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Editor's Comment

In the December 2021 edition of the WAFER Journal, we included three papers, which emanated from the peer-reviewed articles on Dynamic Stochastic General Equilibrium (DSGE) modeling analyses using Maximum Likelihood Approach on three WAIFEM member countries namely Liberia, Sierra Leone, and Nigeria. Those were products of WAIFEM's capacity-building activity in 2021. In this edition of the WAFER Journal, as a follow-up on those efforts, four member countries successfully produced papers using the Bayesian DSGE Approach in Macroeconomic Modelling, conducted under WAIFEM's Capacity Building activity in 2022. The country papers are from Sierra Leone, Nigeria, Ghana and Liberia. These papers equally went through the peer review process to qualify for publication. The titles of the research papers are:

- Analysis of Monetary Policy, Productivity and Demand Shocks on Output, Inflation, and Interest Rate in Sierra Leone: A Bayesian DSGE Approach
- Analysis Of Monetary Policy And Productivity Shocks In Nigeria: A Bayesian DSGE Approach
- Analysis Of Monetary Policy Response To Productivity and Demand Shocks in Ghana: A Bayesian DSGE Approach
- Estimating Dynamic Stochastic General Equilibrium Models for Monetary Policy Analysis in Liberia: An Extension Using Bayesian Approach

The findings from the study on Sierra Leone suggest that; monetary policy shocks have transitory effects on inflation, interest rates, and output, while productivity shocks have permanent effects on inflation, interest rate, and output. However, demand shocks are found to be temporarily inflationary and their overall effects on inflation, interest rates, and output are also transitory. The authors recommend that the Bank of Sierra Leone should continue to reform the financial sector to encourage financial inclusion to improve monetary policy transmission. Moreover, the effort to improve fiscal and monetary policy coordination should be sustained, as the result clearly shows that productivity shocks are permanent. Therefore, growth in productive capacity requires growth in the real sector, which the Central Bank can only effectively support through policy coordination with the fiscal authorities.

In the case of Nigeria, the study finds that monetary policy, productivity, and demand shocks have initial positive effects on the interest rate in Nigeria though the short-term persistence of productivity shock is higher than all three shocks. Also, the impact of productivity shock on policy rate is more persistent than that of demand and monetary policy shocks. A policy implication from the study is that the Central Bank of Nigeria will likely increase interest rates in response to productivity, demand, and own shocks. However, the rate hikes in response to productivity shocks are higher than those to demand and monetary policy shocks. The study thus recommends the need for the CBN to employ alternative monetary policy instruments aside from the interest rate in a bid to stimulate the economy in the face of productivity shocks.

The findings from the study on Ghana suggest that the response of MPR to productivity shock is non-monotonic and somewhat permanent, whilst the response of MPR to demand shock is very transient. Thus, based on the findings, the monetary authority in Ghana has to choose between the objectives of maintaining a stable exchange rate and lowering the interest rate to raise the level of productivity.

The findings for Liberia 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. Moreover, the findings reveal that the impact of productivity shock on inflation and output gap in Liberia is positive and transient while demand shock has a transient positive impact on inflation with a negative transient impact on output. Furthermore, 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.

The painstaking efforts of our facilitators, authors, and reviewers in bringing out these papers are highly commendable.

Baba Yusuf Musa Ph. D
Editor-in-Chief

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TECHNICAL EFFICIENCY OF PRODUCTIVITY IN NIGERIA'S MERGERS AND ACQUISITIONS OF NON-FINANCIAL COMPANIES

Mfon N. U. Akpan*[1], Aye Aye Khin[2], Wong Hong Chau[3], Peter Wanke[4] and Yong Tan[5].

Abstract

This paper examines the long-term impact of mergers and acquisitions (M&As) on technical progress of non-financial companies in Nigeria. The technical progress is measured by the Malmquist Productivity Index. In terms of the long-term impact of mergers and acquisitions, we assess the significance of the productivity changes through the Mann-Whitney U-test and Kruskal Wallis test. The results show that before M&A, the target companies have the highest Malmquist index(MI), followed by one of the resulting controlled companies, the bidder companies have the lowest MI, although the latter two have a very small difference. We further find that there is a long-term impact of M&A on the bidder companies, resulting controlled companies and target companies, as evidenced by the significant efficiency changes few years of the M&A. We recommend that for the bidder and target companies, they should be more careful in making the M&A decisions, but for the resulting controlled companies, the practice of M&A is recommended.

Keywords: Mergers & Acquisitions; Nigeria; Productivity; technical regression; non-financial companies.
JEL: B26, C14, G34, O55.

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1.0 INTRODUCTION

Global integration, competition, and the active market have brought an important shift to the global economy and the operations of large businesses. In 2015, US$ 2 trillion was spent acquiring 1,000 companies in the United States of America (Bommaraj, Ahearne, Hall, Tirunillai, & Lam, 2018). Today, mergers and acquisitions (hereafter, M&As) play an important role in shaping industry activities worldwide and have become an important business strategy to help improve organizational performance (Coccorese, &Ferri, 2020).The benefits from a successful M&A include cost saving, increased profits, up scaling, and abundant resources (Halkos and Tzeremes, 2013; Peyrache, 2013). The cost saving and increased profit can be mainly achieved by the effect of economies of scale and or economies of scope, while up scaling and abundance resources can be achieved by the fact that the merged entity will benefit from the abundance of raw materials including not only the capital and fixed assets, but also talented human resources as well from the perspective of manufacturing, administrative and managerial personnel. Moreover, M&As are undertaken on the assumption that the combined companies will have a greater value compared to two individual companies (Golubov., Petmezas, & Travlos, 2012). The merger and acquisition practitioners recommend the merger and acquisition activities because they will not only improve the productivity of the merging companies, but also benefit the investors in a direct as well as indirect way. More specifically, the direct benefits include economies of scale and scope in the production; reduction in the transportation cost; better optimized use of resources (Arocena, Saal, Urakami, &Zschille, 2020). The indirect benefits include improve innovation abilities, reduce loss and waste, improve the decision making process. In addition, it is supposed that following the structural change and reconfigurations, the M&A activities could resolve the conflicting issues existed in the pre-merger entity (Moeller, Schliemann, &Stulz, 2005b;Chen, Kao, & Lin, 2011).

The current study has mainly two aims: 1) to investigate the productivity of non-financial companies from different economic sectors in Nigeria under the Malmquist Productivity index; 2) to examine the long-term impact of M&A on productivity. In order to correspond to these two general research aims, in the current paper, we try to answer the following three research questions: 1) in terms of different parties (i.e. bidder companies, target companies, and resulting control companies) in the process of M&A, what would be the performance of each party in terms of their productivity? What is the main source of productivity, is it technical change or technological change: 2) what would be the condition of the indicators in 1 for different periods after M&As (1 year, 2 years, and 3 years)? 3) what would be the level of productivity and its components (catch-up and frontier shift) for different industries for bidder companies, target companies, and resulting control companies? Address these questions will fill in the gap of the literature and the significance of address these questions can be reflected by: 1) in order to provide accurate and specific policy implications, we need to think about and look at the M&A process in a careful manner by dividing the entities into three groups: bidder companies, target companies and resulting control companies. Looking at the productivities of each of these three groups of companies could generate more comprehensive and effective policies; 2) it is importantly to look at the source of productivity, if the productivity is derived from the technical change, it would be recommended that the companies should improve their internal operational through better optimize the resources, while it is the productivity is driven by the technological change, policies should be more oriented to capital investment and enhancement of research, development and innovation activities; 3) because we are going to look at the long-term effect, as illustrated in our research aim, defining "long-term" will be one of the main issues. The long-term effects of an M&A can be considered to be between 3 to 5 years after the activity with the medium-term being 2 years, and the short–term being 1 year (Zollo and Meier, 2007;Sudarsanam, (2010). First of all, increasing the period by several years creates problems since the longer the years, the greater the likelihood that other events such as financial, operational, and strategic changes of the bidder company will affect its valuation. Secondly, longer intervals raise queries about the effectiveness of statistical test procedures and decrease the dependability of the test results (Sudarsanam, 2010). Cosh, Guest, and Hughes, (2006); Antoniou, Petmetzas, and Zhao, (2007); Krishnakumar and Sethi (2012); Shams and Gunasekarage (2016); Navio-Marco, Solorzano-Garcia, and Matilla-Garcia, (2016); Mager and Meyer-Fackler (2017) applied 3 years post-M&As as long-term evaluation periods in their studies. Thus, applying a 3-year interval should be suitable for pre-and post-M&A evaluation for this paper. In order to have a better understanding about the impact of M&A in the Nigeria context, we are going to look at the productivity across different economic sectors. This is really important due to the fact that the results could vary among different industries.

In the Nigerian context, M&As have been most commonly reported in the banking and financial sectors of Nigeria (Eferakeya & Alagba, 2015; Onikoyi & Awolusi, 2014; Achua & Ola, 2013; Ebimobowei & John, 2011; Umoren, & Olokoyo, 2007). M&As in Nigeria has been an ongoing process resulting from some economic judgments justified by market forces and have been reinforced and stimulated by both governments as well as the controlling authorities such as the Central Bank of Nigeria (CBN), Nigerian Capital Market (NCM), and the National Insurance Commission (NAICOM) with conglomerate M&As occurring between 1993 and 1994. The most outstanding activities in mergers and acquisitions in Nigeria were undeniably the 2005 amalgamations that took place in the banking sector. Numerous studies have attempted to investigate the M&A in Nigeria's non-financial sector (Akpan, Aik, Wanke, & Chau, (2018); Akpan & Akpan, (2019); Akpan, Wanke, Chen, & Antunes, 2020), this is still an understudied topic. Babatunde and Haron (2015) examined the post-M&A Total Factor Productivity (TFP) change of insurance companies in Nigeria under a time horizon of five years. although the study looked at the productivity change, the significance of the productivity change as well as the significance of the changes in the productivity components was not carefully considered. As a matter of fact, concerning the Nigerian context, studies have primarily focused on how M&As influence bidder and target share price performance in the short-term assessment (e.g., Omoye and Aniefor, 2016; Onikoyi and Awolusi, 2014). Specifically, Omoye and Aniefor (2016) focused on the investigation of the implications of mergers and acquisitions on profitability, leveraged buy-out, and shareholder wealth. No effort has been shown to investigate the linkage between M&A and productivity and its components. Using a sample of data from Nigeria, Akpan *et al*. (2018) investigate the impact of voluntary horizontal M&As on operating performance over the period 1995-2012. However, there are still several issues that have not been explored, one of which would be there is no attempt to investigate the level of productivity and its components for different parties during the M&As process. Also, it seems that the study did not consider the resulting control companies. Akpan *et al*. (2020) further contributed to the previous two studies by investigating the impact of M&A on the performance of Nigeria focusing on five different economic sectors including consumer group, healthcare, industrial, oil and gas, and services over the period 1995-2012. No detailed analysis was provided in terms of the level of productivity and the impact of the period after M&As on the level of productivity and its components.

Our results showed that before M&A, the target companies have the highest MI, followed by the one of the resulting controlled companies. The bidder companies have the lowest MI, although the latter two have a very small difference. We further find that there is a long-term impact of M&A on the bidder companies. The resulting controlled companies and target companies, as evidenced by the significant efficiency changes few years of the M&A. we recommend that for the bidder and target companies, they should be more careful in making the M&A decisions, but for the resulting controlled companies, the practice of M&A is recommended.

2.0 DATA AND METHODOLOGY

2.1 The Data

The sample for this study (see Table 3.1) comprise all the public listed non-financial companies that have initiated and completed a horizontal voluntary M&A in Nigeria with data from 1991 to 2016. This interval allowed for 3-year data pre-1995 M&As (1992 to 1994) and 3-year data post-2013 M&As (2014 to 2016). The interval data needed for the computation of Malmquist productivity index covered the period of 26 years from 1991-2016. This period of investigation covered recent M&As and also ensured that sufficient pre-and post-M&A sample data are available to evaluate the productivity and technical efficiency performance of companies in the study. The criteria for selecting companies are stated as follows: (a) The bidder firm must be listed on the Nigerian stock exchange (NSE) and have acquired more than 60 percent voting rights of the target companies with the assumption that 60 percent is sufficient to give control as specified in section 313(1) of the reviewed Security and Exchange Commission Act of 2011. (b) The target companies are companies listed on the NSE. (c) The merger is restricted to the voluntary horizontal type of M&As that take place in the same industry between companies with the same or similar products, services, markets, and technologies. (d) Both the bidder and target companies are Nigerian domiciled, not foreign companies. (e) The mergers of businesses where acquirers had already acquired more than 60% stake or related companies are excluded. This is because such an arrangement or transaction does not show a firm's intention to seek external growth (Song Ali, Pillay, 2005b), which is the responsive focus of the study. Therefore, including them could amount to a spurious research finding. Another two criteria were included. (f) The combination involving investment trust and financial institutions (banks and insurance companies), which are mostly involuntary with government interventions, are excluded because their accounting requirement needs to be treated separately, and (g) the firm must have three years pre-M&A and post-M&A financial data available for use, excluding the merger year.

Table 3.1 - Summary of Sample Selection

	Bidder	Target	NSE(Non-Merging)
Initial Deal Identifies	270	270	170
Banking	72	41	25
Insurance	56	21	35
Mortgage bank	24	8	30
Investment trust	36	0	14
Discount Houses	22	0	16
Non-Financial (Not selected)	NA	NA	20
Involuntary Excluded	210	70	NA
Not listed on the Exchange	17	126	NA
Annual reports not separated 3 years after	8	9	NA
No Three years before/ after Data	5	35	NA
Total not listed Plus Involuntary	240	240	NA
Voluntary M&As (Listed with complete data)	30	30	NA
Same horizontal business	√	√	√
Comparable year established	√	NA	√
Cross-Border M&A	0	0	NA
NSE Non-Financial selected	NA	NA	30

Source: Security and Exchange Commission (SEC) and Nigerian Stock Exchange (NSE).

This study applied total asset, labor, and cost of sales as inputs variables, net operating profit after tax (NOPAT) as an output variable. This is because all taxes and other reductions have been taken from these company business transactions with this value and our hypothesis is a better variable than a turnover where both taxes and other reductions have not been deducted.

Table 3.2 Variables Summary Statistics

Variables	Bidder Companies Before M&A (in million Naira)	After M&A (in million Naira)
Total Asset	1,847,871,994.00	3,685,023,785.00
Labor cost	249,058,138.00	521,297,468.00
Cost of Sales	167,824,774.00	427,464,542.00
NOPAT	449,680,402.76	927,333,710.69
	Target Companies	

Total Asset	124,483,623.00	304,787,547.00
Labor cost	32,064,231.00	43,654,945.00
Cost of Sales	14,219,952.00	61,222,132.00
NOPAT	14,385,713.01	21,235,861.19
	Control Companies	
Total Asset	953,976,043.00	1,503,366,990.00
Labor cost	149,772,444.00	250,683,367.00
Cost of Sales	79,275,520.00	191,762,455.00
NOPAT	225,831,418.82	210,423,530.01

Source: Respective Company's Annual Reports.

2.2 Variables and Measurement

In this section, the measurement of variables is of key concern to guide readers on quantification of assumed specific effects. Of primary concern are the measurement of M&A and technical progress. As stated above, M&A is often measured in terms of its effects on some indices of performance. The measurement of M&A in this study is based on input and output variables namely Total assets, Cash flow ratio, Market value, Financial leverages or Equity ratio or Debt ratio, Tobin's' Q, Cash & growth, Return on equity, Return on assets, Inventory turnover, Receivables turnover Ratio, Return on sales ,Quick ratio amongst others. Specifically, applied total asset, labor, and cost of sales as inputs variables, net operating profit after tax (NOPAT) as an output variable to measure the performance of M&As. This measurement aligns with that used by Jin, Xia, Li, Li, &Skitmore(2015).

On the other hand, Technical progress is usually measured as the residual between the growth of output and a weighted sum of inputs. This measure is derived from an aggregate production function which was earlier applied by Solow (1957), Thiry&Tulkens(1989) and lately by Zambelli, &Fredholm, (2010). This measurement can be seen and clearly inferred from Figure 10 presented in the paper.

2.3 Methods

The classification of companies into either the financial or non-financial sector is done by the Nigerian Stock Exchange (NSE). The sorting into financial and non-financial sectors is carried out from the NSE list by the Security and Exchange Commission (SEC) on all M&A activities. SEC is the controlling body on all M&A issues and approvals.

Technical efficiency refers to the accomplishment of producing the maximum output by utilizing the input in the most efficient way. Therefore, all technical efficient DMUs are located on the efficient frontier, while all those below the frontier waste their resources relatively (Cooper, Seiford, and Zhn, 2011). DEA model was developed for the analysis of the technical efficiency of such an entity. It is called DEA because statistics for the finest practice decision-making units (DMUs) create the production frontier, then "envelops" the statistics from other DMUs. On DEA benefit, Cummins and Rubio-Misas (2006) discussed the benefits of DEA say, that it does not require an outright specification of the cost function, but rather compute efficient "best-practice" production and cost frontiers obtained on linear combinations of companies in the industry.

As a non-parametric mathematical programming method, DEA flexibly estimates the relative productive efficiency of multi-input and multi-output DMUs. Unlike the multiple regression models, which determine the production function that only deals with a single output and several inputs, another benefit of applying DEA is an assignment of one efficiency score, which allows the categorization of the DMUs in the sample. It identifies where improvement is needed for each DMU such as reducing the excess input or underproduction of the output. It allows for possible making of inferences on DMUs' group profiles. Comparison between the production performances of each DMU to a set of efficient DMUs is called the reference set. This concept allows the DMU owners to know the reference set appearing most for proper maintenance and utilization (Karaduman, 2006). Data envelopment analysis (DEA) was employed by Chen, Kao and Lin (2011) in the long-term efficiency research of Taiwanese banks from 1997 to 2006. In Africa, the assessment of efficiency of six ports in West Africa by VanDyck (2015) involved the use of the DEA model and revealed that the port of Tema in Ghana is the most efficient one in West Africa. In the study of the efficiency of banks, Kutlar, Kabasakal, and Babacan (2015) applied Malmquist index analysis and DEA in Turkey between 2003 and 2012.

Mahadevan (2002) defined efficiency change as a catching-up effect (reaching the production frontier) and the technical (technological) change as a technological change frontier effect (shifting of production frontier). Coelli, Rao, O'Dennel, and Battese (2005) opined that a Malmquist productivity change analysis between two periods is an example of comparative statistics. This is equally defined in terms of catch-up and frontier shifts and the product of both is the Malmquist index. Catch-up shows progress in technical efficiency, from period one to the next, and when the value is greater than one, equals to one or less than one, it shows no change in the first two scenarios and regression in the last scenario respectively. Frontier–shift (technological change) or innovation shows improvement in the frontier technology when the value is greater than one and when equal to one and less than one, it shows no change and regression in technology improvement respectively.

