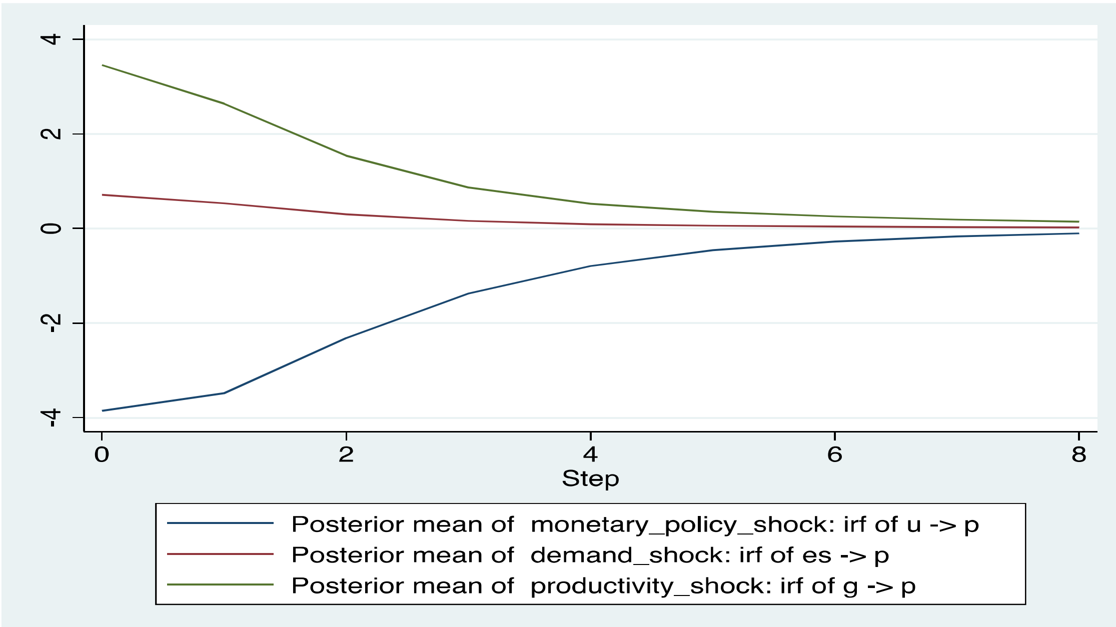
Combined Graphs for Impacts of Shocks on the Policy Rate in the Model without Block Option



Combined Graphs for Impacts of Shocks on Output Gap in the Model with Block Option



Combined Graphs for Impacts of Shocks on Inflation in the Model with Block Option