2.3.1. Data Envelopment Analysis (DEA)

Due to limited resources in both public and private companies or DMUs and pressure on efficient management of resources, a tight budget is called for requiring the need for technical improvements (productive or cost efficiency). This relates the output to a given level of inputs. So efficiency scores are determined by the difference between the ratios observed of combined quantities of output to input and the ratio achieved by the best practice. The main aim is to have the ability to produce the maximum output or utilize the minimum inputs compared to what is technically feasible (Cooper, Seiford, Tone,.2007a). In evaluating the technical efficiency of a DMU involving multiple outputs and multiple inputs, the ratio method is not sufficient because the most efficient DMU according to a specific ratio cannot be efficient according to another (Cooper, Seiford, Tone, & Zhu, 2007b). Therefore, the quantity of all outputs (virtual outputs) to all inputs (virtual inputs) is applied in preventing the disadvantage of simple ratio in multiple inputs/multiple outputs. Chen *et al.* (2011) applied labour cost, depreciation, and total assets as input variables and turnover as an output variable in evaluating company efficiency after M&As. The DEA model for technical efficiency was first proposed by Charnes*et al.* (1978) in a ratio form as provided by Bader, Mohammed, Ariff and Hassan (2008) and expressed as follows:

Max $\beta\ (u_r v_i) = \frac{\sum_{r=1}^{s} u_r \varphi_{r0}}{\sum_{i=1}^{m} v_i x_{io}}$......... (1)

Subject to $\frac{\sum_{r=1}^{s} u_r \varphi_{rj}}{\sum_{i=1}^{m} v_i x_{i0}} \leq 1$ j=0….n

$\frac{u_r}{\sum_{i=1}^{m} v_i x_{i0}} \geq \varepsilon$ r=1,…s

$\frac{v_i}{\sum_{i=1}^{m} v_i x_{i0}} \geq \varepsilon \ \ \mathrm{r} = 1, \ldots \mathrm{m}$

φ_{rj} is the quantity of output r produced by firm j, (NOPAT) obtained from respective annual reports

x_{ij} is the quantity of input i used by firm j,

u_r is the weight of output u, v_i is the weight of input v. In order to surmount the failure of DEA in discriminating between DEA efficient units, cross-efficiency evaluation (Doyle and Green, 1995) has been suggested in the literature. In cross-efficiency evaluation, every DMU determines a set of input and output weights independently; producing n sets of weights for n DMUs, resulting in n efficiency values for every DMU. The n efficiency data for each DMU are lastly averaged as an overall efficiency value of the DMU. The cross-efficiency evaluation guarantees a unique ordering of the DMUs (Ji, Liu, Qiu, Lin, 2015).

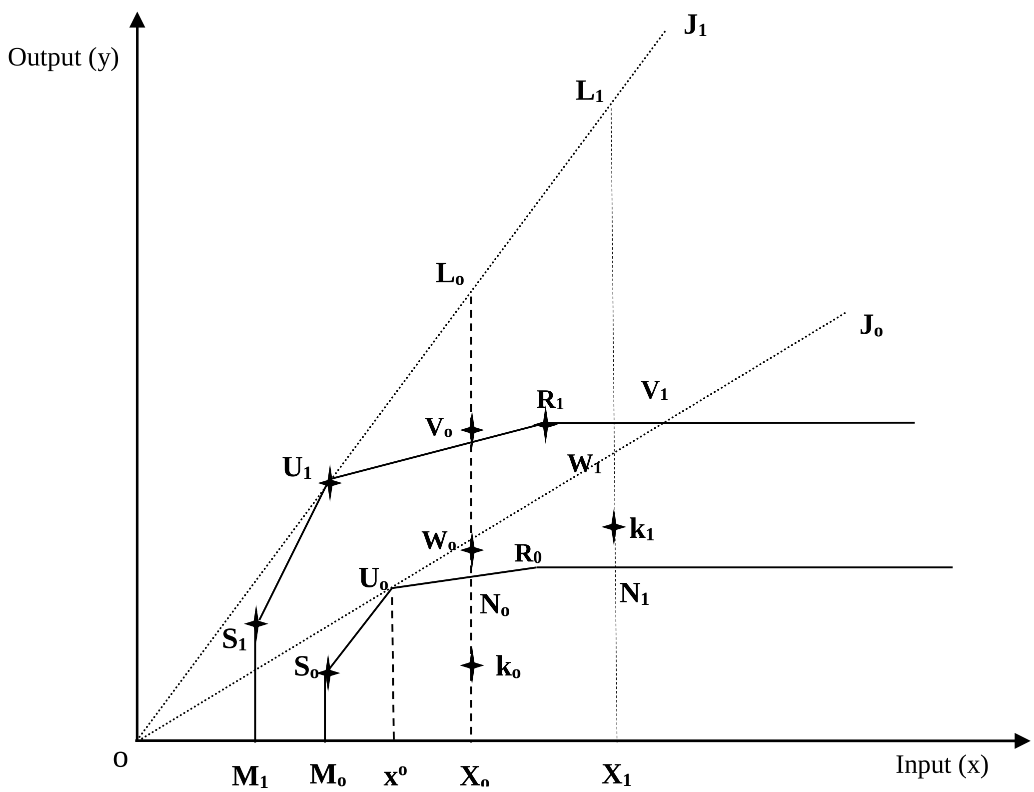
ε = the small positive number to hinder weight from becoming zero. When φ =1, this implies that the DMU is efficient, but if φ< 1, it means that the DMU is not efficient.

2.3.2. Malmquist Productivity Index (MPI)

The MPI decomposition alternative provided by Ray and Desli (1997) (see Figure 1) using MPI decomposition was based on the geometric mean on variable return to scale (VRS) technology. Färe, Grosskopf, Lindgren and Roos (1992)'s MPI decomposition criticism came from Lovell (2003, p. 440-443), whereby, - the alternative approach by Ray and Delsi (1997) overcomes these criticisms. The estimates of the Malmquist index (MI) produced by Ray and Delsi's (1997)'s approach will allow for whether the changes are significant in a statistical sense as indicated appropriately by Simar and Wilson (1999). As it is not enough to know whether the Malmquist index estimator indicates decreases or increases in productivity, but whether the changes are significant (Simar& Wilson, 1999). The issues of concern raised by Ray and Desli (1997) about Färe, *et.al.* (1992) MPI decomposition and their application to analyze the rate of productivity change among the 17 OECD countries over the period 1979 to 1988 are related to them using the constant return to scale (CRS) and variable return to scale (VRS) technology within the same MPI decomposition, bringing about internal consistency problem. First, the Malmquist index was decomposed into two structures, changes in the technical efficiency, which can be interpreted as catching up; - and technical change. Then catching up being further decomposed into pure technical efficiency change and scale efficiency change, - as characterized by variable returns to scale. Because, - if CRS technology is expected to hold, the technical change term rightly corresponds to a shift over time in the frontier. Thus, scale efficiency change and pure efficiency changes are obtained from VRS within two different periods.

On the other hand, there is no scale effect existing at all under CRS, therefore deceptive expanded decomposition occurs. Secondly, if assuming that VRS is accurate, the technical change does not display how the maximum producible output changes as a result of a technical change by keeping the input package constant; meaning that independent shift in the frontier is not measured. Hence, the significance of their MPI decomposition using VRS as a benchmark in measuring technical efficiency changes as a ratio of VRS distance functions while using the geometric mean of the sample. As this affects scale efficiency change value only, the pure technical efficiency change value remains unaffected. The alternative nonparametric method of decomposing the Malmquist index by Ray and Desli (1997) to what Färe*et. al.*(1992) did base on a variable return to scale benchmark is given in Figure I, for which it is possible the changes in the most productive scale size for each technological pack. By attaining at the most productive scale size, estimates based on CRS and VRS assumptions yield the same results, therefore, the consistency issue raised by Ray and Desli (1997) is addressed. This is particularly useful when analyzing DMUs of different industries under different periods utilizing monetary inputs and outputs, in a way that the conclusions as regards the impacts of M&As in the Nigerian economy will not be impacted by distinct assumptions.

Figure I.0: VRS and CRS Production Possibility set



Source: Ray and Desli (1997).

Assuming a single input and output industry, let $x^t{}_k$ and $y^t{}_k$ represent the input and output quantity of company k at time t. The company average productivity (AvP) at time t is

$$AvP = y^t{}_k \,/\, x^t{}_k \quad \ldots. \quad (2)$$

Therefore, a productivity index of this company at time t+1, - at period t being the base will be

$$\bar{A}_k = AvP^{t+1}{}_k \;/\; AvP^t{}_k \ldots..(3)$$

$= (y^{t+1}{}_k \ / \ x^{t+1}{}_k) \ / \ \ y^t{}_k \ / \ x^t{}_k$

We need a benchmark technology (Ray and Delsi,1997) as this productivity index is not dependent on assumption about returns to scale, which is shown in Figure I. Considering an industry of four companies - K, S, U, and R. Points K_0 through R_0 indicate the observed input-output levels of these companies in time 0. Likewise, K_1 through R_1, the input-output levels at time 1. Thus, company K uses input $0x_0$ to produce output K_0x_o in time 0 and input $0x_1$ to produce K_1x_1 in time 1. Therefore, company K in the period 1 productivity index is;

$$\bar{A}_A = (K_{1x1}/0_{x1}) \ /(K_{0x0}/0_{x0}) \ldots . \ (4)$$

All the points, K_0, S_0, U_0,,andR_0, signify possible input-output combinations in period 0. The set of points and the broken line bounded by the horizontal axis – M_O, S_0, U_0, R_0 extension are the free disposal convex hull. All these points in the region represent the possible input-output combination in period 0 under VRS. Also under CRS, all the radial enlargements (non-negative) reduction of possible input-output packages are also possible. Therefore, the CRS production possibility set in period 0 become cone shaped by the horizontal axis and ray $0J_0$ through point U_0. On the other hand, VRS frontier during period 1 is the dotted line $M_1S_1U_1R_1$ - extension and the CRS frontier is the dotted line $0J_1$ through point U_1. Therefore, the maximum producible output in period 0 from input $0x_0$ is W_0 x_0 under the CRS supposition and N_0 x_0 under the VRS assumption. Thus, the distance function (DF) as Ray and Delsi (1997) did is as follows:

$DF^0{}_c(x0, y0) = K_{0x0}/W_{0x0} \ldots . \ (5)$

$DF^0{}_c(x1, y1) = K_{1x1}/W_{1x1}$

On CRS basis

$DF^0{}_v(x0, y0) = K_{0x0}/N_{0x0}, \ \ldots . \ (6)$

$DF^0{}_v(x1, y1) = K_{1x1}/N_{1x1}$

On VRS basis. Alternatively, the productivity index of company K can be stated as:

$\bar{A}^0{}_A \quad = DF^0{}_c(x1, y1) \ / \ DF^0{}_c(x0, y0), \qquad (7)$

$\bar{A}^1{}_A \quad = DF^1{}_c(x1, y1) \ / \ DF^1{}_c(x0, y0), \qquad (8)$

This shows that the productivity index is equivalent to the ratio of the CRS distance function, even if not characterized by constant returns to scale. By comparing the CRS and VRS frontiers at 0, alongside the CRS frontier, - the average productivity remains constant, but this is not the situation along the VRS. This is because both N_0 and N_1 are points on the frontier and are therefore different technically. The mean productivity at N_0 is higher than the average at N_1. The highest point of average productivity along the VRS frontier in the period 0 is U_0. This corresponds to what Banker, Charnes, and Cooper (1984a) and Banker*et al*, (1984b) named the most productivity scale size, as previously discussed. So the mean productivity at the MPSS of the VRS frontier is equal to the constant average productivity at any point on the CR frontier. While the scale efficiency (SE) at any point on the frontier is evaluated by the ratio of the average productivity at that point to the average productivity at MPSS. Therefore,

$SE^0(x0, y0) = DF^0{}_c(x0, y0) \ / \ DF^0{}_v(x0, y0),$ (9)

$SE^0(x1, y1) = DF^0{}_c(x1, y1) \ / \ DF^0{}_v(x1, y1).$ (10)

Thus, the productivity index can be expressed alternatively as Ray and Delsi (1997) did as:

$\bar{A}^0{}_A = \frac{DF^0{}_v\ (x1,y1)}{DF^0{}_v\ (x0,y0),} \frac{SE^0\ (x1,y1)}{SE^0\ (x0,y0)}$ (11)

$\bar{A}^1{}_A = \frac{DF^1{}_v\ (x1,y1)}{DF^1{}_v\ (x0,y1),} \frac{SE^0\ (x1,y1)}{SE^0\ (x0,y0)}$ (12)

By using the geometric mean as Ray and Delsi (1997) did, we have

$$\bar{A}_A = \left(\frac{DF^0{}_v\ (x1,y1)}{DF^0{}_v\ (x0,y0),} \frac{DF^1{}_v\ (x1,y1)}{DF^1{}_v\ (x0,y0),} \right)^{1/2} \times \left(\frac{SE^0\ (x1,y1)}{SE^0\ (x0,y0)} \frac{SE^1\ (x1,y1)}{SE^1\ (x0,y0)} \right)^{1/2} \quad (13)$$

The right hand side first factor can further decompose as:

$$\left(\frac{DF^0{}_v\ (x1,y1)}{DF^0{}_v\ (x0,y0),} \frac{DF^1{}_v\ (x1,y1)}{DF^1{}_v\ (x0,y0),} \right)^{1/2} = \left(\frac{DF^0{}_v\ (x0,y0)}{DF^1{}_v\ (x0,y0),} * \frac{DF^0{}_v\ (x1,y1)}{DF^1{}_v\ (x1,y1),} \right)^{1/2} \times \frac{DF^1{}_v\ (x1,y1)}{DF^0{}_v\ (x0,y0),}$$

Thus, $\bar{A}_A$ = (TeCHCH (v)) x (PEFFCH). (ScCH (v)). (14)

Where technical change efficiency

TeCHCH (v) = $\left(\frac{DF^0{}_v\ (x0,y0)}{DF^1{}_v\ (x0,y0),} * \frac{DF^0{}_v\ (x1,y1)}{DF^1{}_v\ (x1,y1),} \right)^{1/2}$ (15)

Pure technical efficiency change; PEFFCH = $\frac{DF^1{}_v\ (x1,y1)}{DF^0{}_v\ (x0,y0),}$ (16)

Scale efficiency change; ScCH (v) = $\left(\frac{SE^0\ (x1,y1)}{SE^0\ (x0,y0)} \frac{SE^1\ (x1,y1)}{SE^1\ (x0,y0)} \right)^{1/2}$ (17)

3.0 ANALYSIS AND DISCUSSION OF RESULTS

Table 4.1 presents the mean excess efficiency scores using a DEA model with three inputs (total assets, labor cost, and cost of sales) and with the net operating profit after tax (NOPAT) as output for the bidder, target, and resultant control firm before and after the M&A by subtracting the average DEA improvement or decline before from the after average DEA. The results showed a significant decline in efficiency scores by the bidder and target companies three years after the M&A, but a significant improvement in efficiency scores of the resultant control companies, meaning that the technical improvement expected was not realized, but the bidder companies stimulated a significant improvement for the resultant control companies. Our results related to the bidder and target firms are in contrast with Akpan *et al*. (2018) who find that both bidder and target firm experience an increase in the level of efficiency after M&A. the different results to some extent are attributed to the fact that we use a sample of data covering a longer period. The significant improvement in the level of efficiency for the resultant control companies is following the argument of Devos *et al*. (2009) and Takechi (2013). The improvement in the level of technical efficiency of the resultant control firm can be achieved by increasing the turnover, working together with bidders to achieve targets as well as engaging in research and development.

Table 4.1 - Results of efficiency scores for bidder, target, and resultant control firm

Companies	Mean DEA After	Mean DEA Before	Mean Increased/ Decreased	Mann Whitney U-Test (P-value)
Bidder	0.0099	0.0106	-0.0007	0.028*
Target	0.0016	0.0082	-0.0066	0.001*
Resultant control	0.0097	0.0035	0.0062	.041*

Notes: This table shows mean efficiency score results based on available data before and after the M&A using a DEA model. * Indicates Mann Whitney U-test significance test at 5 percent level.

The interval efficiency score results under the DEA model from the bidder companies showed a decrease 1 year before and 1 year after and 3 years before and after the M&A, while 2 years before and after the M&A showed an increase. When these differences were tested, 1 year and 3 years after the M&A was significant, signifying that when the interval is considered, a significant decline is reported 1 and 3 years after, while a non-significant improvement was noted 2 years after for the bidder companies' efficiency scores. The DEA model results of the resultant control companies showed a significant improvement in efficiency scores 2 years and 3 years after the M&A, while 1 year after showed non-significance. Comparing our results with the one of Akpan *et al*. (2018), both of these two studies show that 1year before and 1 year after for the bidder companies and target companies, there are decreases in the level of efficiency and the effects are significant. Also for the bidder companies, there is an increase in the level of efficiency, but the effect is insignificant as shown in our study, however, Akpan *et al*. (2018) show that there is an insignificant decline. Finally, for 3 years before and 3 years after, Akpan *et al.* (2018) report that there is a significant increase in the level of efficiency for the target firm, while we report an opposite result. Karimzadeh (2012) argued that the resulting control companies in

Nigeria could be oversize compared to the scale of the market they are serving, our results indicate that it will take one-year time for the resulting companies to optimize the size of their operation, the resulted economies of scale can be achieved from the 2nd year onward. The Sub-Interval results of mean efficiency scores for bidder, target, and resultant control companies are provided in Table 4.2.

Table 4.2 - Sub-Interval results of mean efficiency scores for bidder, target, and resultant control companies

Bidder Companies	Mean DEA (Inc./Dec)	Mann Whitney U-Test
1Year Before& 1Year After	-0.0028	0.032*
2Years Before &2Years After	0.0016	0.594
3Years Before &3 Years After	-0.002	0.021*
Target Companies		
1Year Before &1Year After	-0.0045	0.011*
2Years Before &2Years After	-0.003	0.407
3Years Before &3 Years After	-0.0062	0.016*
Resultant Control Companies		
1Year Before &1 Year After	0.0038	0.306
2Years Before & 2Years After	0.0057	0.001*
3Years Before& 3Years After	0.0066	0.010*

Notes: This table shows mean efficiency score results based on available data before and after the M&A using a DEA model. * Indicates Mann Whitney significance test at 5 percent level. Inc. represents increase and Dec. for decrease.

With the DEA model, all target industries recorded a non-significant reduction in efficiency scores except healthcare, which was significant.

This result revealed that M&A transactions in the healthcare industry were particularly not favorable for the target companies and that the industry factor makes no difference in the efficiency scores of target companies in the long-term. The industry effect on inefficiency scores is worst for the healthcare sector as the efficiency of the bidder and target companies significantly reduced after the M&A in Nigeria, while being non-significant for the resultant control companies. The impact of M&A on the level of efficiency will vary based on the industry type. Akpan *et al*. (2020) argue that the level of the healthcare sector tends to be higher after M&A, which is different from the results that we report. The significant decline in the level of efficiency for the bidder companies can be explained by the fact that some scalability issues may jeopardize the increase in production levels in the healthcare sector, also, higher levels of customization in healthcare operations may impose additional difficulties in standardizing productive resources with a focus on increased production levels. Our results to a certain extent can be supported by Choi (2017) who found that the majority of hospitals which were intended to obtain the volume effect through M&A did not get much benefit from the volume effect. In addition, they found that only 41% hospital acquired outperform their peer groups. For the Nigeria healthcare sector specifically, the main problems suffer from this sector include inaccessibility of quality health care, poor hygiene, corruption, malnutrition, poor health infrastructure, insufficient financial investment and lack of sufficient health personnel. We would like to in particular link the issue of corruption with the performance of M&A in the Nigeria Health care industry. Sahakyan and Stiegert (2012) argue that larger firms are likely to view corruption as favorable relative to smaller firms. Sharma and Mitra (2015) further argue that corruption reduces firm efficiency. The results regarding the Mean Different Industry Efficiency Scores with Mann Whitney U-Test are presented in Table 4.3 and Table 4.4 provides the results of DEA Productivity Efficiency for Bidder, Target, and Resultant Control Company.

Table 4.3 - Mean Different Industry Efficiency Scores (bidder, target, and resultant control companies) with Mann Whitney U-Test

Bidder Companies	Mean DEA Increased/ decreased	Mann Whitney U-Test
Consumer Goods	-0.001	0.663
Healthcare	-0.529	0.050*
Industrial Group	0.002	0.674
Oil & Gas	-0.012	0.827
Services Group	0.001	0.917
Target Companies		
Consumer Goods	-0.008	0.061
Healthcare	-0.093	0.050*
Industrial Group	-0.023	0.059
Oil & Gas	-0.117	0.275
Services	-0.036	0.117
Resultant control companies		
Consumer Goods	-0.0102	0.274

Healthcare	-0.468	0.376
Industrial Group	0.0001	0.708
Oil & Gas	-0.024	0.744
Services	0.0092	0.075

Notes: * Indicates 5 percent Mann Whitney significance. The industries were grouped based on the Nigerian Stock exchange classification.

Table 4.4 - Results of DEA Productivity Efficiency for Bidder, Target, and Resultant Control Company

	Mean After M&A	Mean Before M&A	Mean Increase/ Decrease	Mann Whitney U Test (p-value)
Bidder Companies				
Catch-Up	0.0464	0.0814	-0.0351	0.259
Frontier Shift	0.0031	0.0435	-0.0404	0.016*
Malmquist Index	0.0216	0.0539	-0.0323	0.026*
Target Companies				
Catch-Up	0.0289	0.1589	-0.1301	0.555
Frontier Shift	0.0936	0.0677	0.0259	0.174
Malmquist Index	0.1658	0.1542	0.0116	0.055
Resultant control companies				
Catch-Up	0.0488	0.0659	-0.017	0.928
Frontier Shift	0.0441	0.0378	0.0063	0.739
Malmquist Index	0.0436	0.0541	-0.0105	0.566

Notes: * Indicates significance at 5 percent level. This table shows productivity results of bidder companies using a DEA model. Average is calculated from all data 3 years before and after the M&As.

The result from the DEA model shows a significant decline in technological change for the bidder companies and a non-significant decline for a catch-up with the Malmquist productivity index declining significantly after the M&A. This means that the total factor productivity for the bidder companies declined significantly as the Malmquist productivity index reduced significantly after the M&A. The results from the DEA model show a non-significant improvement in the Malmquist index for target companies. This signifies that there is no long-term productivity improvement after the M&A probably due to non-significant improvement in the technological change. The resultant control companies' productivity results from the DEA did not indicate any significant decline after the M&A. our results related to the significant decline in technological change for the bidder companies are in contrast with the argument of Bruhn, Calegario, Carvalho, Campos, and Dos-Santos (2017) who argue that there is a positive relationship between technological change and M&A among Brazilian companies.

Our results indicate that this argument is partly right and the relationship between technological change and M&A will depend on the companies of a specific country and also relationships will be differ based on the role played by the companies in the process of M&A. To put this results in simple words, we find that after the M&A, the bidder companies experience a decline in the Malmquist Productivity index derived from lack of innovation. This can be possibly explained by the fact that stockholders of the bidder firms would suffer a statistically significant loss of about 10% after the M&A (Agrawal, & Jain, (2015), this would affect the market value of the company and further influence their capacity of capital investment as well as the ability to engage in innovation related activities, which further explain the deterioration in technological change. The Sub-Interval results of Mean Productivity Efficiency for Bidder, Target, and Resultant control companies are provided in Table 4.5 and the results of Mean Different Industry Productivity Efficiency with Mann-Whitney U test are presented in table 4.6.

Table 4.5 - Sub-Interval results of Mean Productivity Efficiency for Bidder, Target, and Resultant control companies

Bidder Companies	Mean DEA Increase/ Decrease	Mann Whitney U-Test
Catch-up		
1year before and 1 year after	-0.005	0.952
2years before and 2 years after	0.0079	0.040*
3years before and 3 years after	0.0055	0.496
Frontier-Shift		
1year before and 1 year after	-0.0084	0.885
2years before and 2years after	-0.003	0.050*
3years before and 3years after	-0.0052	0.145
Malmquist Index		
1year before and 1 year after	-0.0074	0.261
2years before and 2years after	-0.0131	0.038*
3years before and 3years after	0.0087	0.929
Target Companies		
Catch-up		
1year before and 1 year after	0.0403	0.032*
2years before and 2years after	-0.004	0.555

3years before and 3years after	0.0115	0.166
Frontier-Shift		
1year before and 1 year after	-0.0088	0.007*
2years before and2 years after	0.0046	0.496
3years before and 3years after	-0.0058	0.495
Malmquist Index		
1year before and 1 year after	0.0039	0.051
2years before and 2years after	-0.0078	0.853
3years before and 3years after	-0.009	0.567
Resultant control companies		
Catch-up		
1year before and 1 year after	-0.0097	0.328
2years before and 2years after	-0.0016	0.689
3years before and 3years after	0.0001	0.864
Frontier-Shift		
1year before and 1 year after	-0.0041	0.176
2years before and2 years after	0.0133	0.344
3years before and 3years after	-0.0144	0.178
Malmquist Index		
1year before and 1 year after	-0.0073	0.096
2years before and 2years after	0.006	0.672
3years before and 3years after	-0.0248	0.848

Notes: This table shows mean data of the Malmquist productivity index intervals for bidder, target, and resultant control companies under DEA and Mann Whitney U-test in different sub-periods based on available data before and after the M&A.* Indicates significance at 5 percent Mann Whitney.

Table 4.6 - Mean Different Industry Productivity Efficiency (Bidder, Target, and Resultant control companies) with Mann Whitney U Test

Companies	DEA Before M&A	DEA After M&A	Mean Increase/ Decrease	Mann Whitney U-Test (P-Value)
Bidder (Catch-up)				
Consumer Goods	0.0852	0.1743	0.0891	0.320
Healthcare	0.9891	0.9945	0.0054	0.200

Industrial Goods	0.1297	0.0877	-0.042	0.038*
Oil & Gas	0.3333	0.4909	0.1576	0.700
Services	0.238	0.2506	0.0125	1.000
Frontier Shift				
Consumer Goods	0.1072	0.0559	-0.0513	0.001*
Healthcare	2.5121	0.1804	-2.4117	0.121
Industrial Goods	0.1917	0.1116	-0.08	0.105
Oil & Gas	0.1808	0.2483	0.0675	0.700
Services	0.1096	0.184	0.0744	0.062
Malmquist				
Consumer Goods	0.117	0.0641	-0.0529	0.034*
Healthcare	2.5121	0.1804	-2.3317	0.314
Industrial Goods	0.1954	0.1222	-0.0732	0.328
Oil & Gas	0.1808	0.3556	0.1748	0.400
Services	0.1095	0.241	0.1315	0.151
Target				
Catch-up				
Consumer Goods	0.038	0.0719	0.0338	0.153
Healthcare	0.995	0.9961	0.0011	0.511
Industrial Goods	0.0816	0.1037	0.0221	0.535
Oil & Gas	0.3263	0.4204	0.0941	0.400
Services	0.0806	0.0899	0.0094	1.000
Frontier Shift				
Consumer Goods	0.1102	0.1082	-0.002	1.000
Healthcare	1.4425	0.01	-1.4325	0.311
Industrial Goods	0.0742	0.1167	0.0424	0.057
Oil & Gas	0.5085	1.3454	0.8368	0.100
Services	0.2384	0.3301	0.0917	0.151
Malmquist				
Consumer Goods	0.0856	0.1002	0.0146	0.241
Healthcare	1.4425	0.01	-1.4325	0.124
Industrial Goods	0.0453	0.1167	0.0713	0.067
Oil & Gas	0.3722	1.3163	0.9441	0.200
Services	0.5586	0.1636	-0.3949	0.690

Resultant control companies				
Catch-up				
Consumer Goods	0.136	0.050	-0.085	0.005*
Healthcare	1.000	1.000	0.001	1.000
Industrial Goods	0.525	0.170	-0.35	0.267
Oil & Gas	0.976	1.090	0.117	0.827
Services	0.720	0.190	-0.531	0.746
Frontier Shift				
Consumer Goods	0.087	0.080	-0.011	0.001*
Healthcare	2.715	0.010	-2.705	0.317
Industrial Goods	0.057	0.220	0.166	0.001
Oil & Gas	0.229	0.280	0.049	0.827
Services	0.084	0.320	0.235	0.009
Malmquist				
Consumer Goods	0.153	0.140	-0.027	0.001*
Healthcare	2.715	0.010	-2.705	0.317
Industrial Goods	0.176	0.370	0.121	0.958
Oil & Gas	0.574	0.620	0.045	0.827
Services	0.182	0.310	0.132	0.346

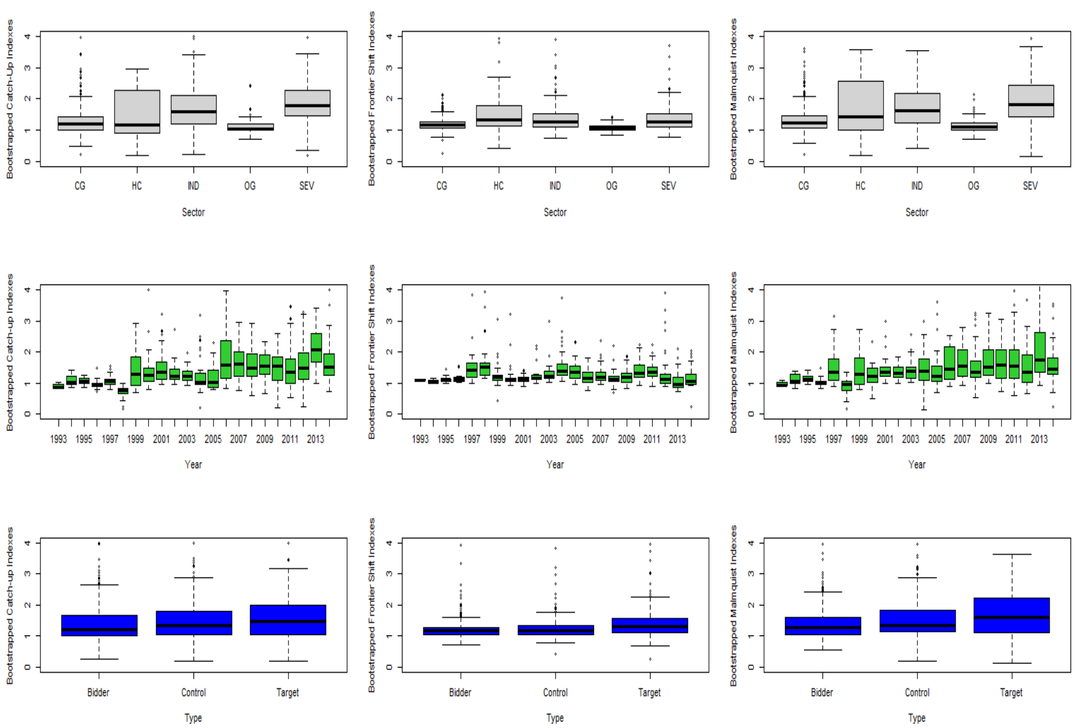
Notes:* Indicates 5 percent Mann Whitney U-Test significance. This table shows mean productivity results and decompositions under DEA models in different industries with the average taken from all data during the 3 years before and after the M&A.

We find that for the bidder companies, there is a significant increase in the level of technical efficiency 2 years after the M&A, however, we find that there is a significant decline in the level of technological change 2 years after the M&A for the bidder companies, in terms of the overall productivity index, we see that 2 years after the M&A, there is a significant decline in the level, which indicates that technological change dominates the overall productivity performance. The MPI as generated by the DEA model showed a significant reduction in productivity efficiency of bidder companies' consumer group because of a significant decline in the frontier shift and a significant decline in the industrial group catch-up. This means that technological change in productivity efficiency is the most important contributor to the bidder companies' improvement. In other word, in Nigeria, the main driver for productivity improvement is to enhance the innovation rather than optimizing the resources in the production process. Oluwajoba, Akinade, Oluwagbemiga, Adeniyi, Aderemi (2009) argue that the manufacturing industries in Nigeria have intensive competitive environment, they need to be continuously innovating to benefit from industrial technologies. This result is not only the case when investigating the issue of M&A when estimating the issue of productivity in the healthcare industry in Ireland and decomposes the productivity into technical change and technological change, but same results were also obtained (Gannon, 2008). The resultant control companies' results from the DEA model indicate a significant decline in the consumer group MPI. This is caused by a frontier shift and catch-up significant decline, respectively. Even with the emerged competitive market following the M&A, the resultant control companies did not record any significant improvements. Instead, those industries under the consumer group were mostly affected by a significant decline in productivity in the long-term, while others remained stagnant. The industry effect result showed that M&A deals did not stimulate productivity growth in the resultant control companies, while the bidder companies recorded a significant decline after the M&A, as evidenced by the consumer group. The industry result reveals a non-significant productivity improvement in the bidder and resultant control company after the M&A in the long run in Nigeria. The industry productivity efficiency of 30 resultant control companies is significantly different particularly with consumer groups between before and after the M&A based on the estimated period.

A robustness analysis was performed in terms of a bootstrapped Malmquist Index (MI) to check the distributional impact of the inputs on the actual confidence levels for productivity estimates, allowing the temporal decomposition of the productive change (MI) in its two major components: efficiency change (or catch-up effect) and technical change (or frontier shift effect).

Fig. 1 presents the 95% confidence intervals for the bootstrapped MI and its decomposed factors under different analytical levels. This result indicates that while there appears to be a slight increase concerning the catch-up effect over the years, the frontier shift effect appears to be stagnant over time. Besides, target companies appear to be more capable of catching-up with the frontier of best practices than bidders and even the resulting control companies, evidencing the difficulty of Nigerian companies to sustain technological progress for longer courses of time. Yet it is noteworthy that despite the heterogeneity of results among distinct economic sectors, the Oil and Gas (O&G) industry, the most relevant in the Nigerian economy, an attractor of FDIs and responsible for a relevant percentage of GDP, tends to remain stagnant even after M&As. This can be partly explained by the overall industry environment. Abdul and Ojenike (2014) argue that following the deregulation in the Nigerian Petroleum sector, the oil and gas industry continues to work through challenging times. There are some problems that are still faced by the companies in this sector including the volatile oil price, uncertain investment and activity levels as well as turbulent financial sector. Our results also indicate that for the companies in the Oil and Gas industry in Nigeria, M&A is not really an effective way to improve productivity. Instead, more emphasis should be given to deliver adequate shareholder return, reduce marginal cost, sustain scale and purse growth. Therefore, it is not possible to conclude in favor of a systematic increase in productive change, efficiency change, and technical change over the years in the Nigerian economy, - as a consequence of M&A activities, - since both lower and upper confidence limits are either below one or above one, respectively. Readers should also pay attention to the difference in scale in Fig. 11 graphs, - as a result of bias removal.

Figure 2.0: Bootstrapped results for MI in Nigerian M&As



Additional OLS regression analyses on unbiased and unbounded MI estimates around 1 were conducted to gain additional insights on the locus of eventual technological improvements derived from M&As in Nigeria. Results presented in Tables 4.7a-4.7c indicate that, differently from catch-up and MI estimates, frontier shift estimates do not present a significant increasing trend over time. Yet, target firms appear to be the key for technological catching-up and innovation, - considering that bidder and control firms do not differ from each other in terms of such dynamism. It seems that M&A spill-overs in Nigerian firms are quite limited and difficult to sustain over time, as can be observed by non-significant coefficients associated to control firms. On the other hand, while different sectors perform heterogeneously with consistent positive behavior in healthcare and services, that does not depend necessarily on M&A to be sustained over time. It is interesting to note that O&G, the prominent sector of the Nigerian economy, presents a significant technological regress. To interpret it in simple words, our results find that Target firm are found to have a higher level of technical efficiency, this is also the case for the healthcare sector as well as the service sector. In other words, we find that the target firms, the healthcare industry as well as the service industry have a more optimal allocation of resources in their operation. In addition, we further notice that the target firms, the healthcare industry and the services industry have a higher score of innovation, as reflected by the positive and significant signs of the coefficients in Table 4.7b.

Table 4.7a. Regression results for catch-up estimates

	Estimate	Std. Error	t-value	Pr (>|t|)
(Intercept)	0.49188	0.37017	1.329	0.184303
Type Non-merger	0.28405	0.24644	1.153	0.249426
Type Target	1.04112	0.31276	3.329	0.000913 ***
Sector HC	2.12313	0.57162	3.714	0.000218 ***
Sector IND	0.49058	0.26952	1.820	0.069110.
Sector O&G	-0.20895	0.37242	-0.561	0.574906
Sector SEV	1.42711	0.36605	3.899	0.000105 ***
I(Year - 1991)	0.03768	0.02115	1.781	0.075249.
Residual standard error	3.13			
Degrees of freedom	788			
R square	0.05644			
Adjusted R-square	0.04805			
F-statistic	6.733			
P-value	9.06e-08			

'*''**''***' represent significant level at 1%, 5% and 10%, respectively.

Table 4.7b. Regression results for frontier-shift estimates

	Estimate	Std. Error	t-value	Pr (>|t|)
(Intercept)	1.110661	0.059191	18.764	0.000 ***
Type Non-merger	0.019575	0.039406	0.497	0.6195
Type Target	0.227271	0.050010	4.544	0.000 ***
Sector HC	0.428328	0.091402	4.686	0.000 ***
Sector IND	0.201374	0.043097	4.673	0.000 ***
Sector O&G	-0.112442	0.059550	-1.888	0.0594.
Sector SEV	0.242512	0.058532	4.143	0.000 ***
I(Year - 1991)	0.003273	0.003382	0.968	0.3335
Residual standard error	0.5004			
Degrees of freedom	788			
R square	0.1013			
Adjusted R-square	0.09336			
F-statistic	12.69			
P-value	1.689e-15			

'*''**''***' represent significant level at 1%, 5% and 10%, respectively.

Table 4.7c. Regression results for MI estimates

	Estimate	Std. Error	t-value	Pr (>|t|)
(Intercept)	0.64590	0.24535	2.633	0.008641 **
Type Non-merger	0.22928	0.16334	1.404	0.160814
Type Target	0.81029	0.20730	3.909	0.000101 ***
Sector HC	1.72721	0.37887	4.559	0.000 ***
Sector IND	0.50673	0.17864	2.837	0.004677 **
Sector O&G	-0.26306	0.24684	-1.066	0.286879
Sector SEV	1.11241	0.24262	4.585	0.000 ***
I(Year - 1991)	0.03622	0.01402	2.584	0.009955 **
Residual standard error	2.074			
Degrees of freedom	788			
R square	0.08458			
Adjusted R-square	0.07644			
F-statistic	10.4			
P-value	1.583e-12			

'*''**''***' represent significant level at 1%, 5% and 10%, respectively.

4. 0 CONCLUSIONS AND POLICY IMPLICATIONS

Using a sample of different economic sectors in Nigeria, the current study investigate the efficiency and productivity of the non-financial companies under the Malmquist productivity index and the study also examine the long-term impact of M&A on efficiency and productivity. In this research paper, we addressed three important questions that have not yet been considered by the previous related studies: 1) in terms of different parties (i.e. bidder companies, target companies, and resulting control companies) in the process of M&A, what would be the performance of each party in terms of their productivity? What is the main source of productivity, is it technical change or technological change: 2) what would be the condition of the indicators in 1 for different periods after M&As (1 year, 2 years, and 3 years)? 3) what would be the level of productivity and its components (catch-up and frontier shift) for different industries for bidder companies, target companies, and resulting control companies? Addressing these three important questions does not only fill in the gap of the literature, but also through comprehensively and careful analysis of these three different questions, we would be able to derive concrete and accurate policies not only for different companies during the M&A process including the bidder companies, target companies as well as the resulting control companies, but also we would be able to provide the results regarding the source of productivity improvement as well as the productivity conditions across different economic sectors in Nigeria.

The study's conclusion is based on the general results obtained, their meanings, with implications. The findings from a robustness check showed that bidder companies' technical and productivity efficiency significantly declined after the M&A in the long term. The technological significant decline by bidder companies was identified as a major cause of significant deterioration in productivity. The target companies significantly declined in efficiency scores and improved non-significantly in productivity after the M&As. The resultant control firm declined non-significantly in productivity and improved significantly in efficiency scores.

The significant improvement in efficiency scores of the resultant control firm after the M&A implies that the bidder companies stimulated the resultant control companies, leading to a positive spill-over effect. The resultant control companies' efficiency scores significantly improved strategized them, remaining competitive, as the market becomes stiffer after the M&A with fewer players. The effect of significant efficiency score improvement by the resultant control company reflected in the study result, while productivity efficiency declined non-significantly compared to the bidder companies' significant declined in both. Therefore, after the M&As, the resultant control company performed better generally than the bidder companies did.

Mann-Whitney U test with robustness check of the bidder company results in the study showing a significant decline in technical and production efficiency, which also has some policy implications. Again, the decline in productivity is caused by a significant reduction in technological change of bidder companies. The resultant control company recorded a significant improvement in technical and productivity efficiency within the same period. The target companies saw a significant decline in efficiency scores with a non-significant productivity efficiency improvement.