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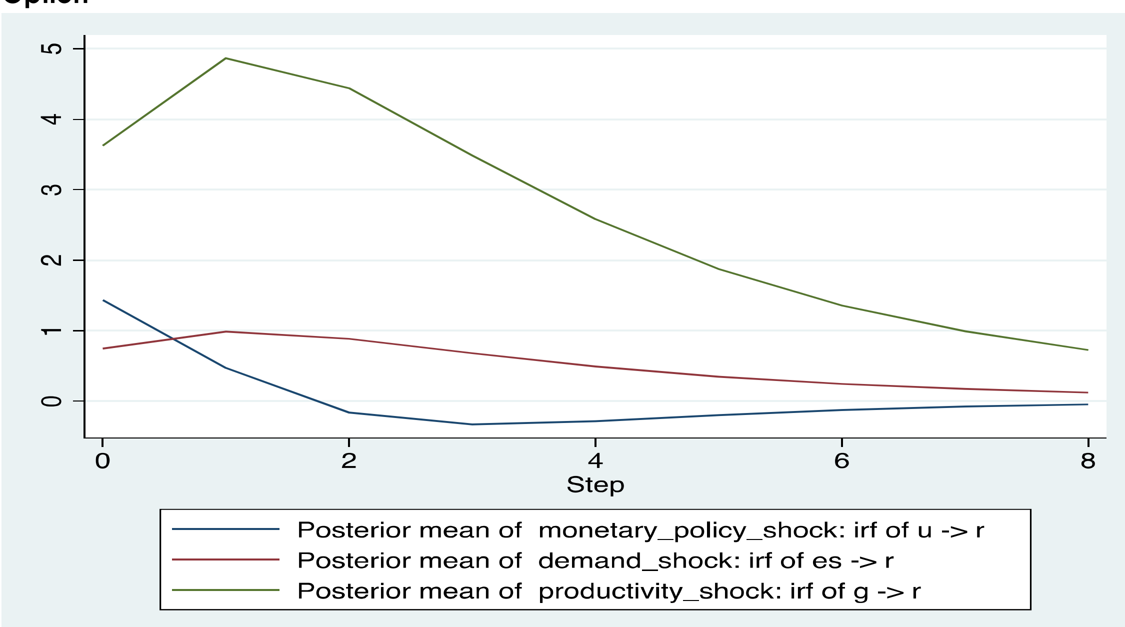
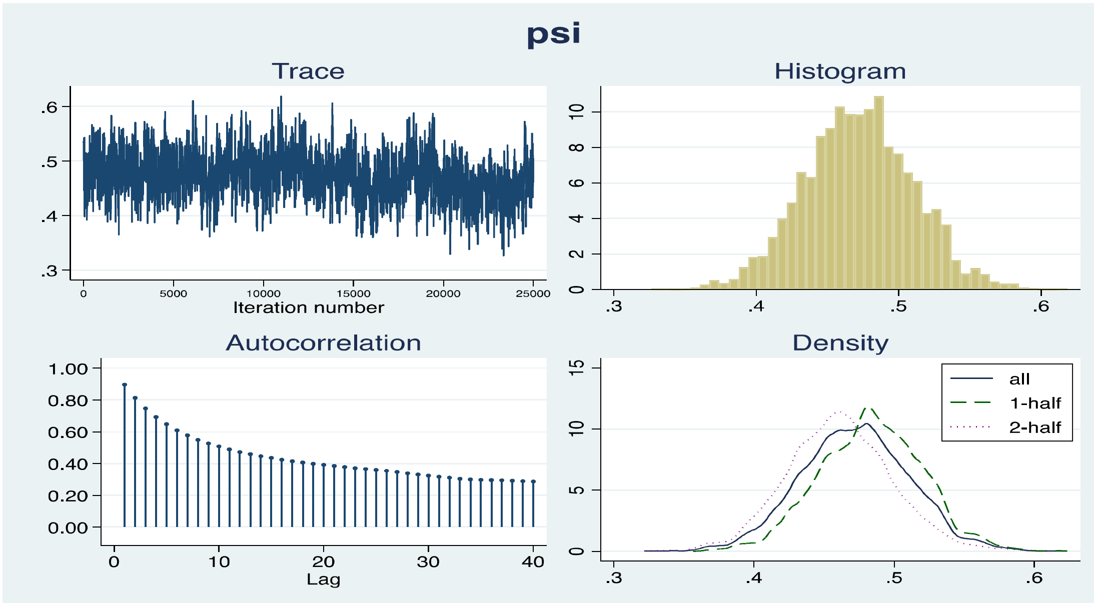
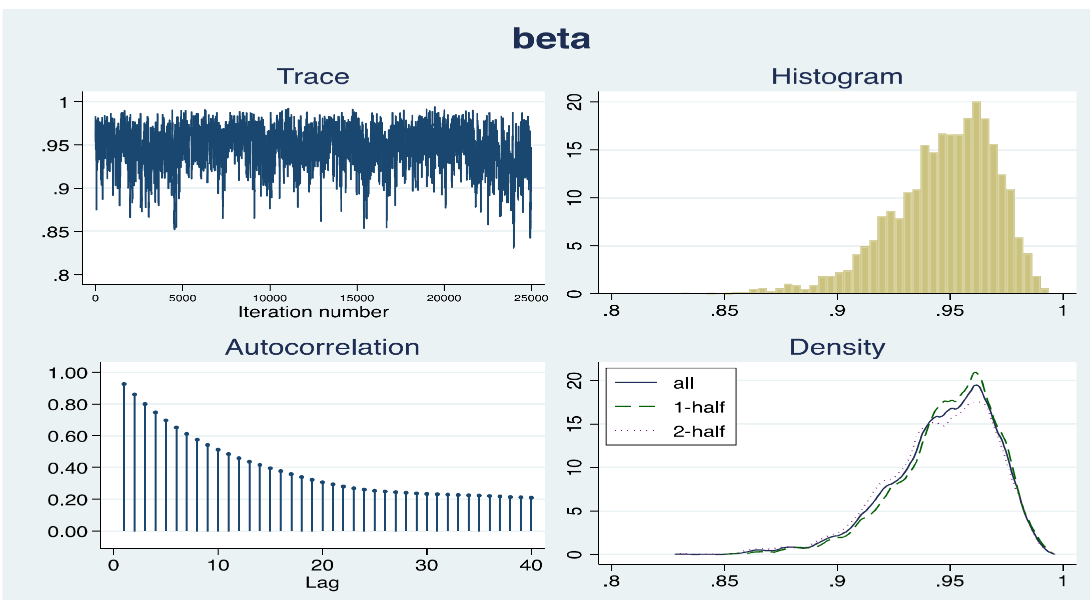
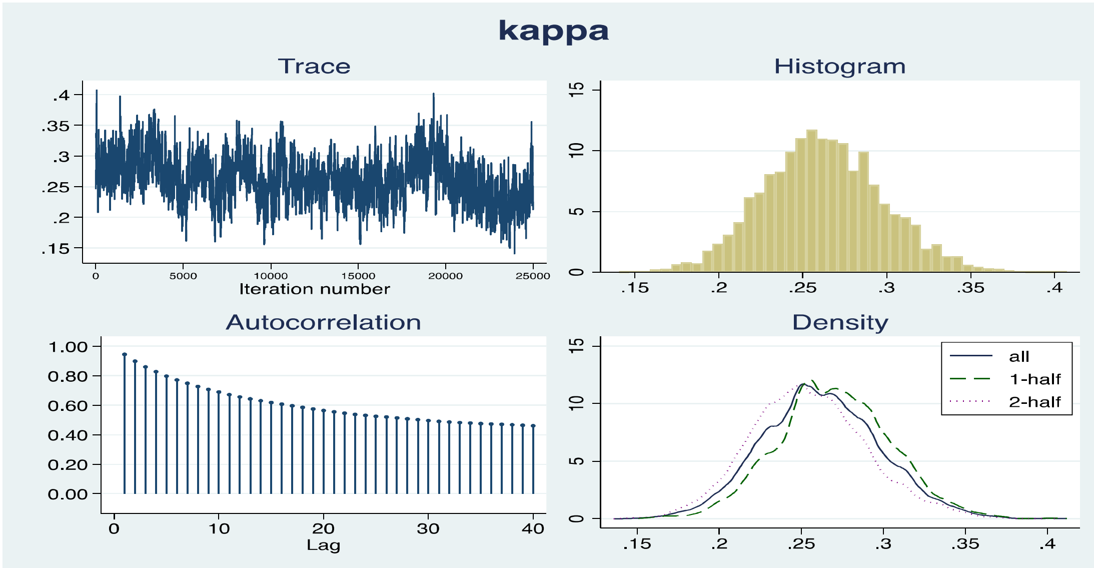


Convergence Diagnostics for Model without Block Option



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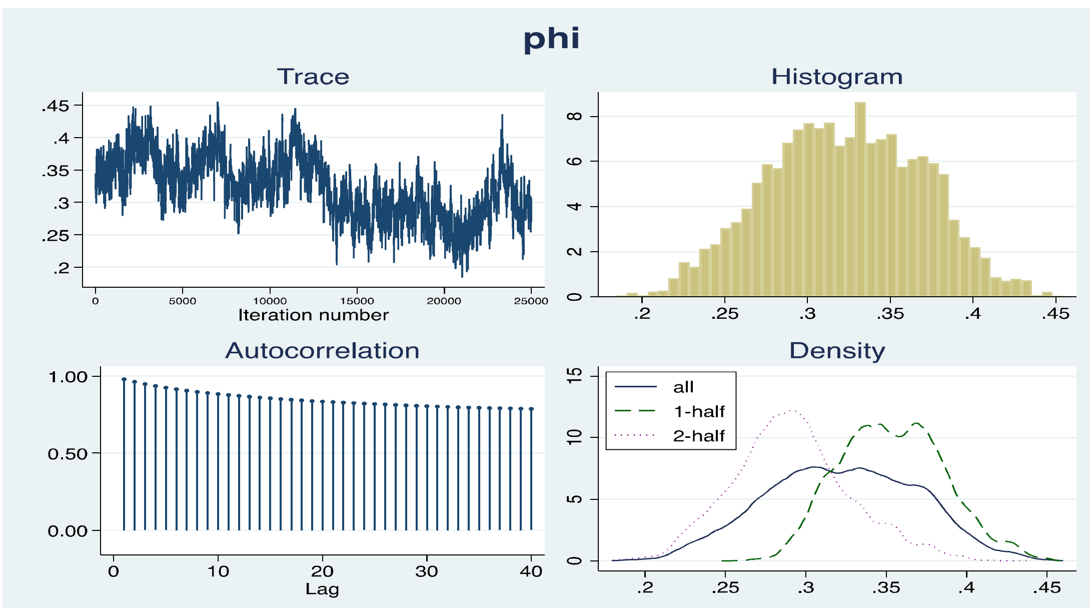
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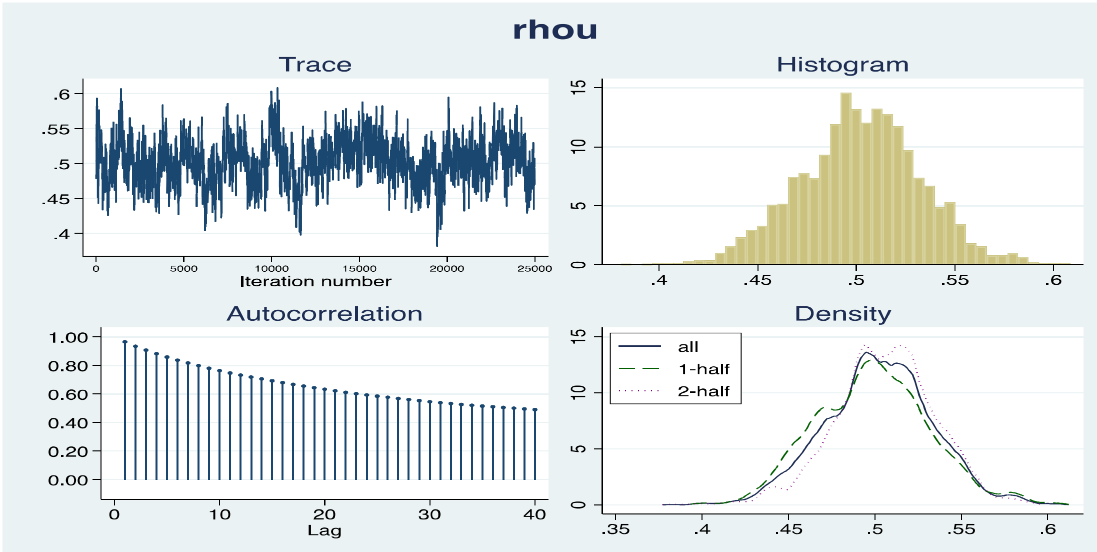