Consequently, policymakers in government and companies should re-strategize and possibly overhaul M&A processes to redirect their focus on issues and aspects of the process that may not have been followed very well. For example, these negative results for technical and production efficiency are organizational based problems. Thus, it can be argued that there may have been some internal workings within the organization that hindered effective management. Such mechanisms could include but are not limited to, poor leadership, lack of competent personnel, lack of supporting infrastructural facilities, and poor customer account management. Under these circumstances, decision and policymakers at an organizational level may wish to look into these areas before, during, and after an M&A deal. Externally it may be argued that due diligences probably are not usually exercised before, during, and after M&A deals. Therefore, policymakers could give priority to due diligence in their future policy directives. Overall, when anticipating an M&A, the bidder firm would have to build policy initiatives carefully taking into consideration the likelihood of running into a worse performance. From a practical perspective, providing training to the staff as well as the leader of the companies would be a necessity for increase the success of an M&A, leaders are expected to improve their ability from the perspective of decision making in the operational process, whereas, the labors are expected to improve their productivity. A particular emphasis could be given to allocate more funding to research and innovation and encourage the activities surrounding these areas, the further resulting improvement in the level of technology will improve the productivity for all the parties involved in the process of M&As.

The current study suffers from several limitations: first, the current study relied on the non-parametric data envelopment analysis for the evaluation, alternative methods were not used such as the parametric stochastic frontier analysis and the multi-criteria decision-making method, heavily relying on one method reduces the level of robustness of the results. Second, the study did not address the impact of current socio-economic and demographic variables on M&A considering that most problems verified in M&As in Nigeria appear to be a consequence of poor levels of human and physical capital. Future research endeavors should focus on using alternative modeling techniques to assess the M&A beneficial impact. Not only parametric frontier approaches such as SFA could be tested by controlling the industry type, but also multi-criteria decision making (MCDM) modeling could be applied to capture different nuances in the operational and financial performance of M&As, as well in terms of frontier shift and catch-up metrics. Such MCDM could allow the modeling of the inherent trade-offs between short and long-term perspectives of the M&A dilemma. Besides, future studies should attempt, for instance, to understand M&A benefits in light of current conditions of human development, Gini, and other relevant indexes often used to describe a country's current development.

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CLIMATE CHANGE AND ECONOMIC GROWTH IN WEST AFRICA

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Abstract

This study examines the impact of climate change (measured as temperature and precipitation) on economic growth (measured as real GDP per capita) across 15 West African countries from 1990 to 2021. Also, the analysis focuses on income classifications (low and middle-income countries) and economic sectors (agriculture, forestry, and fishing; manufacturing; and services). Using the Pooled Mean Group (PMG), Panel Autoregressive Distributed Lag (ARDL) estimation approach, the results indicate that higher temperature significantly reduces economic growth in the short run but improves economic performance in the long run in West Africa. Also, increased temperature and precipitation significantly reduce economic growth in middle-income countries in the long run. In addition, agriculture, forestry, and fishing are the most vulnerable sectors due to higher temperatures and precipitation in the long run. Lastly, an increase in temperature significantly reduces productivity in the manufacturing and services sectors in the short run. Thus, this study proffers the following policy recommendations: First, West African governments should continue to align their Nationally Determined Contributions (NDCs) to their national strategies to promote a green economy. Second, West African governments should encourage investment in the agriculture, forestry, and fishing sectors that would mitigate the impact of climate change. Third, West African governments should continue to promote human capital development to enhance the fight against climate change.

Keywords: Climate Change, Economic Growth, Panel ARDL, PMG Estimator, West Africa

JEL Classification: C23, O40, O55, Q54

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1.0 INTRODUCTION

Over the decades, climate change has significantly affected economic activities and livelihood globally. According to the United Nations,[3] climate change refers to long-term changes in temperatures and weather patterns. Since the 1800s, it has been driven by natural variabilities and primarily due to human activities linked to fossil fuels such as coal, oil, and gas. However, both nature-induced and human-induced factors are responsible for the changes in temperature and precipitation in the climate regime (Kadanali and Yalcinkaya, 2020). In particular, climate change due to human-induced factors might subject millions of people to health effects, lower crop production in low latitudes, reduced water supply, and lower precipitation in arid regions (Intergovernmental Panel on Climate Change (IPCC), 2007b). Thus, on December 12, 2015, a legally binding international climate change treaty, "The Paris Agreement," was adopted and became effective on November 4, 2016. The main objective of this agreement is to limit global warming to below 2 degrees Celsius and preferably 1.5 degrees Celsius[4] by reducing Greenhouse Gas emissions, mainly carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O).

The debates and empirical evidence regarding global warming resulting from climate change have presented a fundamental shift regarding its impacts globally. In particular, Africa remains one of the most vulnerable Continents due to climate change. According to the former United Nations Chief Ban Ki-Moon, the African Continent emits only three percent of global CO_2 emissions. Still, the Continent is most affected by climate change, notably through droughts and floods.[5] In addition, the African Development Bank (African Economic Outlook, 2022) stated that about $1.3 trillion to $1.6 trillion between 2020 and 2030 would be needed to implement the Continent's climate action commitments, and the Nationally Determined Contributions (NDCs) or between $118.2 billion to $145.5 billion annually. Moreover, an estimated financing gap exists between $99.9 billion to $127.2 billion yearly through 2030 to support Africa's climate resilience and energy transition efforts.[6]

Hence, a gap in existing knowledge remains, which points to further investigation. Therefore, this study aims to bridge that gap, particularly in West Africa, for several reasons. First, West Africa has more countries than other regions, where over 30% of the populace lives on under $1.90 per day (Oxfam, 2019). Second, West African countries

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[3] www.un.org/en/climatechange/what-is-climate-change
[4] The Paris Agreement | UNFCCC
[5] African nations demand climate change financing ahead of COP27 | Climate Crisis News | Al Jazeera
[6] african_economic_outlook_2022_web.pdf

still relate on biomass which accounts for 60 percent of their energy supply (African Development Bank, African Economic Outlook, 2022). Third, due to higher temperatures, West Africa's GDP per capita is expected to experience a reduction of 15 percent by 2050.[7] Fourth, West Africa is ranked third out of five African regions in the Climate Resilience Index, which measures the effectiveness against climate-related disasters. Fifth, Climate Vulnerability and Climate Readiness Indices show that West Africa is one of the most vulnerable and least readiness regions to withstand the impact of climate change.

Thus, this study investigates the impact of climate change (measured as temperature and precipitation) on economic growth (measured as real GDP per capita) in West Africa. The contribution of this study is twofold: first, the study attempts to bridge the gap in understanding the effects of climate change on West Africa's economic growth in the short and long run. Second, the analysis focuses on income classifications (low-income[8] and middle-income countries[9]) and economic sectors (agriculture, forestry, and fishing; manufacturing; and services) to comprehensively analyze the short and long-run impact of climate change on economic growth to tailor the solution to address West Africa's inclusive and sustainable development goals.

Results of this study reveal that higher temperature significantly reduces economic growth in the short run but improves economic performance in the long run in West Africa. Also, increased temperature and precipitation significantly reduce economic growth in middle-income countries in the long run. In addition, agriculture, forestry, and fishing are the most vulnerable sectors due to higher temperatures and precipitation in the long run. Lastly, an increase in temperature significantly reduces productivity in the manufacturing and services sectors in the short run.

Sections 2 and 3 present the theoretical background and literature review, respectively. Then, in Section 4, the data and estimation method are described. Next, Section 5 offers and discusses the empirical results. Finally, Section 6 presents the study's conclusion and policy recommendations.

2.0 THEORETICAL BACKGROUND

The analysis of climate change effects on economic growth has a foundation using enumerative and dynamic approaches (Akram, 2012). In the enumerative approach,

[7] afdb-economics_of_climate_change_in_africa.pdf
[8] Low-income countries: Benin, Burkina Faso, Guinea, Guinea-Bissau, Liberia, Mali, Niger, Sierra Leone, and Togo.
[9] Middle-income countries: Cabo Verde, Côte d'Ivoire, The Gambia, Ghana, Nigeria, and Senegal.

the effect of climate change on economic growth utilized sectoral analysis (e.g., agriculture, manufacturing, services) to estimate the total change in social welfare (Nordhaus, 1991; Cline, 1994; Tol, 1995). However, this approach does not consider the intertemporal effects and their long-run implications. On the other hand, the dynamic approach incorporates a damage function with varying specifications of growth models. Under this approach, the Solow-Swan (1956), Ramsey (1928), and Cass-Koopmans models (1965) are the most widely used for examining the impact of climate change on economic growth. Also, Mankiw, Romer, and Weil (1992) and Fankhauser and Tol (2005) models are applied to determine the impact of climate change on economic growth. Hence, climate change reduces output and investment under the assumption of a constant saving rate in these models. Moreover, the long-run implication indicates that capital stock and consumption per capita will decline, reducing aggregate demand and output. According to Lecocq and Shalizi (2007), in an endogenous growth model, lower investment resulting from capital accumulation effects slows technical progress and labor productivity or human capital accumulation.

3.0 LITERATURE REVIEW

Prior to and after the Paris Agreement on December 12, 2015, there have been several studies on the effects of climate change on economic growth. For instance, Nordhaus (2006) found a negative relationship between temperature and output per capita. However, the results indicate a robust positive relationship between temperature and output per area (country size adjusted GDP). Dell et al. (2012) showed that higher temperatures significantly reduced economic growth in poor countries. Also, higher temperature reduces growth rates, not just the output level. Finally, higher temperatures reduce agricultural output, industrial output, and political stability. Akram (2012) argued that economic growth is negatively affected by changes in temperature, precipitation, and population growth. Also, agriculture is the most vulnerable sector, while manufacturing is the least affected sector. Lanzafame (2012) investigated the effects of temperature and rainfall on African economic growth for 36 African countries. The results indicate short- and long-term relationships between temperature and per capita income growth. However, the impact of rainfall on growth is not significant. Abidoye and Odusola (2015) examined the effect of climate change on economic growth in selected African countries. The results indicate that an increase in temperatures has a negative impact on economic growth. Alagidede, Adu, and Frimpong (2015) show that a temperature increase significantly reduces Sub-Saharan Africa's economic growth. Kahn et al. (2019) suggested that real GDP per capita is negatively affected by changes in temperature above or below the historical norms, but it was not statistically significant for precipitation. Kadanali and Yalcinkaya

(2020) examined the effects of climate change on economic growth in the 20 biggest economies globally and stated that climate change negatively and significantly impacts economic growth.

The literature reveals that previous studies regarding climate change's impact on West Africa's economic growth are limited, focusing mainly on Africa, Sub-Saharan Africa, and globally. In view of this, this study, therefore, attempts to bridge the gap in understanding climate change's impact on West Africa's economic growth and its implications on income classifications and economic sectors.

4.0 DATA AND ESTIMATION METHOD

4.1 Data

This study focuses on 15 West African countries with annual observations from 1990 to 2021. This analysis consists of the following variables: Real GDP per capita (constant 2015 US$). Real GDP per capita (constant 2015 US$) (a proxy for economic growth) adjusts for inflation and provides a meaningful interpretation of the country's average living standards and economic well-being. Temperature and precipitation are proxies for climate change. The average temperature is measured in degrees Celsius, while precipitation (in millimeters) represents any water that falls from the cloud as liquid or solid. Thus, temperature and precipitation are Climatic Research Unit (CRU) annual data. Next, human capital is proxy by the Human Development Index, which measures three critical human development terms: a long and healthy life, knowledge, and decent living. Also, gross fixed capital formation considers land improvement, plant, machinery, equipment purchases, construction of roads, etc. Finally, the data include the total labor force and agriculture, forestry, and fishing, manufacturing, and services sectors (value added, constant 2015 US$). The data on real GDP per capita, gross fixed capital formation, labor force, agriculture, forestry, and fishing, manufacturing, and services are from the World Bank World Development Indicators.[10] The temperature and precipitation data are sourced from the World Bank Climate Change Knowledge Portal.[11] Finally, the Human Development Index is from the United Nations Development Programme.[12]

This study uses real GDP per capita as a dependent variable for the full model and the model that considers the income classifications. However, the sectoral analyses have

[10] World Development Indicators | DataBank (worldbank.org)
[11] Download Data | Climate Change Knowledge Portal (worldbank.org)
[12] Human Development Index | Human Development Reports (undp.org)

the following dependent variables: 1) agriculture, forestry, and fishing, 2) manufacturing, and 3) services sectors. In all the models, the explanatory variables are temperature, precipitation, human capital, gross fixed capital formation, and labor force. These explanatory variables are selected based on the augmented Solow growth model's theoretical foundation for exploring economic growth determinants.

Table 1 shows that West Africa's average real GDP per capita over the period is US$1004.0. Thus, this reiterates that many countries in West Africa have low-income levels, although the population size of a country influences real GDP per capita. The standard deviation across times and countries is 655.9. It indicates the heterogeneity of income levels amongst West African countries. In terms of climate conditions, the average temperature is 27.1 degrees Celsius, with a minimum and maximum of 22.8 and 30.0 degrees Celsius, respectively. Also, the average precipitation is 1176.5 millimeters, with a minimum and maximum of 42.8 and 2995.8 millimeters, respectively.

Table 1: Summary Statistics

Variables	**Obs**	**Mean**	**Std. Dev.**	**Min**	**Max**
Real GDP per capita	470	1004.020	655.896	345.284	3482.448
Temperature	480	27.093	1.569	22.790	30.010
Precipitation	480	1176.478	710.131	42.760	2995.830
Human capital	393	0.428	0.091	0.220	0.665
Gross fixed capital formation	345	21.122	1.772	15.292	25.095
Labor force	480	14.812	1.331	11.614	17.982
Agriculture, forestry, and fishing	420	21.163	1.553	17.163	25.494
Manufacturing	346	20.120	1.904	17.349	24.564
Services	409	21.688	1.603	18.983	26.423

Source: Author's Computation

Figure 1 presents scatter plots of real GDP per capita and climate variables (temperature and precipitation) to ascertain the nature of their relationship. The upper panel shows real GDP per capita and temperature with and without the natural logarithm. In contrast, the lower panel presents real GDP per capita and precipitation with and without the natural logarithm. The introduction of a natural logarithm is to reduce the outlaying observation in the data. The upper and lower panels' results indicate that real GDP per capita negatively correlates with temperature and precipitation with or without the natural logarithm.

Figure 1: Scatter Plot of Real GDP per Capita and Climate Variables (Temperature and Precipitation)

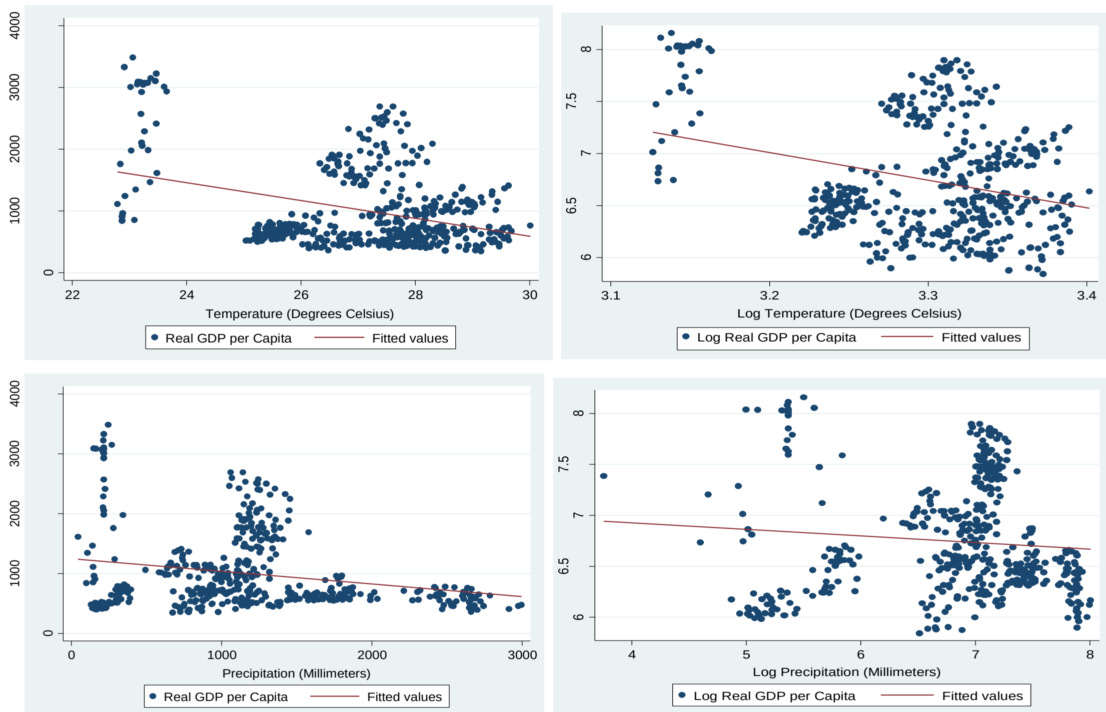
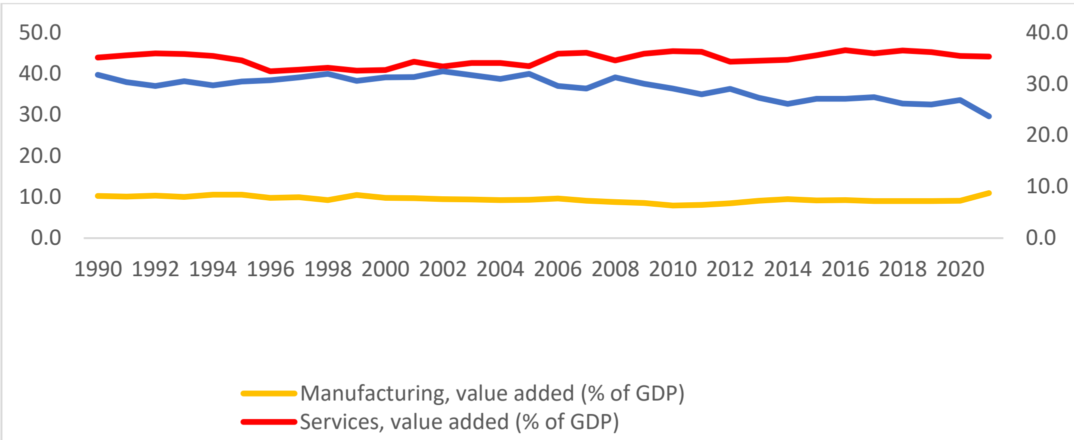


Figure 2 depicts West Africa's agriculture, forestry, and fishing, manufacturing, and services sectors, value-added as a percent of GDP from 1990 to 2021. First, the services sector accounts for 43.6 percent of GDP and remains a significant sector contributing to West Africa's economic growth, employment, and development. Next, the agriculture, forestry, and fishing sector contribute 29.4 percent of GDP and are associated with a critical source of jobs and income, particularly in rural areas. Finally, the manufacturing sector accounts for 9.4 percent of GDP. It has been flat, indicating lower employment, income, and innovation, which helps reduce unemployment and poverty and promotes inclusive growth and development.

Figure 2: West Africa's Agriculture, Forestry, and Fishing, Manufacturing, and Services Sectors



Source: World Bank, World Development Indicators

4.2 Estimation Method

4.2.1 Panel Autoregressive Distributed Lag (ARDL) Model

There are two primary approaches in the growth literature. The first approach focuses on convergence theory, and the second uses the growth theory framework to stipulate and estimate growth equations (Kedir, 2017). This study utilizes the second approach to model the effects of climate changes on real GDP per capita (a proxy for economic growth) in West Africa. Also, this study focuses on income classifications and economic sectors, which involves a combination of cross-section (*N*) and time-series (*T*) observations in which *N* and *T* represent countries and the number of years, respectively. Furthermore, this study utilizes the augmented Solow growth model's theoretical framework.