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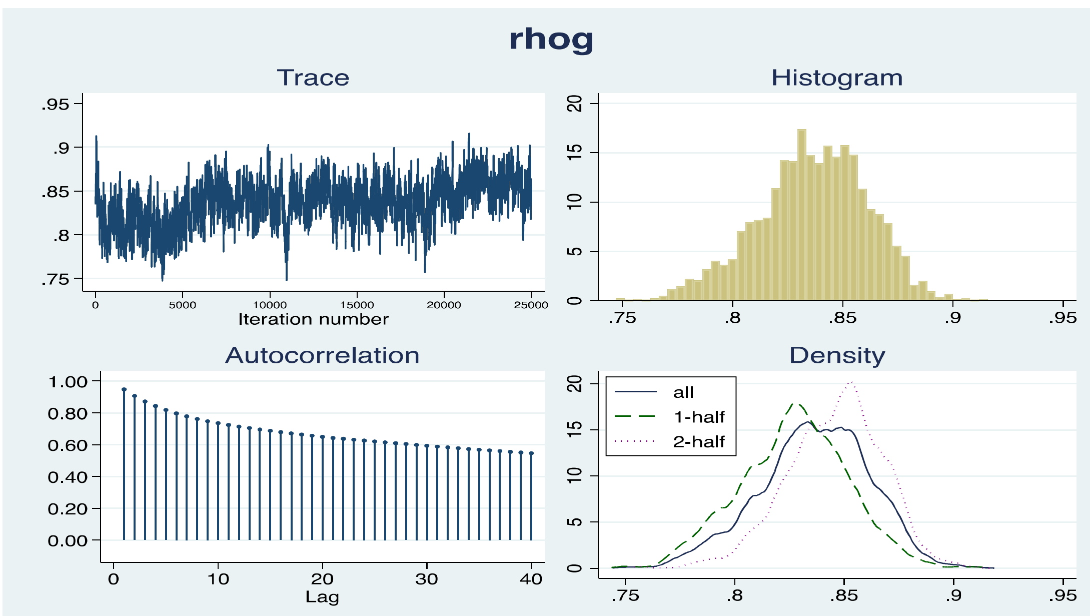
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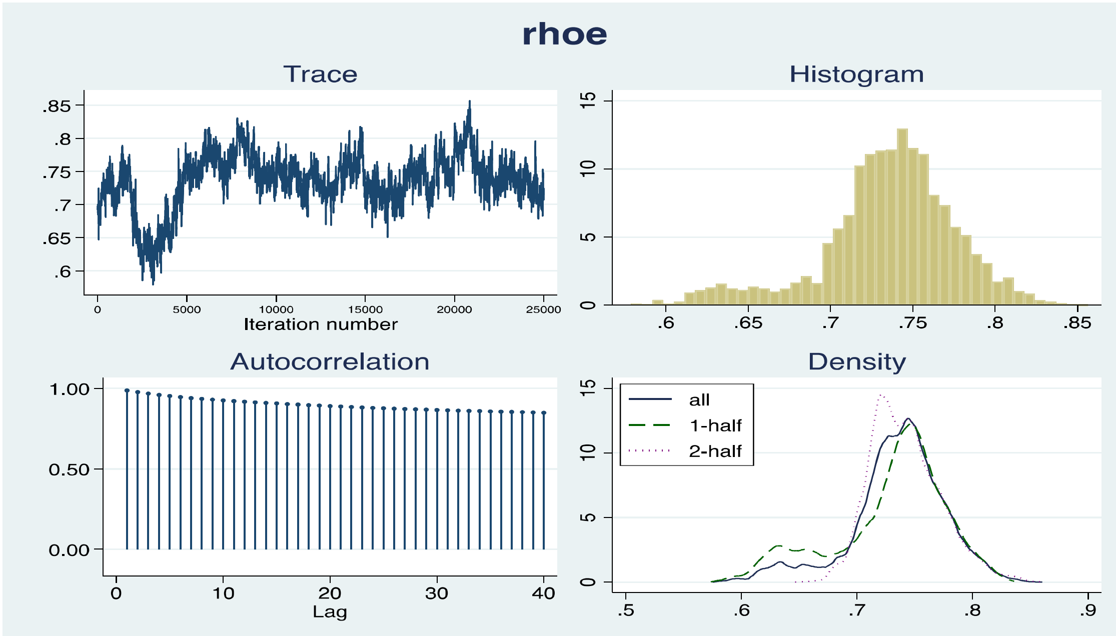
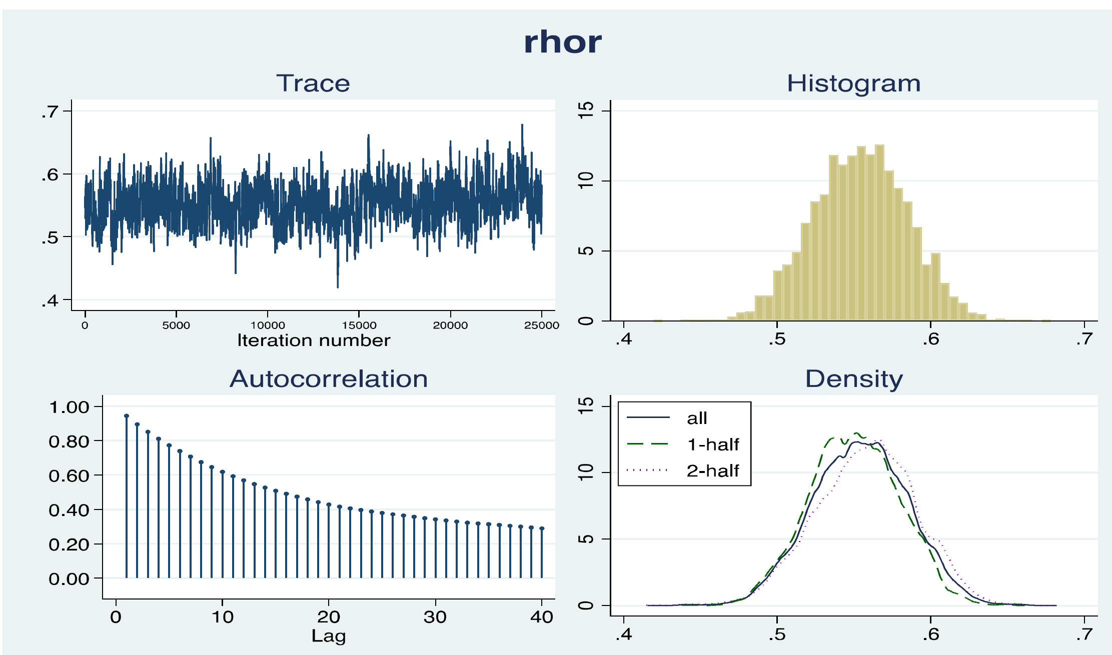
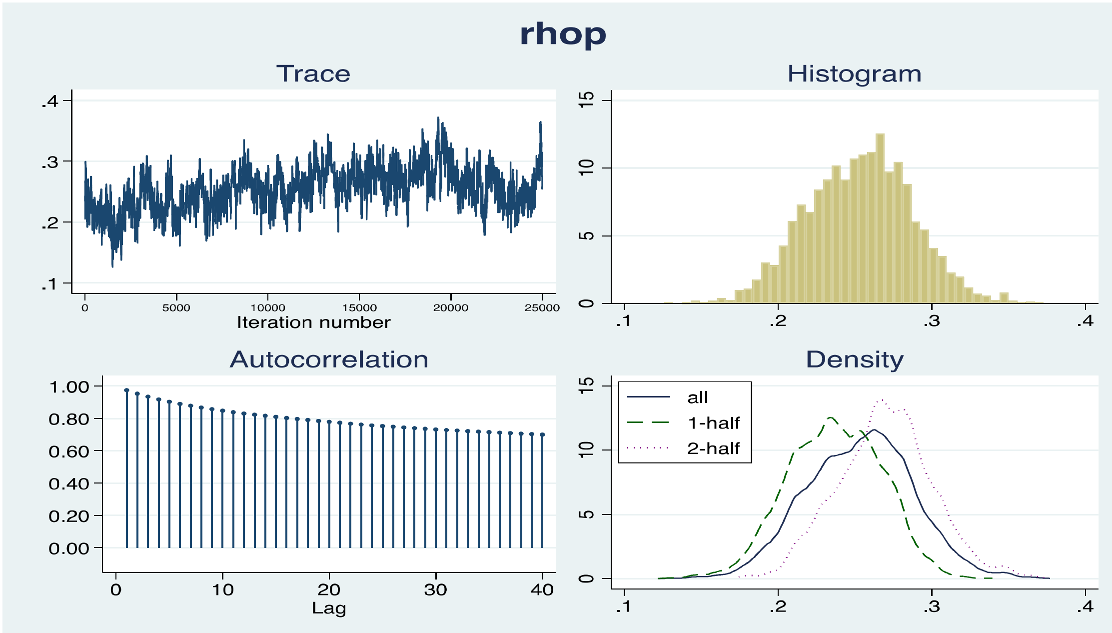

rhoe
Trace
Histogram
Iteration number
Autocorrelation
Density
all
1-half
2-half
Lag

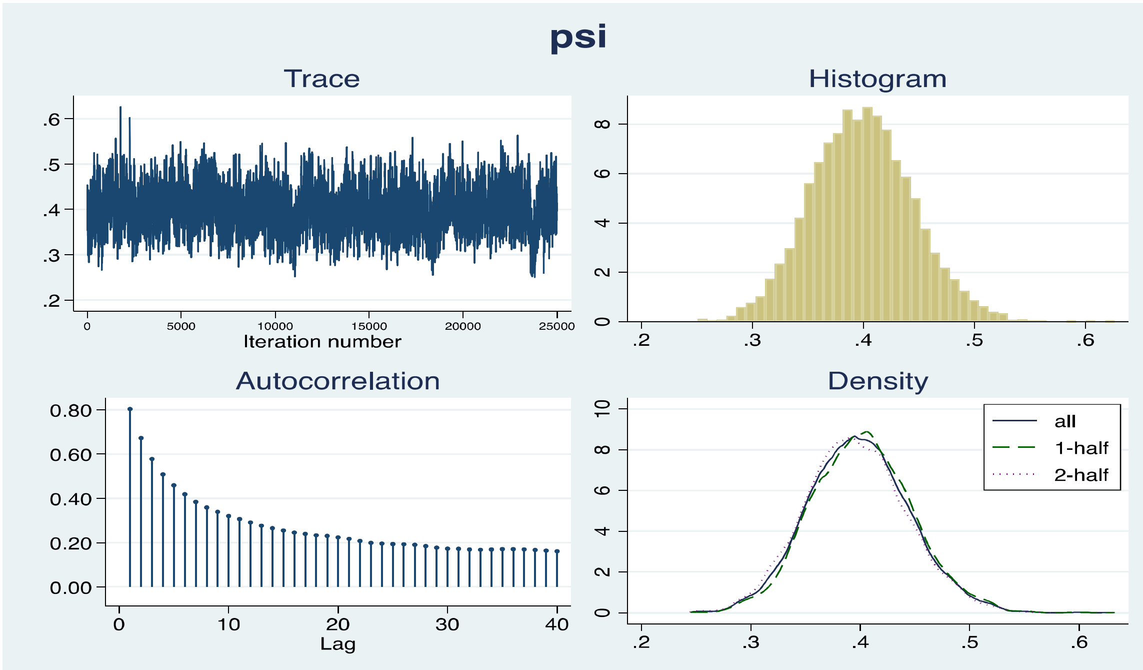

rhor
Trace
Histogram
Iteration number
Autocorrelation
Density
all
1-half
2-half
Lag