According to Baltagi (1995), regarding panel estimation, neither the Generalized Least Squared (GLS) estimator nor Fixed Effect (FE) would produce consistent estimates in the presence of dynamics and endogenous regressors. Thus, instrumental variables (IV) are needed to produce consistent estimates, particularly in the presence of dynamics (Baltagi and Li, 1995). To produce a consistent estimate in the presence of dynamic and endogenous regressors, Arellano and Bond (1991) suggested a dynamic panel Generalized Method of Moments (GMM) estimator. The dynamics GMM panel estimator is an IV estimator which considers both current and past values of endogenous regressors and uses them as instruments. However, the GMM estimator would produce spurious results in large *T* and *N*. This is because as *T* becomes larger, the instruments increase, affecting the Sargan test's validity over-identifying restriction (Roodman, 2009). Also, a small *N* may lead to unreliable autocorrelation test results. Thus, using panel ARDL estimators such as Mean Group (MG), Pooled Mean Group (PMG), or Dynamic Fixed Effect (DFE) can overcome the problems associated with the GMM estimator.

4.2.2 MG, PMG, and DFE Estimators

The MG estimator produces consistent average parameter estimates for large *N* and *T*. However, this estimator may not account for the similarity of parameters across the same groups. On the other hand, the PMG estimator considers both pooling and averaging and allows the intercepts, short-run coefficients, and error variances to differ without restriction across groups while keeping the long-run coefficients homogeneous (Pesaran and Smith, 1995). Finally, the DFE estimator keeps the coefficients of the co-integrating vector to be the same across all panels with an equal speed of adjustment coefficient and short-run coefficients (Blackburne and Frank, 2007). But, there is an inherent bias to the simultaneous equation for small samples due to the endogeneity between the lagged dependent variable and error term (Baltagi, Griffin, and Xiong, 2000). Thus, given that this study focuses on the short and long terms relationship between climate change and real GDP per capita, the Hausman test is conducted to select the best estimator (MG or PMG) for the model.

4.2.3 The Model

Following Pesaran, Shin, and Smith (1999), suppose that a given data on time is, *t*=1, 2,…, *T*, and groups, *i*=1, 2,…, *N*, then the generalized ARDL (p, q, q,…q) model is specified as:

$$y_{it} = \sum_{j=1}^{p} \delta_i y_{i,t-j} + \sum_{j=0}^{q} \beta'_{ij} X_{i,t-j} + \varphi_i + \varepsilon_{it} \quad (1)$$

where y_{it} is the dependent variable, $(X'_{it})'$ is a k x 1 vector that is allowed to be purely I(0) or I(1) or co-integrated, δ_i denotes the coefficient of the lagged dependent variable called scalars, β_{ij} are the k x 1 coefficient vectors, φ_i is the unit-specific fixed effects, *p* and *q* are the optimal lag orders, and ε_{it} is the error term. Thus the re-parameterized ARDL (p, q, q,…q) error correction model is specified as:

$$\Delta y_{it} = \theta_i\left[y_{i,t-1} - \lambda'_i X_{i,t}\right] + \sum_{j=1}^{p-1} \xi_{ij}\, \Delta y_{i,t-j} + \sum_{j=0}^{q-1} \beta'_{ij}\, \Delta X_{i,t-j} + \varphi_i + \varepsilon_{it} \quad (2)$$

where θ_i is the group-specific speed of adjustment coefficient and expected to be less than zero, λ'_i is a vector of long-run relationships, ECT is the error correction term specified as $\left[y_{i,t-1} - \lambda'_i X_{i,t}\right]$, ξ_{ij} and β'_{ij} are the short-run dynamic coefficients, and ε_{it} is the error term. Thus, this general specification can be adapted to estimate the empirical model as follow:

$$\Delta GDP_{it} = \theta_i\left[GDP_{i,t-1} - \lambda'_i X_{i,t}\right] + \sum_{j=1}^{p-1} \xi_{ij}\, \Delta GDP_{i,t-j} + \sum_{j=0}^{q-1} \beta'_{ij}\, \Delta X_{i,t-j} + \varphi_i + \varepsilon_{it} \quad (3)$$

where GDP_{it} denotes real GDP per capita (a proxy for economic growth) in *i* country at time *t*, X_{it} indicates the set of explanatory variables in *i* country at time *t*: temperature, precipitation, human capital, gross fixed capital formation, and labor force, θ_i is the group-specific speed of adjustment coefficient, λ'_i is a vector of long-run relationships, $[GDP_{i,t-1} - \lambda'_i X_{i,t}]$ is the error correction term (ECT), ξ_{ij} and β'_{ij} are the short-run dynamic coefficients, and ε_{it} is the error term. Equation (3) is also utilized to estimate the sectoral impact of climate change using agriculture, forestry, and fishing; manufacturing; and services as dependent variables with the same above explanatory variables. Furthermore, the natural logarithm is taken for all the variables in equation (3) to reduce the outlaying observation in the data and interpret the coefficients as elasticities.

4.2.4 Econometric Approach

In this study, several econometric procedures are performed. First, this study tests for cross-sectional dependence to ascertain whether or not there exist cross-sectional dependency in the errors due to shocks and unobserved components in the panel data. Second, if cross-sectional dependence is present, Pesaran's (2007) Cross-Sectional Augmented Dickey-Fuller (CADF) test is conducted. Third, a residual-based cointegration test by Pedroni (1999, 2004) is applied to determine the long-run relationship among the variables. Fourth, the cointegration results are also determined from the statistical significance of the long-run coefficients assuming long-run homogeneity. So, the cointegration is the joint significance of the level's equation. Fifth, the optimal lag selection obtained after the unit root test indicates no integration of order 2. Sixth, the Hauman test determines the best panel-ARDL estimator for the long and short equilibrium. Finally, a similar analysis is undertaken for agriculture, forestry and, fishing, manufacturing, and services as dependent variables with a set of explanatory variables.

4.2.5 Cross-Sectional Dependence

Studies have found that panel-data models likely exhibit substantial cross-sectional dependence in the errors due to common shocks and unobserved components in panel-data literature (Pesaran, 2004). These common shocks and unobserved components become part of the error terms, spatial dependence, and idiosyncratic pairwise dependence. The increasing economic and financial integration of countries and financial entities may explain the interdependency between cross-sectional units.[13] Thus, it is essential to test the cross-sectional dependence before detecting unit

[13] Testing for Cross-Sectional Dependence in Panel-Data Models (sagepub.com)

roots among the variables. Pesaran (2004) stated that the following test statistic is appropriate for sizeable cross-sectional data to detect cross-sectional dependency.

$$CD = \sqrt{\frac{2T}{N(N-1)}\left(\sum_{i=1}^{N-1}\sum_{j=i+1}^{N}\rho_{\tilde{ij}}\right)} \quad (4)$$

Hence, the null hypothesis of no cross-sectional dependence, CD is distributed *N* (0,1) for *N*→∞ and *T* sufficiently large.

4.2.6 Panel Unit Root Test

To conduct the panel unit root, the Pesaran (2007) Cross-Sectional Augmented Dickey-Fuller (CADF) is employed to account for cross-sectional dependence in the panel data. The following equation is applied to measure the CADF unit root test:

$$\Delta x_{it} = \varphi_i + \rho_1 x_{it-1} + c_1 x_{\bar{t}-1} + \sum_{j=0}^{n} d_{ij}\,\Delta x_{\bar{it}-1} + \sum_{j=0}^{k} \delta_{ij}\,\Delta x_{\bar{it}-1} + \varepsilon_{it} \quad (5)$$

where x_{it-1} and $\Delta x_{\bar{it}-1}$ represent the cross-sectional averages of lagged levels and first differences individual series.

4.2.7 Cointegration Test

This study utilizes the residual-based cointegration test Pedroni (1999, 2004) developed to ascertain the long-run equilibrium relationship among the variables under consideration. The test is divided into panel and group tests. The panel test provides the within-dimension approach using four statistics: panels *V*, *Rho*, *T*, and *ADF*. The group test provides the between-dimension approach using groups *Rho, PP*, and *ADF*. Under the assumption of normal and asymptotically distribution, the residuals are obtained from the long-run model as follows:

$$Y_{it} = \theta_i + \delta_i + \sum_{j=1}^{m} \beta_{ji}\, X_{jit} + +\varepsilon_{it} \quad (6)$$

where Y and X are assumed integrated at order one and the error term $\varepsilon_{it} = \tau_i \varepsilon_{it-1} + \mu_{it}$. Thus, this study uses the maximum likelihood panel cointegration statistics to compare the within and between dimensions. Therefore, the null hypothesis suggests that no cointegration exists among the variables. Accordingly, the Pedroni (1999, 2004) cointegration system for panel data is as follows:

$$Y_{it} = \theta_i + \beta X_{it} + +\varepsilon_{it} \quad (7)$$

4.2.8 Optimal Lags Selection and Hausman Test

The optimal lag selection is performed after the unit root test indicates that no variable is integrated at order 2. Then, the optimal lags using the unrestricted model and an information criterion (BIC) are utilized to decide the most common lag for each variable in the model. In addition, the Hausman test is conducted to determine the model's best estimator. Hence, the null hypothesis of homogeneity is tested based on a Hausman-type test by comparing MG and PMG. The decision criterion is as follows: PMG is more efficient than MG under the null hypothesis. Therefore, the null hypothesis is selected if PMG ($p>0.05$), while the alternative hypothesis is selected if MG ($p<0.05$).

5.0 RESULTS AND DISCUSSION

This section presents results regarding the cross-sectional dependence test, panel unit root test, cointegration test, optimal lags selection, and Hausman test. Also, equation (3) is estimated to ascertain the long and short-run relationship between climate change and real GDP per capita. Moreover, the results account for income classifications (low-income and middle-income countries) and economic sectors (agriculture, forestry and, fishing; manufacturing; and services).

5.1 Cross-Sectional Dependence Test Results

Table 2 shows the results from the Pesaran cross-sectional dependence test. The results show that the null hypothesis of cross-sectional independence is rejected at the 1 percent significant level for all variables. Thus, the cross-sectional dependence test outcomes demonstrated that the econometric estimation might provide spurious results. Therefore, this study uses the PMG panel ADRL estimation approach, which accounts for cross-sectional heterogeneity through short-term parameters and enables the long-run and short-run causalities inference.

Table 2: Cross-Sectional Dependence Test Results

Variables	CD-test
Real GDP per capita	23.85***
Temperature	48.35***
Precipitation	22.74***
Human capital	47.59***
Gross fixed capital formation	29.16***
Labor force	57.37***
Agriculture, forestry, and fishing	40.43***
Manufacturing	30.62***
Services	46.25***

Notes: The null hypothesis is cross-section independence, CD ~ N (0,1) and the parameter estimates are significant at ***1% level.

5.2 Panel Unit Root Test Results

Table 3 displays the results of Pesaran's (2007) CADF unit root test, considering the cross-sectional dependence shown in Table 3. The results present the constant and constant and trend at a level and first difference. The results (constant) indicate that real GDP per capita, human capital, gross fixed capital formation, agriculture, forestry and fishing, manufacturing, and services are stationary after the first difference. However, the other variables (temperature, precipitation, labor force) are stationary at the level. On the other hand, the results (constant and trend) show that real GDP per capita, human capital, gross fixed capital formation, agriculture, forestry, and fishing, manufacturing, and services are stationary after the first difference. Therefore, this mixture of I(0) and I(1) recommends using a panel ARDL model that produces accurate results.

Table 3: Panel Unit Root Test Results

Variables	**Constant**		**Constant and Trend**	
	Level	**1st Difference**	**Level**	**1st Difference**
Real GDP per capita	-0.062	-6.382***	1.302	-5.181***
Temperature	-3.270***		-3.534***	
Precipitation	-4.017***		-4.213***	
Human capital	-0.847	-4.238***	0.986	-3.920***
Gross fixed capital formation	0.245	-6.695***	-0.873	-6.455***
Labor force	-2.899***		-2.547	-2.110
Agriculture, forestry, and fishing	-1.757	-3.728***	-2.025	-3.937***
Manufacturing	-0.513	-4.176***	2.402	-3.401***
Services	2.224	-3.000***	-0.772	-3.144***

Notes: Robust standard errors in parentheses and the parameter estimates are significant at ***1% level.

5.3 Cointegration Test

Table 4 presents the Pedroni cointegration test to determine whether or not there exists a long-run relationship between the explanatory variables and real GDP per capita under various models specification. The results indicate a long-run relationship between the explanatory variables and real GDP per capita, statistically significant at 1 percent, 5 percent, and 10 percent. Moreover, these results hold within (panel) and between (group) dimensions.

Table 4: Pedroni Cointegration Test Results

Test Statistic	Panel	Group
Model 1		
V-statistic	-0.886	.
Rho-statistic	2.224**	3.813***
T-statistic	0.823	0.904
ADF-statistic	2.551**	2.710***
Model 2		
V-statistic	-2.484**	.
Rho-statistic	3.708***	4.399***
T-statistic	3.938***	2.880***
ADF-statistic	6.269***	7.420***
Model 3		
V-statistic	-2.484**	.
Rho-statistic	2.925***	4.210***
T-statistic	2.574**	2.656***
ADF-statistic	5.174***	4.507***
Model 4		
V-statistic	-1.997**	.
Rho-statistic	2.473**	4.566***
T-statistic	1.760*	3.105***
ADF-statistic	4.498***	4.749***

Notes: All test statistics are distributed N (0,1), under a null of no cointegration, and diverge to negative infinity (save for panel v). *** denotes 1%, ** denotes 5%, and *10% significance levels.

5.4 Hausman Test Results

The optimal lags for the panel ARDL models present one lag of the dependent variable and 0 lag for all the explanatory variables. Table 5 displays the Hausman test results, which indicate that the PMG is more efficient than MG under the alternative hypothesis because the results are statistically insignificant at the 5% level. Therefore, these results support the panel's short-run heterogeneity and the long-run homogeneity presented in the PMG estimator. Thus, the empirical model in equation (3) is estimated using the PMG estimator.

Table 5: Hausman Test

Estimators	Chi-square Statistic	Prob>chi2
Model 1: H_0: PMG vs. H_1: MG	1.80	0.877
Model 2: H_0: PMG vs. H_1: MG	6.74	0.241
Model 3: H_0: PMG vs. H_1: MG	2.97	0.705
Model 4: H_0: PMG vs. H_1: MG	6.38	0.271

Notes: H_0: Select PMG if ($p>0.05$) vs. H_1: Select MG if ($p<0.05$).

5.5 Full Panel

Table 6 presents the full panel showing the effect of climate change (proxy by temperature and precipitation) on West Africa's real GDP per capita (a proxy for economic growth) using the PMG estimator. The first column reports the estimated results of regressing real GDP per capita on temperature, precipitation, human capital, gross fixed capital formation, and labor force for West Africa. In the second and third columns, the estimated results show real GDP per capita is regressed on temperature, precipitation, human capital, gross fixed capital formation, and labor force categorized as low-income and middle-income countries in West Africa, respectively. In Table 6 (Column 1), temperature positively correlates with real GDP per capita in the long run and is statistically significant at 10 percent. For instance, a percentage increase in temperature will significantly increase real GDP per capita by 0.46 percent in the long run, ceteris paribus. Also, human capital, gross fixed capital formation, and labor force positively correlate with real GDP per capita at a 1 percent significant level in the long run. However, in the short run, an increase in temperature negatively impacts real GDP per capita, and it is statistically significant at 10 percent. For example, a percentage increase in temperature will reduce real GDP per capita by 0.52 percent, ceteris paribus.

Moreover, the existence of a long-run relationship (dynamic stability) requires that the error-correction term (ECT) should be negative and not lower than -2 (Norman and Romain, 2005). The results indicate that the ECT is negative, not lower than -2, and statistically significant at 1 percent. Thus, the adjustment coefficient illustrates how fast short-term disturbances return to the long-run equilibrium. For example, in column (1), the value of -0.822 indicates that real GDP per capita short-run disturbances would adjust in the long run by 82.2 percent each year.

In Table 6 (Column 2), temperature positively correlates with real GDP per capita in the long run and is statistically significant at 10 percent. For instance, a percentage increase in temperature will significantly increase real GDP per capita by 0.89 percent in the long run, ceteris paribus. Also, human capital and gross fixed capital formation positively correlated with real GDP per capita at a 1 percent significant level. In comparison, the labor force positively correlates with real GDP per capita and is significant at 5 percent in the long run. However, in the short run, higher temperature reduces real GDP per capita, and it is statistically significant at 10 percent. For example, a percentage increase in temperature will reduce real GDP per capita by 0.83 percent, ceteris paribus. In addition, the error-correction coefficient is negative and statistically significant at 1 percent. For example, in column (2), the value of -1.016 indicates that real GDP per capita short-run disturbances would adjust in the long run by 101.6 percent each year.

In Table 6 (Column 3), temperature and precipitation negatively correlate with real GDP per capita in the long run and are statistically significant at 10 percent and 1 percent, respectively. For instance, a percentage increase in temperature will significantly reduce real GDP per capita by 0.82 percent and 0.15 percent, in the long run, ceteris paribus. In contrast, human capital and gross fixed capital formation positively correlate with real GDP per capita at a 1 percent significant level in the long run. In the short run, gross fixed capital formation negatively impacts real GDP per capita and is statistically significant at 10 percent. Furthermore, the error-correction coefficient is negative, not lower than -2, and statistically significant at 1 percent. Thus, the adjustment coefficient illustrates how fast short-term disturbances return to the long-run equilibrium. In column (3), the value of -0.525 indicates that real GDP per capita short-run disturbances would adjust in the long run by 52.5 percent each year. Thus, the results in Table 6 reveal that climate change has varying impacts on West Africa's economic growth in the short and long run. The positive and significant impact of human capital on economic growth is supported by theory and documented by studies such as Romer (1986) and Barro and Sala-i-Martin (2003). Also, the results support the theoretical foundation of the robust positive relationship between gross fixed capital formation and economic growth (e.g., Levine and Renelt, 1992; Mankiw et al., 1992; De Long and Summers, 1992). In addition, the labor force has a positive and significant effect on economic growth. Thus, human capital, gross fixed capital formation, and labor force remain integral to West Africa's economic growth in the long run.

Table 6: Estimation Results: Pooled Mean Group (PMG)

Dependent Variable: Real GDP per Capita			
	West Africa	**Low-Income Countries**	**Middle-Income Countries**
Variables	(1)	(2)	(3)
Long-run coefficients			
Temperature	0.458*	0.890*	-0.824*
	(0.252)	(0.268)	(0.442)
Precipitation	-0.018	-0.038	-0.147***
	(0.026)	(0.030)	(0.044)
Human capital	1.354***	1.187***	0.672
	(0.216)	(0.227)	(0.737)
Gross fixed capital formation	0.045***	0.044***	0.165***
	(0.014)	(0.014)	(0.029)
Labor force	0.041***	0.029**	0.133***
	(0.012)	(0.014)	(0.039)
Error-correction coeff.	-0.822***	-1.016***	-0.525*
	(0.102)	(0.113)	(0.288)
Short-run coefficients			
∆ Temperature	-0.523*	-0.834*	0.240
	(0.300)	(0.454)	(0.273)
∆ Precipitation	-0.019	-0.001	0.039
	(-0.031)	(0.042)	(0.053)
∆ Human capital	0.315	0.083	1.159
	(0.339)	(0.244)	(1.129)
∆ Gross fixed capital formation	0.003	-0.006	-0.019*
	(0.011)	(0.014)	(0.011)
∆ Labor force	0.509	-0.609	2.302
	(1.520)	(1.655)	(1.540)
Constant	-1.671***	-3.155***	0.817*
	(0.186)	(0.331)	(0.486)
Number of observations	271	180	79
Number of Countries	13	8	4

Notes: Robust standard errors in parentheses and the parameter estimates are significant at the ***1%, **5%, and *10% levels, respectively. ∆ is the first difference operator. The first panel of the table presents the long-run estimation and speed of adjustment, while the second panel reports the short-run estimated coefficients.