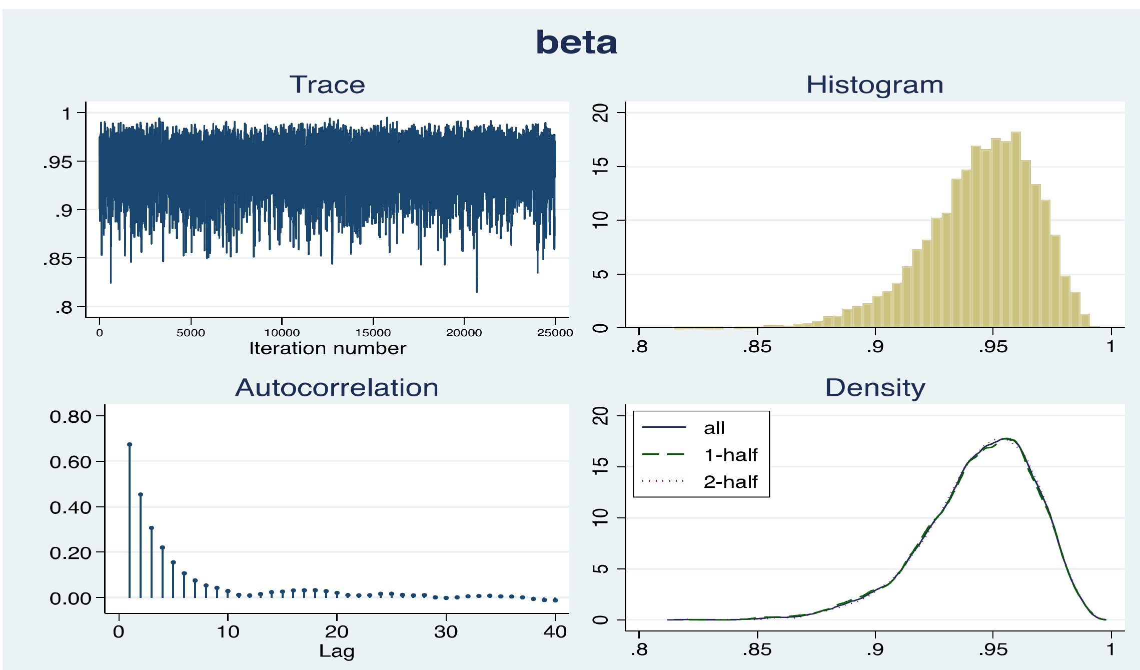


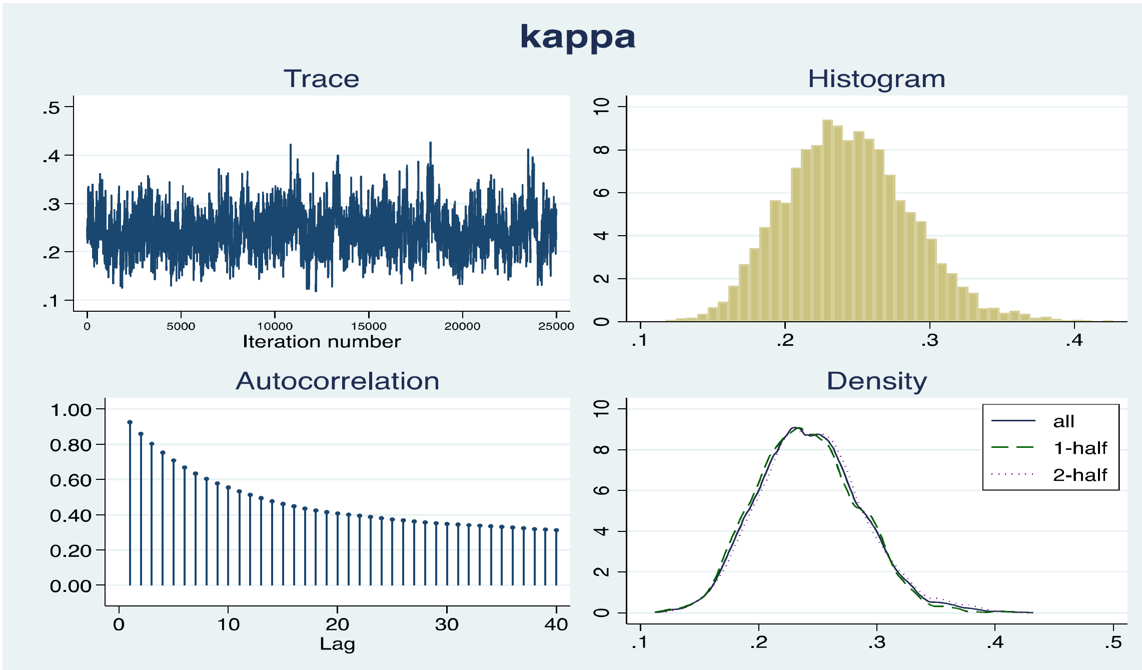

```
Efficiency summaries    MCMC sample size =     25,000
                        Efficiency:  min =    .001399
                                     avg =    .003676
                                     max =    .007455
```

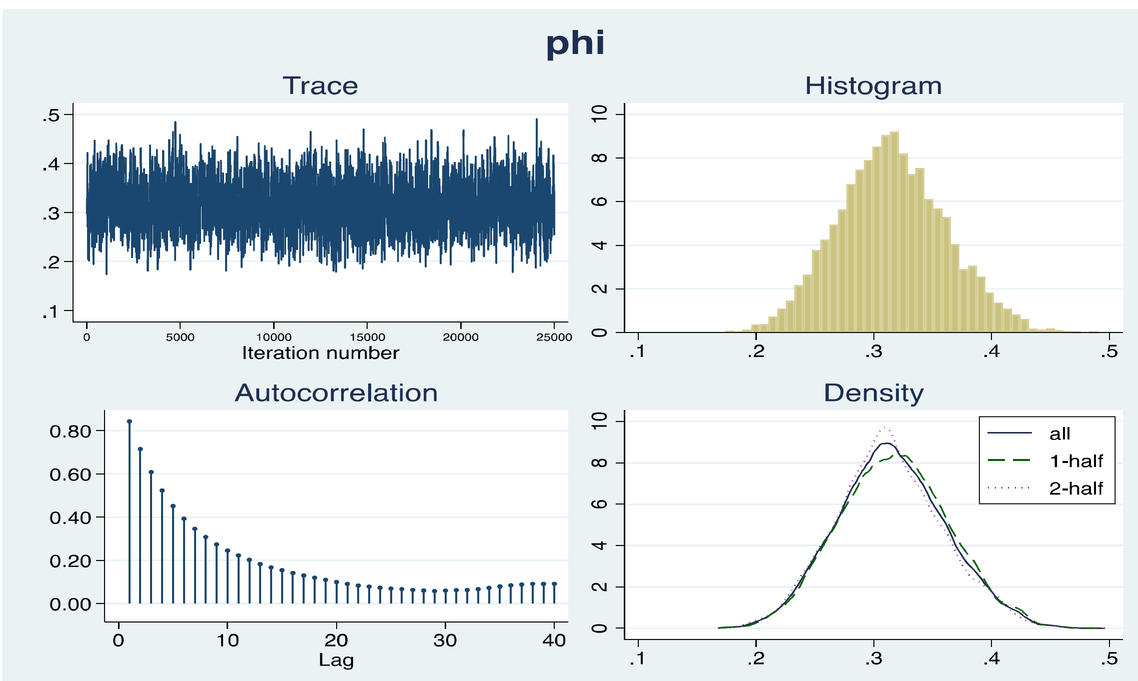
	ESS	Corr. time	Efficiency
rhor	151.75	164.74	0.0061
psi	141.32	176.90	0.0057
rhop	48.44	516.14	0.0019
beta	186.39	134.13	0.0075
kappa	74.26	336.68	0.0030
phi	36.61	682.93	0.0015
rhou	106.72	234.26	0.0043
rhog	62.93	397.28	0.0025
rhoe	34.97	714.86	0.0014
sd(e.u)	92.86	269.23	0.0037
sd(e.g)	78.09	320.15	0.0031
sd(e.es)	88.51	282.45	0.0035

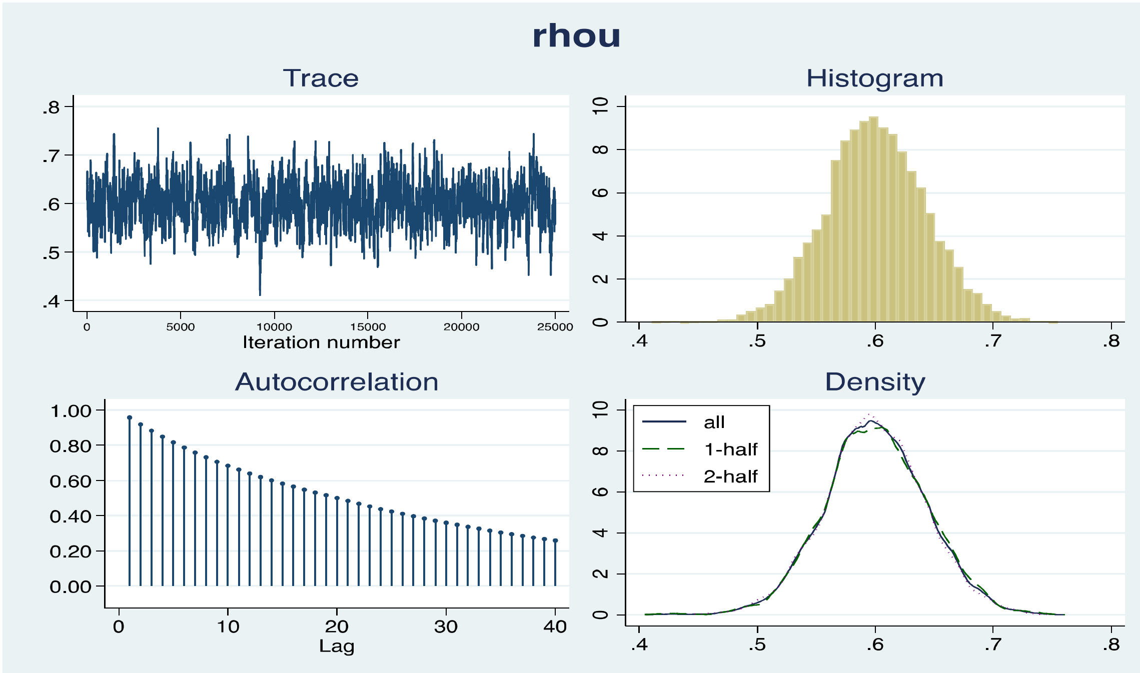
Convergence Diagnostics for Model with Block Option