5.6 Economic Sectors

In Table 7 (Column 1), an increase in temperature and precipitation reduces agriculture, forestry, and fishing productivity in the long run and is statistically significant at 5 percent. A percentage increase in temperature and precipitation will reduce agriculture, forestry, and fishing by 0.67 percent and 0.06 percent, respectively. Also, gross fixed capital formation negatively correlates with agriculture, forestry, and fishing, with a statistically significant 1 percent. In addition, the labor force is positively associated with agriculture, forestry, and fishing in the long run, with a 5 percent statistic significant. However, precipitation is positively correlated with the agriculture, forestry, and fishing sector, with a 10 percent significant level in the short run. Finally, the adjustment coefficient in column (1) is -1.045, indicating that agriculture, forestry, and fishing sector short-run disturbances would adjust in the long run by 104.5 percent each year.

In Table 7 (Column 2), an increase in temperature in the long and short run increase and reduces manufacturing productivity and are statistically significant at 5 percent, respectively. In addition, human capital and gross fixed capital formation negatively impact manufacturing in the long run. Still, they are positive at 5 percent and 10 percent significance levels in the short run. Moreover, the labor force positively affects manufacturing in the long and short run at 10 percent and 5 percent, respectively. Finally, the adjustment coefficient in column (2) is -0.845, indicating that the manufacturing sector's short-run disturbances would adjust in the long run by 84.5 percent each year.

Table 7 (Column 3) shows that higher temperature in the long run and short run increase and reduces services sector productivity and are statistically significant at 1 percent, respectively. In addition, human capital, gross fixed capital formation, and labor force positively impact the services sector at a 1 percent significance level in the long run. Finally, the adjustment coefficient in column (2) is -0.264, indicating that the services sector's short-run disturbances would adjust in the long run by 26.4 percent each year.

Overall, the results from the PMG estimator presented in Tables 6 and 7 indicate that climate change affects economic growth in West Africa. These results support previous studies (Nordhaus, 2006; Dell et al., 2012; Odusola, 2015; Alagidede, Adu, and Frimpong, 2015), which established that higher temperature reduces economic growth. In addition, the results further support that agriculture is the most vulnerable sector, as previously found by Akram (2012).

Table 7: Estimation Results: Pooled Mean Group (PMG)

Dependent Variable:	**Agriculture, forestry, and fishing**	**Manufacturing**	**Services**
Variables	**(1)**	**(2)**	**(3)**
Long-run coefficients			
Temperature	-0.673**	1.105**	7.478***
	(0.295)	(0.532)	(0.846)
Precipitation	-0.064**	0.013	-0.076
	(0.025)	(0.047)	(0.106)
Human capital	0.360	-1.310**	2.971***
	(0.269)	(0.526)	(0.251)
Gross fixed capital formation	-0.049***	-0.058**	0.075***
	(0.012)	(0.024)	(0.015)
Labor force	0.041**	0.044*	0.784***
	(0.016)	(0.026)	(0.139)
Error-correction coeff.	-1.045***	-0.845***	0.264***
	(0.141)	(0.064)	(0.083)
Short-run coefficients			
Δ Temperature	-0.677	-1.327**	-1.622***
	(0.503)	(0.694)	(0.512)
Δ Precipitation	0.138*	-0.039	0.023
	(0.0823)	(0.075)	(0.039)
Δ Human capital	0.255	1.972**	0.203
	(0.810)	(0.937)	(0.660)
Δ Gross fixed capital formation	0.004	0.072*	0.011
	(0.015)	(0.040)	(0.021)
Δ Labor force	-0.734	4.654**	-1.474
	(3.607)	(1.985)	(3.849)
Constant	2.210***	-3.818***	-3.050***
	(0.350)	(0.301)	(1.010)
Number of observations	259	233	256
Number of Countries	13	13	13

Notes: Robust standard errors in parentheses and the parameter estimates are significant at the ***1%, **5%, and *10% levels, respectively. Δ is the first difference operator. The first panel of the table presents the long-run estimation and speed of adjustment, while the second panel reports the short-run estimated coefficients.

6.0 CONCLUSION AND POLICY RECOMMENDATIONS

This study examines the impact of climate change (measured as temperature and precipitation) on economic growth (measured as real GDP per capita) across 15 West African countries from 1990 to 2021. The PMG panel ADRL estimation approach is applied to investigate the effects of climate change on real GDP per capita in West Africa by income classifications and economic sectors, with short and long-run implications. Based on the dataset, the results indicate the following: First, there exists a long and short-run significant relationship between temperature, precipitation, and real GDP per capita. Second, the magnitude of the impact of temperature and precipitation on real GDP per capita depends on the specification. Third, increased temperature and precipitation significantly reduce economic growth in middle-income countries in the long run. Fourth, agriculture, forestry, and fishing are the most vulnerable sectors due to higher temperatures and precipitation in the long run. Fifth, an increase in temperature significantly reduces productivity in the manufacturing and services sectors in the short run. Finally, the results indicate that the relationship between real GDP per capita, its determinants, and climate changes (temperature and precipitation) is nonlinear. Thus, the implication is that below a certain threshold level, annual mean temperature and precipitation, an increase in temperature and precipitation may boost economic performance in the long run, all things being equal. But if this threshold is bridged, an increase in temperature and precipitation beyond the threshold tends to have a negative impact on long-run growth in West Africa. Given the above empirical findings, further research on the impact of climate change is needed to determine the cost of mitigation, adaptation, and transition for each country and the optimal financing strategies for a pathway to a green economy.

Based on these results, this study proffers the following policy recommendations: First, West African countries should continue to align their Nationally Determined Contributions (NDCs) to their national strategies to promote innovative financing (e.g., green bonds and loans) and investment in green technology as a pathway to a green economy, with the goals of inclusive growth and development, and poverty reduction. Second, the effectiveness of addressing climate change's impact on West African economies' should consider the countries' classification (e.g., low-income and middle-income countries) to avoid one solution that fits all. Third, West African countries heavily rely on the agriculture, forestry, and fishing sectors for employment, income, food security, and poverty reduction; thus, West African governments should encourage investment in these sectors to mitigate the impact of climate change. Fourth, West African governments should continue to promote human capital development to enhance the fight against climate change.

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TRADE OPENNESS AND PERFORMANCE OF SMALL AND MEDIUM ENTERPRISES IN ECOWAS COUNTRIES

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Abstract

Small and Medium Scale Enterprises (SMEs) have been reckoned as the backbone and engine of economic growth of most emerging economies. They are critical to job creation, poverty reduction, innovation and entrepreneurship, as well as income distribution. This study investigates the impact of trade openness on ECOWAS SMEs. The study utilises a barrage of panel regression techniques, namely: the Dynamic Common Correlated Effects ARDL (CS-ARDL) and the Cross-sectional Distributed Lag (CS-DL) techniques on data from seven ECOWAS countries (Cote d'Ivoire, Cape Verde, Ghana, the Gambia, Niger, Nigeria and Senegal). Our results suggest that trade openness is beneficial to the performance of SMEs in ECOWAS countries in the short term, however, its effect is detrimental in the long run. The paper recommends to individual countries to initiate strategies to solve the perennial challenge of energy poverty and infrastructure deficit within the ECOWAS.

Keywords: SMEs, Trade openness, ECOWAS, CS-ARDL, CS-DL

1.0 INTRODUCTION

Small businesses, more formally called small and medium enterprises (SMEs), have been touted as the backbone of the global economy (Effiom & Edet, 2020; ECOWAS Commission, 2016). This is because it accounts for a significant proportion of most businesses in nearly every region. For instance, in Africa SMEs represent over 90 percent of businesses and employ more than 60 percent of workers (International Trade Centre, 2018; Ayyagari et al., 2011; Runde, et al. 2021); in the Asian-Pacific region, it constitutes over 96 percent of all Asian businesses, accounting for two out of three private sector jobs (Yoshino & Taghizadeh-Hesary, 2018), while in Latin America it is responsible for 99.5 percent of all businesses and are key drivers of social inclusion and economic growth in the region (OECD/CAF, 2019). It provides approximately 80 percent of jobs

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across the African continent (ECOWAS Commission, 2016), and represents a critical driver of economic growth. For instance, 44 million micro, small and medium enterprises (MSMEs) are located in sub-Saharan Africa alone. SMEs are responsible for a considerable share of businesses in Nigeria, Ghana and South Africa (Abor & Quartey, 2010; Gbandi & Amissah, 2014), and their share in the GDP of Nigeria was 49.8 percent in 2017 (SMEDAN/NBS, 2018; Effiom and Edet, 2020) and 49 percent for Ghana in 2012 (Quartey, et al. 2017; PWC, 2013). This staggering figures have positive implications for poverty reduction, income distribution and bridging of the socio-economic inequality gap.

The growth of small businesses reflects the growth of the middle class, which by extension is responsible for growth in processed and semi-manufactured goods' consumption in emerging economies. Growth of SMEs is also responsible for increased investment in financial services, retail business, manufacturing and other services in the economy. They are wealth creators, and a critical variable in enhancing economic diversification, innovation, entrepreneurship, and employment generation. It is therefore trite to conclude that for African governments to effectively tackle the problem of unemployment and poverty, policy must be deliberately targeted at strengthening this critical sector of the economy (Torres & Seters, 2016).

But how has African SMEs, particularly those within the Economic Community of West African States (ECOWAS) subregion, fared amidst the rising trends of phenomena such as trade liberalisation and globalisation? Classical and neoclassical international trade and growth theories predict that more open economies experience faster growth and development compared to those in autarky. This implies that the growth agents in those liberal economies, in particular SMEs, would benefit more from liberal trade policies. In particular, it is hypothesised that the positive growth effect would encourage domestic firms to invest in technology transfer and in physical capital (Rivera-Batiz & Romer, 1991; Kim et al., 2016). But the empirical position in the literature seems to be mixed, and not so sanguine. On the one extreme are studies which find evidence of a positive impact of trade openness or liberalisation on the performance of SMEs (Ogba, et. al 2018; Rahmaddi and Ichihashi, 2011; Sun and Heshmati ,2010; Li, Chen & San, 2010; Can & Gozgor, 2018; Javed, Qaiser, Mushtaq, Saif-ullaha & Iqbal, 2012), and on the negative extreme, there are studies which conclude that openness imperils the performance of domestic small businesses (Elizabeth and James, 2006; Aarti, 2014; Oladimeji, et. al. 2017).

While there are country-specific studies investigating the nexus and impact of trade openness on SMEs, few exist on ECOWAS as a regional bloc, whose overarching charter is to promote trade, economic integration and growth among its members. The Economic Community of West African States that composed of 15 member states are not insulated from the global economy. If anything, its name suggest that not only do they espouse the doctrine of free trade, Member States do trade with the global community. Within this framework of free trade, the region's 2017 GDP at current prices was estimated at $556.9 billion, which represents approximately 35 percent of sub-Saharan Africa's GDP (UNCTAD, 2020).

According to the World Trade Organisation (WTO, 2016) report, SMEs in developing countries only exported a 7.6 per cent of total SME sales in the manufacturing sector relative to 14.1 percent for large enterprises. In fact, Africa exhibits the lowest export share (3 percent), relative to 8.7 percent for Asia among developing regions. In terms of direct export of services, participation by SMEs in developing countries is insignificant, accounting for only 0.9 percent of total sales relative to 31.9 percent for large enterprises. With particular reference to the subregion, while ECOWAS is unarguably the oldest of the eight Regional Economic Community (RECs) acknowledged by the African Union (AU) as the foundation of Africa's integration, its intra-ECOWAS exports accounted for a paltry 10.8 percent of the region's aggregate exports relative to shares of 18.8 percent, 12.2 percent, and 20.9 percent documented for Common Market for East and Southern Africa (COMESA), East African Community (EAC) and Southern African Development Community (SADC), respectively. In terms of trade integration, ECOWAS ranked seventh out of the eight RECs recognised by the AU. (Fajana, 2018). Besides, while exports of ECOWAS exhibit very little product diversity, with huge reliance on extractive products like natural gas and petroleum, its imports are however strongly diversified with a significant share of capital goods like vehicles, refined petroleum, ships, communication equipment, etc. (Torres & Seters, 2016).

Our purpose in this paper is to explore and further contribute to the literature by investigating trade liberalisation's impact on SMEs performance in the ECOWAS subregion. With the increasing trend towards integration of regional blocs, ECOWAS stands to gain if it could harmonise its regional SMEs policy so that its Member States could be more competitive in the global market. Furthermore, exploring a Subregional-wide impact of trade liberalisation on SMEs performance is needful because it potentially unravels the mechanisms through which trade policy reforms influence the subsector's performance.

The rest of the paper proceeds with an overview of the structure of trade and performance in ECOWAS in section 2; the theoretical and empirical literature is also handled in this section. Section 3 details the empirical methodology as well as the model for estimation, while analysis and discussion of the ensuing results are presented in section 4. Section 5 concludes the study with some policy recommendations.

2.0 OVERVIEW OF TRADE STRUCTURE AND PERFORMANCE IN ECOWAS

The preceding two decades have witnessed growth in ECOWAS trade. This is partly due to the approval and implementation of the ECOWAS Trade Liberalisation Scheme (ETLS). Within this period, there was a significant increase in the share of both exports and imports (measured as exports volume and value) in the GDP. While intra-regional trade accounted for only $16 billion, which is 11 percent of total trade, aggregate value of ECOWAS external trade in goods was estimated at $155 billion (See Table 2) in 2017 (UNCTAD, 2020). A key highlight from Table 1 is the decreasing value of trade ECOWAS countries. With over $26 million in 2013, the value of intra-regional trade declined steadily in the succeeding years up to 2017.

Table 1: Trend of intra-regional trade in value

Flows/Years	2013	2014	2015	2016	2017	Average
Intra trade exports (in million dollars)	14 004	13314	10229	9166	9154	11173
Intra trade imports (in million dollars)	12 762	10429	9104	6515	7281	9218
Total intra trade (in million dollars)	267666	23743	19333	15682	16435	20392
Share of intra trade exports (in percentage)	12	10	13	15	11	12
Share of intra trade imports (in percentage)	14	11	11	8	10	11
Share of total intra trade (in percentage)	13	10	12	11	11	11
Variation of intra trade exports (in percentage)		-5	-23	-10	-0	-10
Variation of intra trade imports (in percentage)		-18	-13	-28	12	-12

Source: UNCTAD, 2020; ECOWAS Commission,

Table 2: Trend of ECOWAS External Trade

Flows/Years	**2013**	**2014**	**2015**	**2016**	**2017**	**Average**
Exports (in million dollars)	118793	131960	78877	61616	79555	94160
Imports (in million dollars)	92503	97042	81785	81043	75991	85673
Total trade (in million dollars)	211296	229002	160662	142659	155546	179833
Trade balance (in million dollars)	26290	34917	-2908	-19426	3564	8487
Variation exports (in percentage)		11	-40	-22	29	-6
Variation imports (in percentage)		5	-16	-1	-6	-5
Variation total trade (in percentage)		8	-30	-11	9	-6

Source: UNCTAD, 2020; ECOWAS Commission,

While value of total external trade exceeded trade within the subregion, yet a similar declining trend is noticed for the former: from $21 million in 2013, it slightly grew to $22milion in 2014 and declined in subsequent years. Regrettably, intra-ECOWAS trade is not robust, because it consists of narrow range of commodities such as chemicals, transport equipment, minerals, live animals, food industries products, as well as vegetables. In 2017 alone, petroleum products significantly accounted for over 41 percent of exports and close to 63 per cent of imports within ECOWAS. The main trading partners of ECOWAS are Europe which, between 2015 and 2017 imported close to 41.4 percent of the region's goods, while ECOWAS itself absorbed about 41.9 percent of goods from Europe. The next major trading partner after Europe is the Asian continent which exports an average of 32.5 percent of goods and imports about 40.2 percent of ECOWAS imports (UNCTAD, 2020).

ECOWAS has a common trade policy encapsulated in the ECOWAS Vision 2020. The strategy is to foster regional integration and promote deeper cooperation among Member States. "From an ECOWAS of States to an ECOWAS of People", the mantra provides a vision and basis that would create a virile and borderless regional ambience, with resources readily available and accessible to the people. This strategy emphasises on human capital development, good governance, regional peace and security, economic and monetary zone integration, and the development of the private sector. To a large extent, this strategy is achieving its objectives, as there have been substantial elimination of tariffs and promotion of trade liberalization within the subregion. There has also been the consolidation of relationship of Member States with external trading partners.

Several constraints imperil the performance of SMEs in the ECOWAS. Theses include paucity and inefficient infrastructure, non-certification of SMEs to enhance international competitiveness, fragmented and inconsistent data which impedes SMEs' integration into the formal economy, absence of low quality skillset and human capital, lack of finance to accelerate investment levels, informality of a significant number of SMEs which limits options for investments, and a host of other challenges.

International Trade Centre (2018) notes that the competitiveness of African SMEs depends largely on the quality of infrastructure and logistics services on the continent. Infrastructure impacts directly on the performance of SMEs. For instance, almost 60 percent of African firms opine that infrastructure constraints in transport and power are the main challenges to their daily operations (AfDB OECD & UNDP, 2018). The absence of quality infrastructure results in delivery delays, long journeys, as well as damaged goods. These have considerable cost implications on productivity and profit levels of SMEs. Electricity is required to power machines in the process of production, while a healthy ICT infrastructure encourages the efficient deployment of ICT tools, thus assisting SMEs to better manage their finances, inventory and production processes, as well as gain access to relevant information and business opportunities. Effiom and Agala (2020) argue that Africa's infrastructure funding gap has been widening annually, while the public private partnership (PPP) funding model is critical in bridging the transport and ICT infrastructure deficit on the continent (Effiom, 2020).

With growing standardization and regulation of products in national and international markets, African SMEs find it difficult to navigate through the labyrinth of international standards for goods and services. Because standards are critical to value chain and international trade, they guarantee safety of products and harmonise inputs in the different stages of production. However, SMEs across sub-Saharan Africa face the challenge of bearing the costs of standard compliance and regulation, since they are generally fragmented, less productive and smaller in size compared to those in developed countries (International Trade Centre, 2018). Obstacles to standards compliance by African SMEs include burdensome and lengthy certification processes, clumsy product testing procedures, absence of facilities for control and testing, as well as requisite trained personnel and infrastructure. Others include exorbitant payments for certifications and information accessibility relating to certification and standards requirements (World Bank, 2018). These constraints, notwithstanding, African SMEs must compete in the same global market with other SMEs from developed economies; they must comply with international standards if they must be competitive and expect to participate in value chains.

The empirical literature on the constraints of SMEs in Africa is unanimous in admitting that lack of access to finance is the greatest challenge facing SMEs. For instance, over 20 percent of SMEs surveyed conclude that lack of access to finance constitutes the biggest bottlenecks (International Trade Centre, 2018). International Financial Corporation (2017) submits that SMEs in Africa are confronted with a yearly financing gap exceeding $136billion. Besides this fiscal crises, close to 60 per cent of African MSMEs that require bank loan cannot obtain one. Explanations differ across countries as to the cause of SMEs inability to access finance. These include discouraging macroeconomic policies to obtain bank credit as in Ghana or firm level financial illiteracy in Nigeria. With costless access to finance, African SMEs could invest in productive capacities for growth. Which is why Fowowe (2017) concludes that those firms on the continent with access to credit grow faster compared with those who cannot obtain credit. Evidence from cross-country analysis suggests that firm innovation is positively associated with better access to formal finance (Sharma, 2007). Thus, the International Trade Centre SME Competitiveness Surveys Report (2018) points to five crucial areas that can tip the balance of attractiveness and competitiveness in favour of African SMEs. These include: capacity to meet quality, time, human capital, infrastructure and access to finance requirements.

2.1 Theoretical Review

The conceptual understanding of SMEs are as diverse as there are economies. This is because economies are typically at different stages of growth and development; therefore, what passes as an SME in one context might not apply in the other. Thus, with no universally accepted definition, its conceptualisation therefore depends on many factors, notable among which are size of the country's population, industry structure, degree of international economic integration, and business culture (Kushnir, 2010). In the European Union, for instance, a business is classified as an SME if it has in its employ workers less than 250 persons, in addition to a yearly turnover not exceeding EUR50 million or total assets of EUR 43 million (European Small and Medium-sized Enterprises Center, 2019). A different definition applies in the United States, where a manufacturing firm is classified as an SME if its employees do not exceed 500 (CFI, 2020). In Nigeria, SMEs are classified using a twin criteria of asset ownership (excluding buildings and land) and employment. On these criteria, a micro enterprise is any business enterprise that employs less than 10 workers with total assets less than 5 million naira, while a small enterprise is that which employs between 10 and 49 employees with a total asset of 5 to less than 50 million naira (SMEDAN/NBS, 2018).