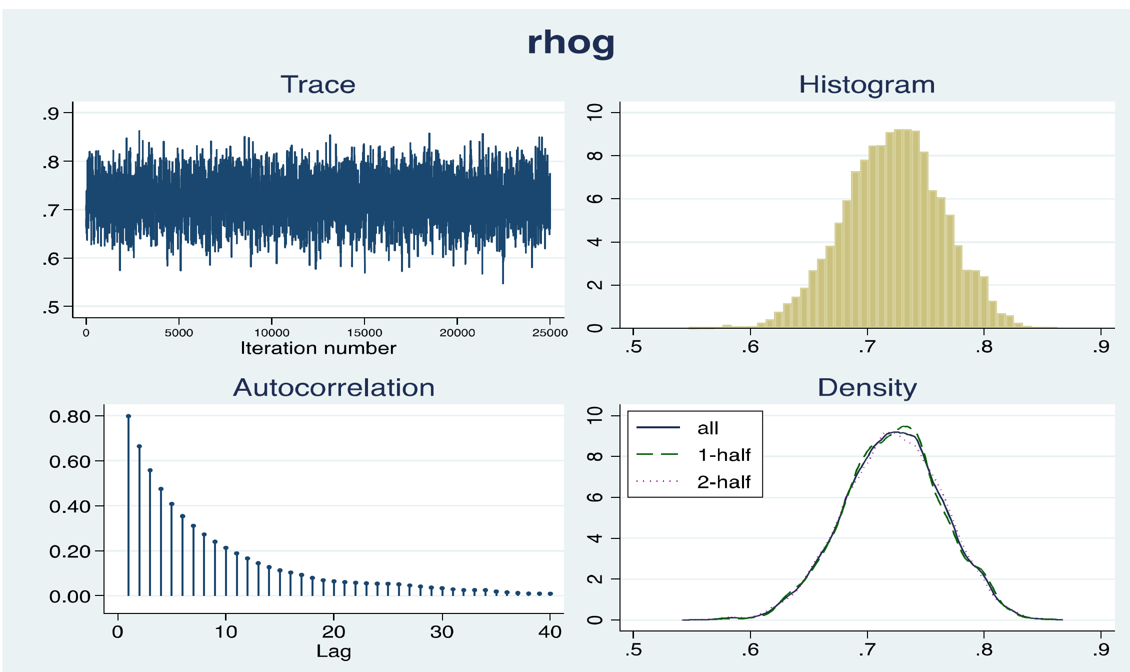


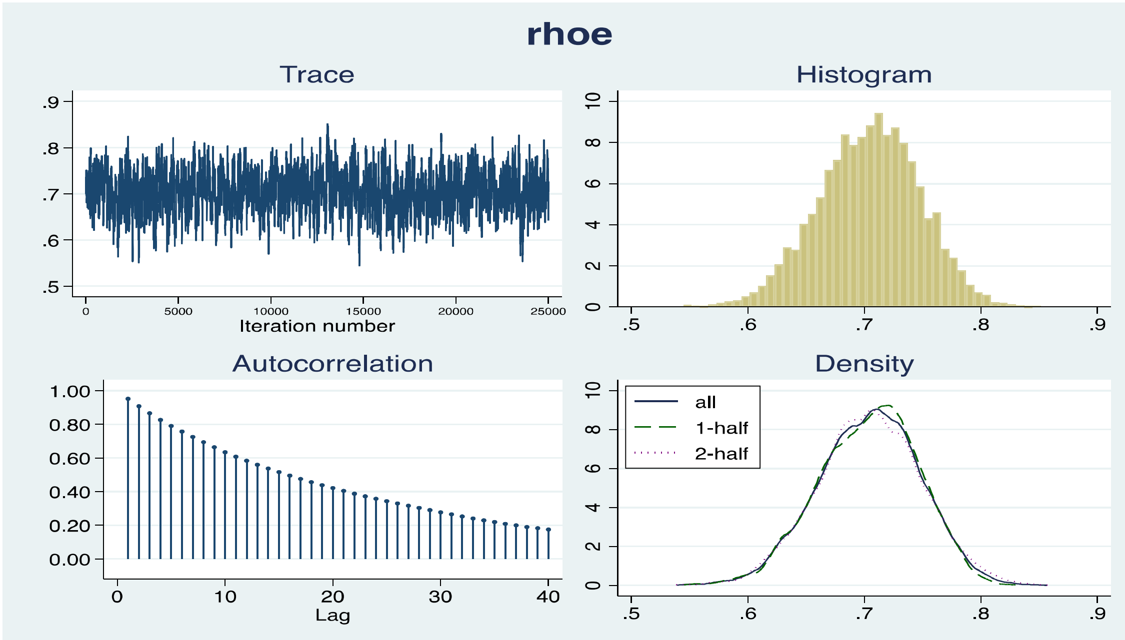


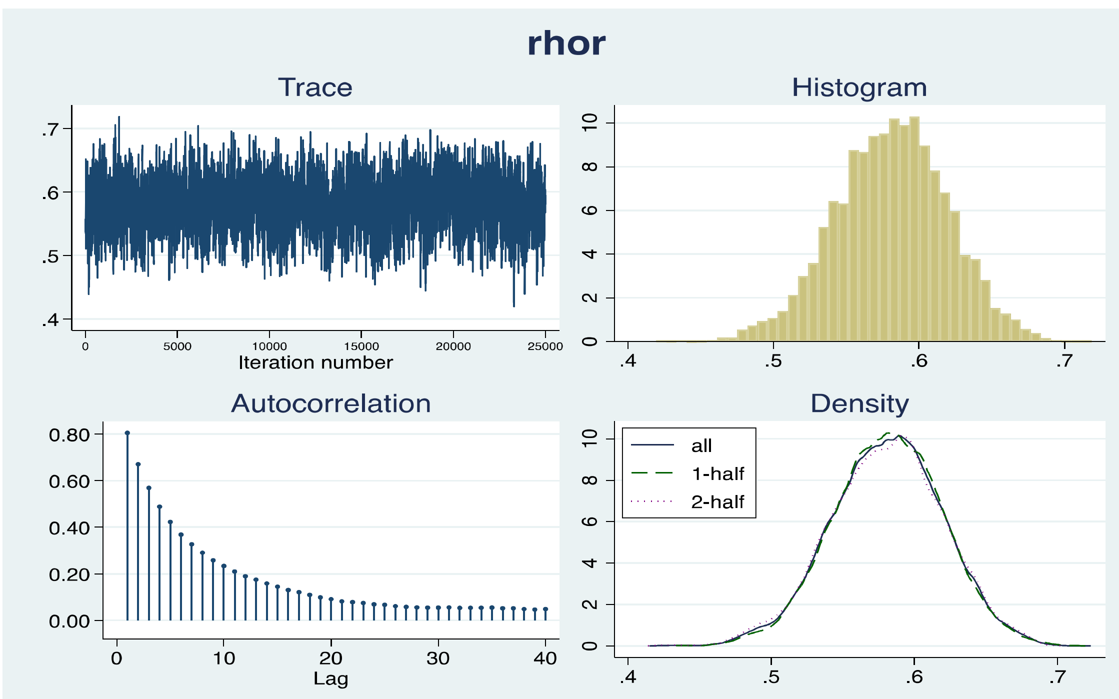

kappa
Trace
Histogram
Iteration number
Autocorrelation
Density
Lag
all
1-half
2-half

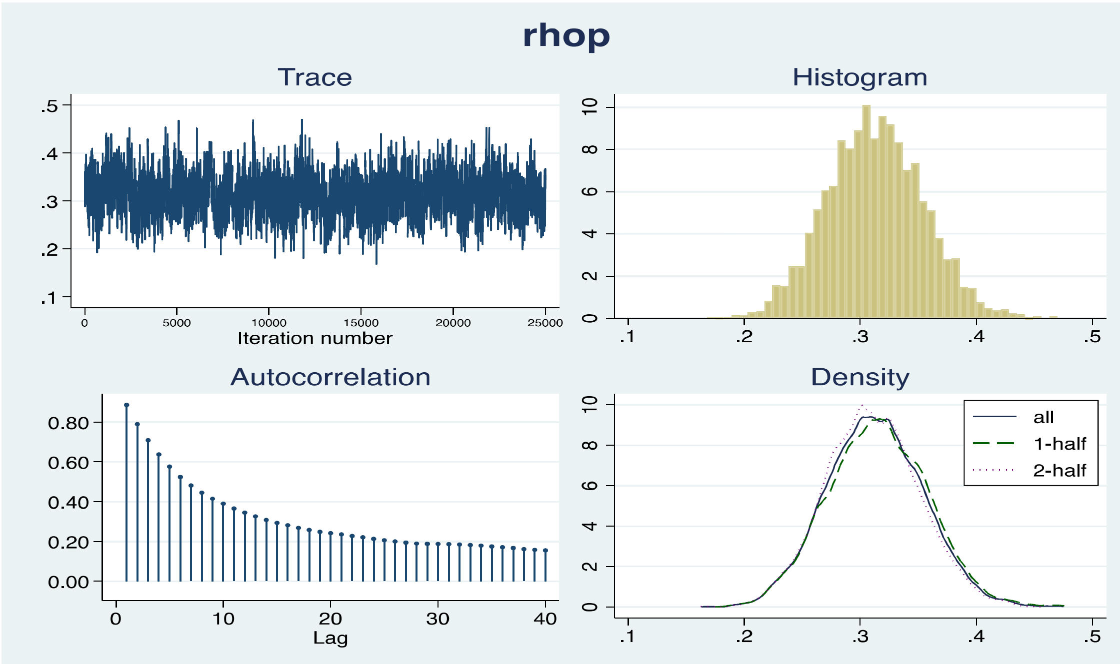

phi
Trace
Histogram
Iteration number
Autocorrelation
Density
Lag
all
1-half
2-half


rhou
Trace
Iteration number
Histogram
Autocorrelation
Lag
Density
all
1-half
2-half


rhog
Trace
Iteration number
Histogram
Autocorrelation
Lag
Density
all
1-half
2-half


rhoe
Trace
Histogram
Iteration number
Autocorrelation
Density
Lag
all
1-half
2-half


rhor
Trace
Histogram
Iteration number
Autocorrelation
Density
Lag
all
1-half
2-half




```
Efficiency summaries    MCMC sample size =     25,000
                        Efficiency:  min =    .004634
                                     avg =     .04142
                                     max =      .1902
```

	ESS	Corr. time	Efficiency
rhor	1265.89	19.75	0.0506
psi	345.29	72.40	0.0138
rhop	413.30	60.49	0.0165
beta	4755.60	5.26	0.1902
kappa	219.72	113.78	0.0088
phi	1275.50	19.60	0.0510
rhou	430.03	58.14	0.0172
rhog	1902.22	13.14	0.0761
rhoe	560.32	44.62	0.0224
sd(e.u)	115.86	215.78	0.0046
sd(e.g)	413.97	60.39	0.0166
sd(e.es)	727.36	34.37	0.0291