The Solow-Swan growth theory (Solow, 1956; Swan, 1956) explains how economic growth can be initiated and sustained through the appropriate combination and accumulation of capital (*K*), labour (*L*), and technology (*A*). The structure of the model, which mimics the Cobb-Douglas production function, is assumed to exhibit constant returns to scale as well as diminishing returns to the variable inputs, i.e. capital, and labour. By the first assumption, a doubling of either labour or capital, for instance, would proportionately double output, whereas by the second assumption, an increase in capital, for instance, holding labour constant would result in an increase in output but by a lesser amount compared to the previous increase.

The assumptions of the neoclassical model and their ensuing conclusions have been refuted by the endogenous growth theory, the severest of which has been the assumption that technological change (the Solow residual or total factor productivity) cannot be determined by factors within the model or economic system. By retaining the basic structure of the neoclassical model, but altering the latter's underlying assumptions (i.e. substituting increasing returns to the factor inputs for diminishing returns), and endogenizing technological change – the endogenous growth theory comes to different conclusion compared to the exogenous theory, namely, the possibility of continuous long-term growth.

Both theories are relevant to our present investigation as they provide a clear pointer of how trade openness can impact positively on the domestic economy via its SMEs sector on the one hand, and how SMEs can in turn propel the rate of economic growth and development through capital accumulation and expansion of investments. In the Solow model, the assumption of technology globalisation or transfer means that participating SMEs in international trade are guaranteed a costless access to new techniques of production which would make them more competitive at the global level. And in the Romer model, the performance of SMEs can be affected through international spillovers or externalities arising from cross-border investment or trade. However, the sanguine predictions of these models have been the subject of much debate and scathing criticism by scholars. Essia (2012), for instance, argues that technology transfer is unrealistic given the growing tacitness of new technologies which has made it increasingly easier for high technology firms to hoard vital information on innovations, thus restricting the flow of new technology to firms in developing countries. With the hoarding of new technology, the prediction of convergence based on technology diffusion is submitted to be a fallacy.

Equally relevant in this paper is the classical theory of trade as formalized in the Smithsonian and Ricardian theories of free trade (Smith, 1776; Ricardo, 1817). According to Smith, the benefits of trade rest in the capacity of nations to produce for export commodities that it produces at absolutely lower real cost than its trading partner. When that happens, trade will benefit participating countries by widening their markets and increasing their productivity. Smith's theory rests on the proposition that there are two commodities and two participating countries with absolute advantage in the production of one commodity each. It however fails to provide adequate explanation of the basis of trade when one country has absolute advantage in the production of the two commodities (Esang, 2001). This dilemma is addressed by the Ricardian theory of comparative cost advantage.

In weaving together the major strands of the theories reviewed above, we come to the following conclusion: in the classical trade theories, trade openness is underscored as a critical driver of economic growth, which generally passes through small firms in the local economy; in the Solow model, the role of capital is underlined as necessary to stimulate growth. Thus, in our specific instance, SMEs might benefit from capital via external and internal sources – through foreign direct investment, direct credit to the private sector via the monetary and fiscal policies, as well as provision of critical infrastructure (e.g. energy or electricity consumption). The Solow and Romer models equally emphasise the possibility of globalisation of technology in the presence of free trade, implying that SMEs can access and adopt new technologies, perhaps embodied in FDI and other cross-border investments. An open economy mandates the existence of exchange rate regimes and policies, which informs the inclusion of the exchange rate variable and other variables highlighted above in the ensuing model specification. Thus, on *a priori*, we expect trade openness, FDI, credit to the private sector, and energy consumption to be positively correlated with the performance of SMEs. However a negative impact of exchange rate on SMEs performance is expected.

2.2 Empirical Literature

Contrasting results on the nexus and impact of trade liberalisation on SMEs performance dot the empirical literature. Three positions can be gleaned: first, that SMEs respond positively to trade liberalisation; two, that trade impacts negatively on performance of SMEs; and lastly, that liberalisation's impact on SMEs are mixed, inconclusive and dependent on the domestic economy's institutional arrangements and market configuration. It is worth emphasising that these contrasting results largely emanate either from (a) the proxies used to measure trade liberalisation and SMEs performance, or (b) the empirical methodology of research adopted. Proxies like sum of import and export divided by the GDP, inward foreign direct investment, tariffs comprising of export and import duties, are all employed in operationalizing trade openness. This results in differing evidences and conclusions.

Studies which investigate the influence of trade openness on SMEs generally come to a conclusion implicitly. By establishing that free trade promotes economic growth, such studies infer that growth is generated through trade's direct effect on domestic firms of the economies under consideration. For instance, Kim et al. (2016) come to the conclusion that liberalisation has positive growth effect on emerging economies, principally through domestic small businesses who benefit from technology transfer in the course of trading. Kukeli et al. (2006) using FDI as a measure of trade openness avers that trade liberalisation engenders positive spillover effects on the domestic economy because of management skills and technology transfer coming from developed countries. Using cross country growth equation, Sachs and Warner (1995) emphasise the merits derivable from trade liberalisation, namely that trade openness results in higher growth rates in poorer countries compared to richer ones. Specifically, they classified a country as closed if: average rates of tariff exceeded 40 per cent; non-tariff barriers (NTB) on average exceeded 40 percent of imports; it had a socialist economic system; the government had monopoly over major exports; and if its black market premium was more than 20 percent during the decades of the 1970s and 1980s.

Perhaps the work of Ayyagari et al. (2007) provides one of the most comprehensive study of the effect of SMEs to economic growth. Using a sample of 76 countries, comprising 43 developing and 33 developed, with data spanning 1990-1999, formal SMEs were discovered to contribute 45 percent on the median to economic growth. The disaggregated contribution shows that the percentage contribution of SMEs to developed and developing countries was 49 and 35 percent respectively. Almost similar conclusions are drawn with data from the Economist Intelligence Unit (EIU) (2010), Asian Development Bank (ADB) (2013), the Edinburgh Group (2013) and the European Commission (2013). Descriptive analysis of these data consisting of a sample of 33 countries, 23 developing and 10 developed, show that the median GDP contribution of SMEs is 45 percent – 55 percent in developing countries; 35 percent in developing (WTO, 2016). These results though must be interpreted cautiously because the statistical analysis does not include micro enterprises, nor does it account for SMEs operating in the informal sector. On the share of informal SMEs contribution to the GDP, Ayyagari et al. (2007) analyse data for 29 and 26 developed and developing countries respectively. The median contribution of the informal sector in GDP is 20 percent, consisting of 14 and 34 percent in developed and developing countries respectively.

This implies that overall, the relative contribution of SMEs (formal and informal) to the economy is quite significant.

One of the channels through which liberalisation might benefit the performance of SMEs is in the area of knowledge spillovers. A long line of research beginning from Romer (1986) indicates that knowledge spillovers are an important instrument undergirding economic growth (see also, Lucas 1988; 1993; Grossman and Helpman, 1991). Proximity of geography mainly via clusters is important in channelling knowledge via cost reduction and innovation commercialisation (Autant-Bernard, 2001a; Autant-Bernard, 2001b; Orlando, 2000). Clusters might improve firm productivity through the firm's closeness to other firms that innovate (Paunov & Rollo, 2016). Beaudry and Swann (2001), Dumais et al. (2002), Rosenthal and Strange (2005) and Pe'er and Vertinsky (2006) show that clusters could well enhance the chances of entry, survival as well as growth of new firms. Yet other studies come to the conclusion that cluster location decreases the chances of survival of new firms through mega competition for personnel and resources among firms (Beaudry and Swann, 2001; Sorenson and Audia, 2000; Folta et al., 2006).

Emphasis on clusters as a tool for the promotion of firm productivity resonates with the ECOWAS Trade Liberalisation Scheme (ETLS) which was adopted in 1979 by Member States. The ETLS is the primary instrument directed to the achievement of trade and market integration within the subregion. With the objective of harnessing the benefits of a large integrated market in West Africa, which includes the promotion of entrepreneurial development, investment, and industrialisation, the ETLS has been buffeted by several constraints, among which are: the absence of political will on the part of Member States to relinquish some of their sovereignty for the sake of the success of the ETLS, inadequacy of productive capacity and trade-related information and infrastructure, as well as institutional and technical deficiencies on the part of the ECOWAS Commission (Fajana, 2018). These constraints have undoubtedly impacted negatively on the performance and productivity of SMEs within the subregion. It remains to be tested empirically how SMEs have fared under this constraining scenario.

3. 0 METHODOLOGY

3.1 Data description

The current study verifies the influence of trade openness as well as the enlisted control variables on the performance of SMEs within the ECOWAS regional block. Among the ECOWAS countries selected on the basis of data availability, and listed in alphabetical order are – Cote d'Ivoire, Cape Verde, Ghana, the Gambia, Niger, Nigeria and

Senegal. Furthermore, the panel series span the period 1990 – 2019 for all the countries. Consequently, a macro panel framework with larger time-dimension (T) and smaller cross-sectional dimension (N) is envisaged. That is, the empirical evaluations are on the basis of (T>N) macro-panel specification. In addition, the study relied on secondary datasets extracted from World Development Indicators (WDI [World Bank]) for its empirical analysis. Thus, Table 3 provides more insights on the relevant panel datasets in terms of notations, measurements and sources.

Table 3. Data descriptions

Series	Notation	Measurement	Source
SME value-added	SME	Medium and high-tech manufacturing value added (% manufacturing value added)	WDI
Trade openness	OPEN	Trade (% of GDP)	WDI
Foreign direct investment	FDI	Foreign direct investment, net inflows (% of GDP)	WDI
Exchange rate	EXR	Official exchange rate (LCU per US$, period average)	WDI
Credit to private sector	CPS	Domestic credit to private sector (% of GDP)	WDI
Energy consumption	ENG	Access to electricity (% of population)	WDI

Note: WDI denotes World development indicators.

3.2 Model Specification

The Solow-Swan neoclassical growth model underpins our model specification. We begin with the Cobb–Douglas production function of the form,

$$Y = f\ (AK^{\alpha}L^{1-\alpha}) \quad \ldots\ldots\ldots \quad (1)$$

where Y is economy-wide output, K is capital and L is labour. A represents technological progress or total factor productivity. The Cobb–Douglas production function is flexible and permits the amplification of A by incorporating other factors that directly affect the growth of SMEs. Thus, we incorporate openness (*OPEN*), herein measured as the ratio of imports and exports to the GDP, net foreign direct investments (*FDI*), exchange rate (*EXR*), credit to private sector (*CPS*), and energy consumption (*ENG*) into the model as critical factors affecting the performance of

SMEs following some previous studies, including Belderbos et al. (2021) and Narayanan (2019).

Thus, *A* in equation (1) becomes

$$A_{it} = f(OPEN_{it}, FDI_{it}, EXR_{it}, CPS_{it}, ENG_{it}) \quad (2)$$

Putting equation (2) into (1), we have the functional form of the model expressed as:

$$Y_{it} = f(OPEN_{it}, FDI_{it}, EXR_{it}, CPS_{it}, ENG_{it}) \quad (3)$$

The economy-wide aggregate output Y_{it} is replaced with the output of a subsector. This is in line with similar studies that augment the neoclassical growth model to investigate the output growth of a specific sector (Ada & Anyanwu, 2013; Adebiyi & Dauda, 2004; Lucas, 1988; Ogbuagu and Udo, 2012)

Thus, the linear econometric form of equation (3) becomes:

$$SME_{it} = \delta_0 OPEN_{it} + \delta_1 FDI_{it} + \delta_2 EXR_{it} + \delta_3 CPS_{it} + \delta_4 ENG_{it} + \mu_{it} \quad (4)$$

Thus, SME_{it} denotes the performance of SMEs in the selected cross-section over time, while $\delta_1 \ldots \delta_5$ are the coefficients of the explanatory variables. On *a prior*, we expect $\delta_1, \delta_2, \delta_4$ *and* δ_5 to be positively correlated with the dependent variable, SME_{it}, while δ_3 is expected to be negative. μ_{it} is the stochastic error term, representing the unexplained residual or variation in the dependent variable. While *i* and *t* denote the cross-sections and time series dimensions, respectively.

3.3 Estimation techniques

The study adopts array of panel estimators, including pre-estimation and post-estimation, for the empirical narratives of the influence of trade openness on SMEs performance in ECOWAS. First, the study considers the characteristics of individual series in terms of the mean, median, mode and standard deviations using descriptive statistics. The descriptive statistics are followed by the pairwise cross-correlation analysis. Another notable step adopted in this study is the cross-sectional dependency tests, unit-root tests, including a third generation unit-root test that accounts for structural breaks (Karavias & Tzavalis, 2017), as well as cointegration tests. These steps are essential when dealing with macro panel analysis where the time dimension is larger than the cross-section dimension (T>N). Furthermore, the outcomes of the cross-sectional dependency (CD) tests determines the appropriate panel unit-root tests to be adopted, that is, either first-generation or second-generation panel unit-root procedures (Effiom & Uche, 2022; Opuala et al., 2022). Likewise, the choice of the cointegration technique is also a function of the outcomes of the CD tests. For the CD test, in line with prior studies (Opuala et al., 2022), the current study relies on Pesaran

(2004) cross-sectional dependency test and Pesaran (2015) weak cross-sectional dependency test.

Dynamic Common Correlated Effects ARDL (CS-ARDL)

The empirical outcomes of this investigation in terms of the impacts of the explanatory variables on the response variable are based on the CS-ARDL panel estimator extended by Chudik & Pesaran (2015). The CS-ARDL is a more efficient dynamic panel estimator that accounts for both heterogeneities in panel series and long- and short-run dynamic interactions of relevant variables (Effiom & Uche, 2022; Opuala et al., 2022). Other advantages of the CS-ARDL include its ability to produce efficient estimates among fractionally integrated panel series. The model also avails reliable estimates amidst cross-sectional dependences (Usman et al., 2022). Likewise, the procedure is equally formidable in the case of weak exogeneity that may appear due to the lagged response variable in the specified equation. Furthermore, the technique prevents the endogeneity problem by adding the lagged cross-sectional averages in the equation (Usman et al., 2022). However, some notable drawbacks of the CS-ARDL procedure is that it requires rank conditions and it is only robust to unit-specific specifications (Chudik et al., 2016) The CS-ARDL functional scheme is depicted in Eq. (5).

$$\Delta EQ_{it} = C_i + \lambda_i\left(EQ_{it-1} - \beta_i^1 \text{Ꭓ}_{it} - \text{þ}_{1j} E\bar{Q}_{it-1} - \text{þ}_{2j}\text{Ꭓ}_{t-1}\right) + \sum_{j=1}^{p-1} \theta_{ij}\, \Delta EQ_{it-j} + \sum_{j=0}^{q-1} \phi_{ij}\, \Delta \text{Ꭓ}_{it-j} + \delta_{1i}\Delta E\bar{Q} + \delta_{2i}\Delta \text{Ꭓ}_t + \varepsilon_{it} \quad (5)$$

where EQ_{it} represents the response variable, while Ꭓ_{it} denotes the long-run coefficients of all the explanatory variables. The short-run dynamic coefficients of the explanatory and response variables are denoted by θ and ϕ, respectively, while the long-term coefficients are denoted by β, while ε_{it} represents the stochastic error term.

Cross-Sectionally Augmented Distributed Lag (CS-DL) model

Furthermore, the Cross-sectionally Augmented Distributed Lag (CS-DL) proposed by Chudik et al. (2016) was adopted for robustness check on the outcomes of the CS-ARDL panel estimator. Accordingly, the estimates of the CS-DL are consistent and reliable in the face of cross-sectional dependence and transnational heterogeneity (Opuala et al., 2022). Furthermore, the CS-DL outputs remain robust amidst serially correlated errors and when the dynamics are miss-specified (Chudik et al., 2016; Ditzen, 2018). Likewise, within the CS-DL, the estimated regression is augmented with both the deviations and lags of the explanatory, and the cross-sectional averages (Chudik et al., 2016). Moreover, the CS-DL performs better than the CS-ARDL given that it is robust to dynamic specification unlike unit-specific CS-ARDL specifications. Additionally, unlike the CS-ARDL, the CS-DL panel estimator does not require the rank condition that is often required in the CS-ARDL procedure, thereby allowing the cross-sectional averages approximate the space of the unobserved factors arbitrarily well as N tends to infinity (Chudik et al., 2016). Irrespective of the notable advantages of the CS-DL, Chudik et al., (2016) emphasized that the model should be considered as a complementary and not a superior estimation tool to the CS-ARDL. A notable limitation of the CS-DL procedure is that it does not allow for feedback effects from the response variable unto the explanatory variables (Chudik et al., 2016). On the above notion, the functional scheme of the CS-DL panel estimator is represented in Eq. (6).

$$\gamma_{it} = \theta_i \times_{i,t} + \sum_{l=0}^{\rho_{\times-1}} \delta_i \, l\Delta X_{i,t-1} + \sum_{l=0}^{\rho_{\gamma}} \delta_i \, l\Delta \gamma_{i,t-1} + \sum_{l=0}^{\rho_{\times}} \delta_i \, l\Delta X_{i,t-1} + \varepsilon_{i,t} \qquad (6)$$

where ρ_γ and $\rho_\times$ depict the cross-sectional average number of lags.

4.0 Analysis and discussion

The empirical narratives and the consequential policy remarks contained in this study emerged through several in-depth and rigorous analytics. The outcomes have been sequentially summarized in the relevant tables for empirical overview beginning with the summary statistics and correlation matrix illustrated in Table 4.

Table 4. Summary statistics and correlation matrix

Summary Statistics						
Series	*SME*	*OPEN*	*FDI*	*EXR*	*CPS*	*ENG*
Mean	14.782	73.335	1.727	517.182	15.925	47.756
Std. Dev.	0.516	15.811	1.038	118.573	7.838	20.485
Min.	13.699	46.067	0.176	264.691	8.854	0.032
Max	15.685	95.069	6.026	732.397	36.495	68.550
Correlation Matrix						
	ENG	*CPS*	*EXR*	*FDI*	*OPEN*	*SME*
SME	-0.12*	0.30***	0.61***	-0.10	-0.14**	1.00
OPEN	0.14**	0.58***	-0.18***	0.35***	1.00	
FDI	0.25***	0.38***	-0.14**	1.00		
EXR	-0.01	0.19***	1.00			
CPS	0.11	1.00				
ENG	1.00					

*Note: ***, ** and * denote significant correlation among the series at 1%, 5% and 10% levels of significance, respectively.*

As highlighted earlier, Table 4 provides the summarized versions of the descriptive statistics (upper panel) and correlation matrix (lower panel). According to the descriptive statistics, the exchange rate (*EXR*) has the highest expected value, followed by trade openness (*OPEN*), access to electricity (*ENG*), foreign direct investment (*FDI*), the series of small and medium enterprises (*SME*) and the least, credit to private sector (*CPS*). The series of *FDI* and *EXR* are more dispersed than others, while openness is the least dispersed. Furthermore, the standard deviations of all the series lie between the maximum and their minimum values. This outcome suggests a mean reversion tendency among all the enlisted series except *ENG*. Furthermore, the correlation matrix (lower panel) reveals significant negative correlation between trade openness, access to electricity and SMEs, while it also indicates significant positive correlation between *CPS*, *EXR* and *SME*. Further insight reveals an insignificant negative correlation between FDI and SME in West Africa. Following this preliminary diagnosis is the summary of the CD and inter cross-sectional heterogeneity tests that have been summarized in Table 5.

Table 5. CD and slope heterogeneity tests

Variable	CD (Pesaran, 2004)	p value	W- CD (Pesaran, 2015)	p value
lnSME	-2.09**	0.03	21.60***	0.00
lnOPEN	2.09**	0.03	25.04***	0.00
lnFDI	2.83***	0.00	17.37***	0.00
lnEXR	17.23***	0.00	16.17***	0.00
lnCPS	9.18***	0.00	24.65***	0.00
lnENG	20.44**	0.00	23.61***	0.00
Slope heterogeneity test outcome:				
	Delta	p value		
	2.82***	0.00		
Adjusted Value	3.23***	0.00		

*Note: *** and ** denote 1% and 5% significance levels.*

The outcomes of the CD and inter cross-sectional heterogeneity tests summarized in Table 5 indicate that all the enlisted series are cross-sectional dependent and inter cross-sectional heterogeneous. This implies the rejection of the null hypothesis of cross-sectional independency and inter cross-sectional homogeneity. Given the outcome of the CD and slope heterogeneous tests, the peculiar characteristics of the enlisted panel series can only be captured by second generation panel data techniques, including panel unit-root and panel cointegration tests. For the panel unit-root test, the study adopts two second generation unit-root procedures (CIPS and CADF) two second generation cointegration test (Westerlund and Pedroni) procedures following some previous studies (See Opuala et al., 2022). Furthermore, based on insights gained from Olaoye et al. (2020), this study extends the trajectory of knowledge by employing a third-generation panel unit-root procedure developed by Karavias & Tzavalis (2017) which most previous studies rarely considered. Accordingly, through this technique, we perform Lagrange multiplier (LM) panel unit root tests in the presence of structural breaks on the series SMEs and all the explanatory variables. Additionally, the third generation panel unit roots process test is capable of distinguishing between the null hypothesis of unit roots and its alternative of stationarity, as they can exploit both cross section and structural breaks information of the enlisted series. The null hypothesis implies that all panel time series are unit root processes, while the alternative hypothesis suggests that some or all of the panel time series are stationary processes. Meanwhile, the summaries of all the panel unit-root tests and panel cointegration tests have been illustrated in Tables 6 and 7, respectively.

Table 6. Panel unit-root test results

Series	CIPS		CADF		Karavias and Tzavalis (2017)		
	Level	First Diff.	Level	First Diff.	MinZ-stat	p value	Break date
lnSME	-2.29	-4.63***	-2.52	-4.36***	-2.64***	0.00	1993
lnOPEN	-2.36**	-5.53***	-1.91	-3.98***	-6.19***	0.00	2014
lnFDI	-2.69**	-5.40***	-2.21	-3.85***	-5.28***	0.00	2007
lnEXR	-2.30	-4.52***	-2.28	-3.91***	-0.27	1.00	Na
lnCPS	-2.71***	-5.36***	-3.08***	-3.74***	-4.73***	0.00	1993
lnENG	-3.07***	-5.75***	-1.89	-4.93***	-6.54***	0.00	2001

*Note: *** and ** indicate the rejection of the null hypothesis of non-stationarity and absence of structural breaks at 1% and 5% significance levels, respectively. na denotes not applicable.*

The evidence arising from the panel unit-root tests (Table 6) suggests that the series are mutually integrated. That is, the outcome of the stationarity tests indicates that while some series are stationary at level, others are first differenced stationary series. Moreover, most of the series, except the exchange rate were affected by structural breaks in different years. Accordingly, the series *lnSME* and *lnCPS* had the impact of structural breaks in 1993, *lnENG*, *lnFDI* and *lnOPEN* had its share of structural shocks in 2001, 2007 and 2014, respectively. Overall, it is interesting that none of the enlisted series is second differenced stationary variable, such that may not be applicable to selected empirical model of this investigation. Following the above is the test for long run convergences among the panel series that have been illustrated in Table 7.

Table 7. Cointegration test results

Westerlund			Pedroni		
Parameter	Value	p-value	Parameter	Statistic	p-value
Ga	-1.987	0.709	Modified Phillips-Perron t	2.508***	0.006
Gt	-4.805**	0.021	Phillips-Perron t	-0.309	0.378
Pt	-9.338***	0.000	Augmented Dickey-Fuller t	-0.524	0.299
Pa	-1.640	0.983			

*Note: *** and ** imply the rejection of the null hypothesis of no cointegration among the panel series at one and five percent levels of significance, respectively.*
Accordingly, the null hypothesis specifies that the variables do not converge at the long-term, whereas the alternative hypothesis specifies that the series coevolve in the long-term.

Table 7 provides the summaries of the cointegration tests results drawn from the two enhanced second generation procedures – Pedroni and Westerlund procedures. Accordingly, the outcome of the long run tests indicate that the enlisted panel series are cointegrated. This implies that the performance of SME (*lnSME*) trend together with the explanatory variable - series of trade openness (*lnOPEN*) and the enclosed control variables in the long run. This further implies the rejection of the null hypothesis of no long run cointegration among the series. Therefore, the study proceeds to evaluate both long and short run implications of trade openness and other control variables on the performance of SMEs in West Africa with the aforementioned enhanced panel estimators as summarized in Table 8.

Table 8. Estimates of CS-ARDL and CS-DL panel models

	CS-ARDL			CS-DL		
Long-run estimates						
Series	Coefficient	z_stat	p-value	Coefficient	z_stat	p-value
lnOPEN	-1.074*	-1.66	0.096	-0.292*	-1.44	0.060
lnFDI	0.099**	2.01	0.044	0.025	0.44	0.660
lnEXR	0.509	1.21	0.226	0.502*	1.71	0.087
lnCPS	0.467*	1.76	0.078	0.733	1.28	0.200
lnENG	-0.365	-1.32	0.188	0.134	0.25	0.804
Short-run estimates						
ΔlnOPEN	-0.568	-1.15	0.249	-0.329	-0.94	0.349
ΔlnOPEN(-1)	-0.618**	-2.30	0.022	-	-	-
ΔlnFDI	-0.016	-0.74	0.460	-	-	-
ΔlnFDI(-1)	0.126**	2.38	0.017	-	-	-

ΔlnEXR	-0.668	-0.70	0.486	-	-	-
ΔlnEXR(-1)	1.219	1.33	0.183	-	-	-
ΔlnCPS	0.338	0.96	0.336	-	-	-
ΔlnCPS(-1)	0.239	0.63	0.527	-	-	-
ΔlnENG	-0.254	-1.28	0.202	-0.074	-0.46	0.649
ΔlnENG(-1)	-0.110	-0.88	0.380	-	-	-
ECT	-0.379**	-2.01	0.045	-	-	-

*Note: ***, ** and * imply significant relationship at the one, five and ten percent significance level, respectively. POS and NEG indicate positive and negative partial deviations, while Wald-LR and Wald-SR imply Wald long- and short-run asymmetric coefficients, respectively.*

The summarized estimates of the three panel estimators (CS-ARDL and the CS-DL) as illustrated in Table 8 provides the following interesting empirical evidences. Based on the outcomes of the CS-ARDL, it is established that trade openness (*lnOPEN*) provides long run significant negative influence on the performance of SMEs in West Africa within the study period. Specifically, the performances of SMEs deteriorate by approximately -1.07 percent whenever the economy opens its borders to more external trade. This outcome presupposes an unhealthy relationship between the local industries who lack the prerequisite capacities to compete favourably within the globalized corridor. This outcome contradicts the findings of Kim et al. (2016) that report that openness is favourable to SMEs in emerging economies. It further implies that for the survival of the local industries, the sub-region must apply caution while embracing trade openness in its entirety. Interestingly, the outcome of the CS-ARDL is consistent with that of the CS-DL in terms of the long run significant negative influence of trade openness (*lnOPEN*) on the performances of SMEs in West Africa. Specifically, the outcomes of the CS-DL indicate that SMEs performances deteriorate by approximately 30 percent in response to one-percent change in the country's trade relationship with other countries. Undoubtedly, the outcomes suggest unhealthy implications of open trade with SMEs performances in the region. Thus, policy directives must be sensitive to the challenges and peculiarities of the local entrepreneurs, thereby, providing relevant incentives that allow for optimal performances amidst widening global trade relationship.

Similar to the long – run implications of open trade on SMEs performance, the short run result based on the CS-ARDL and the CS-DL procedures equally highlight the unfavourable relationship existing between the two variable in the case of ECOWAS countries. The short run outcome which suggest more unpleasant outcomes reveals that after some time lags ($OPEN_{t-1}$), SMEs performance deteriorate by approximately -0.62% in response to one-percent adjustment in trade relationships. This ensuing poor performance of SMEs in relationship with open trade could be attributable to fierce competition and unfavourable business environment in terms of capital inadequacy, infrastructural deficits, etc., they tend to perform poorly in the long-term. Thus a crucial remedy to the conflicting short-term and long-term results is a policy that deliberately targets the improvement of the domestic operating environment of SMEs, both in terms of infrastructure provision and policy consistency. On this premise, strategic policies are required to position the SMES appropriately to withstand the dynamics of global competitiveness.

Among the enlisted control variables, the estimated results from the two robust panel models denote that FDI[*lnFDI*] and credit to private sector (*lnCPS*) in the case of CS-ARDL and exchange rate (*lnEXR*) in the case of CS-DL are significant long run predictors of SMEs performances in the region. Unfortunately, such cannot be ascribed to the effects of energy availability (*lnENG*) which consistently limits the performance of SMEs significantly in the long run. This outcome (negative impacts of energy) which negates theoretical postulations is a glaring confirmation of the poor state of infrastructure (energy poverty) in the region which had over the years, constrained the general performances of SMEs. Given this outcome, policies that are targeted to improving energy availability will, ceteris paribus, enhance the performance of SMEs within the sub-region. Moreover, greater emphases on ways to attract more FDI to the sub-region, more stable exchange rate regimes and robust access to credits are pertinent for greater performances and survival of SMEs in West Africa.

Similar to the short run outcomes of the explanatory variable, the short run effects of the control variables on the explained variable is generally inconsistent. Suffice it to note that greater emphases are placed on long rather than short run relationships. It is also pertinent to highlight that the speed at which SMEs performance in the region reverts to equilibrium after initial perturbations is uncomfortably low going by the evidences from the three panel estimators. Specifically, it returns on the average of approximately -37% based on the outcomes of the CS-ARDL.

5.0 CONCLUSION AND POLICY REMARKS

This study evaluated the performance of ECOWAS SMEs within the context of trade openness or liberalisation. While country-specific investigations abound in the trade-SMEs literature, our review revealed a glaring dearth of studies within the ECOWAS regional bloc. For empirical investigation, the study selected seven ECOWAS countries (Cote d'Ivoire, Cape Verde, Ghana, the Gambia, Niger, Nigeria and Senegal), based on consistent data availability. The empirical analytics of the underlying macro data were underpinned by two rigorous and enhanced panel regression estimators namely, the CS-ARDL and the CS-DL procedures. Long run results distilled from these frameworks were overwhelmingly consistent to the fact that trade openness imposes a deleterious influence on the performance of SMEs in the ECOWAS subregion. However, our findings established mixed short run results, generally indicating that for the most part, the performance of SMEs responds positively to trade openness. This comforting short run results indicate that trade openness may not be bad after all, given the right domestic environment. A probable explanation of the long run negative response of ECOWAS SMEs to trade openness is that in the short term, there may be initial, momentary but unsustainable positive effect arising from SMEs exposure to new technology, new skills set, etc. But these peter out in the long term, because of the problem of sustainability due to non-competitive local environment.

Given these outcomes the burden of policy should therefore be aimed at replicating and sustaining in the long term the benign short run results of a positive impact of trade openness on SMEs performance. This demands a careful consideration of domestic policies and the underlying factors that impinge directly on SMEs performance. A cursory examination of the response of SME performance to the control variables of the study reveals that policy makers in the individual countries must focus more on addressing and mitigating the negative effects of energy poverty in the subregion. ECOWAS SMEs cannot thrive in the face of trade liberalisation when critical infrastructure like electricity, road and rail transportation, as well as communication are in very bad shape. More specifically, governments are encouraged to sustain policies to attract more inward FDI as well as stabilise the exchange rate of their respective currencies.

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ANALYSIS OF MONETARY POLICY, PRODUCTIVITY AND DEMAND SHOCKS ON OUTPUT, INFLATION, AND INTEREST RATE IN SIERRA LEONE: A BAYESIAN DSGE APPROACH

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Abstract

This paper examines the response of output, inflation and interest rate to monetary policy, productivity and demand shocks in Sierra Leone using a Bayesian Dynamic Stochastic General Equilibrium (DSGE) Model. Using quarterly data spanning from 2011Q1 to 2018Q4, our findings suggest that; monetary policy shocks have a transitory effect on inflation, interest rates, and output. Productivity shocks have a permanent effect on inflation, interest rate, and output in Sierra Leone. However, demand shocks are found to be temporarily inflationary and their overall effect on inflation, interest rates, and output is also transitory. We recommend that the Bank of Sierra Leone should continue to reform the financial sector to encourage financial inclusion to improve monetary policy transmission. Moreover, the effort to improve fiscal and monetary policy coordination should be sustained, as the result clearly shows that productivity shocks are permanent- growth in productive capacity requires growth in the real sector, which the Central Bank can only effectively support through policy coordination with the fiscal authorities.

Keywords: Bayesian analysis, DSGE, Impulse response analysis, Monetary policy, Open economy, Sierra Leone.
JEL Classification: C11, E30, E32, E37

Disclaimer

This paper is a product of the authors. In this respect, the views presented here are those of the authors and do not represent in any way the views of the Bank of Sierra Leone on the subject matter.

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1.0 INTRODUCTION

The Sierra Leone economy has been hit by several external and internal shocks over the years, thereby causing the economy to fluctuate and at most times deviate from its steady state. This situation has also made the prediction of macroeconomic variables in the country somehow difficult to determine. The motivation for this study, therefore, has stemmed from the need to assess the effect of shocks on key macroeconomic variables using a Bayesian Dynamic Stochastic General Equilibrium model. In this paper, we propose the revision of a closed economy Dynamic Stochastic General Equilibrium (DSGE) model of Edmund & Barrie (2021) for analyzing monetary policy and productivity shocks in Sierra Leone to capture the influence of informative priors within an open economy framework. We are motivated by the need to construct a model that allows the monetary policy authorities to determine the appropriate response to the varied economic uncertainties affecting the Sierra Leone Economy. This is particularly important in this period of economic uncertainties, where external shocks such as supply chain disruptions, crude oil prices, and exchange rates exert significant influence on the Sierra Leonean economy. In addition, the need to capture the productivity effects of the widespread adoption of financial technologies (FinTech) which accompanied the pandemic on the structure of the economy is quite helpful and informative for the monetary policy authorities.

To achieve this objective, we employ an open economy Bayesian DSGE model due to its ability to incorporate initial values that account for the peculiarities of the Sierra Leone economy, for which data alone may be inadequate. Relative to the Maximum Likelihood-based DSGEs, the Bayesian variant can provide more efficient estimations of the model parameters and more consistent estimates of the shocks driving economic development (Smets & Wouters, 2004) all of which are imperative for monetary policy decision-making.

Our paper differs from others in distinct ways. To the best of our knowledge, no study on the Sierra Leone economy has used Bayesian DSGE in an open economy framework to account for the impact of monetary policy and productivity shocks. Moreover, we employ an open economy Bayesian DSGE model that accounts for the effect of shocks on the Sierra Leone economy. The study contributes to an existing body of literature, particularly on how shocks can affect the macroeconomy of Sierra Leone. The use of a Bayesian DSGE model is a step forward in supporting the effective formulation and implementation of monetary and financial stability policies at the Bank of Sierra Leone.

The empirical literature on DSGE model-based estimates of potential output is scarce and the reported findings are still preliminary reflecting the fact that the literature is relatively new. Modeling and capturing the dynamics of Emerging Market and Developing Economies (EMDEs) is no easy task. This is partly related to idiosyncratic structural features exhibited by these economies, as well as due to the historical vulnerabilities to external factors and resulting periods of high macroeconomic instability. Under such circumstances, an important question to ask is what features of the benchmark DSGE model need to be modeled to capture relevant features characterizing developing economies.

The use of DSGE models to analyse the dynamic responses of macroeconomic variables to shocks has not been new. It relevance in terms of accounting for shocks in policy analysis and forecasting has been highlighted by some scholars (focusing on structural models), policy makers and monetary authorities especially in the design and implementation of monetary policy. The effectiveness of DSGE models in analyzing policy make them appealing to policy makers (Sbordone, Tambalotti, Rao, & Walsh, 2010).

Others have used New Keynesian DSGE models to analysis the impact of monetary policy, productive, and exchange rate shocks on inflation and output (Adnan, Titoe, Lewis, & Collins, 2021). DSGE models can also be useful to conduct counter-factual experiments and simulation analysis and a typical example is the work done by Chow, Lim, & McNelisc (2014) using a DSGE and DSGE-VAR approach to assess the impact of the varied shocks as well as to determine the appropriate monetary regime choice for Singapore's economy. The use of DSGE model has also been evidently useful for constructing optimal policy projections and policy analysis for open-economies (Adolfson, Laseen, Linde, & Svensson, 2008). While Edmund & Barrie (2021) consider a closed economy maximum likelihood DSGE model framework for Sierra Leone using quarterly data from 2011 q1-2022 q2 to analyze the effects of monetary policy and productivity shocks on output, inflation and monetary policy rate, we employ a Bayesian DSGE Approach which offers better estimates even with small samples if the priors are carefully determined. In other words, we examine the response of output, inflation, and interest rate to monetary policy, productivity and demand shocks in Sierra Leone using a Bayesian DSGE Approach. Ours being a small open economy, most of our results will be useful to the monetary policy authorities at the Bank of Sierra Leone for the direction of policy actions. Moreover, this will serve as a basis for future research.

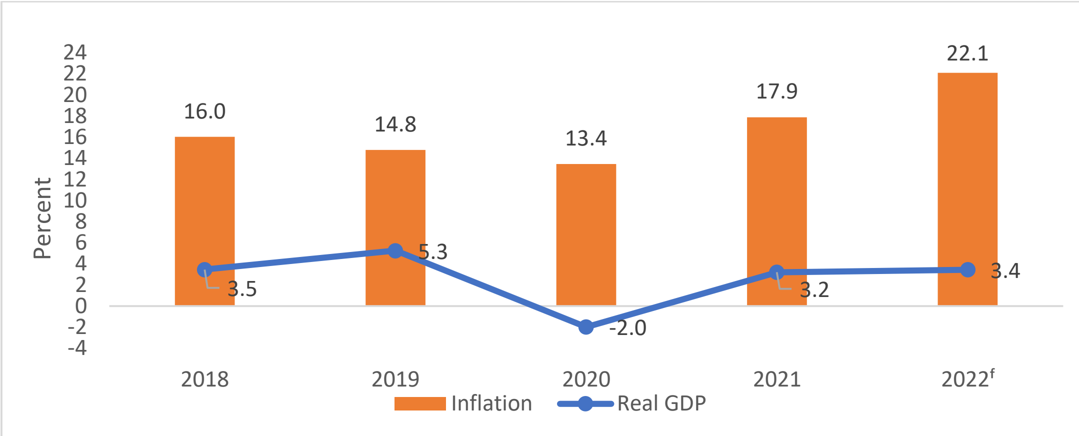
Following the introduction in this section, the next section presents the recent structure of the Sierra Leone economy, Section three presents the Monetary Policy Framework, Methodology, and Data used in the study, section four presents the result and discussions, and section five presents the conclusion of the study.

2.0 RECENT STRUCTURE OF THE SIERRA LEONE ECONOMY

Like most developing countries, the macroeconomic fundamentals in Sierra Leone do respond to both internal and external shocks. The need to analyse this response is further reinforced during the COVID-19 pandemic. The Sierra Leone's economy has been hurt by the COVID–19 pandemic with a severe distortion to real sector economic activities. Real GDP contracted by 2.0 percent in 2020 after growing by 5.3 percent in 2019. The decline was attributed to weak external demand for major exports, particularly diamonds, and to declines in the mining, transport, trade, and tourism sectors. Real GDP growth in 2021 is estimated at 2.9 percent, from an earlier projection of 3.2 percent. However, Real GDP growth is expected to improve in 2022 at 3.4 percent. The projected improvement in growth reflects an expected rebound in the economic activities in both the non-mining and mining sectors.

Despite the numerous economic challenges, inflation was subdued in 2020 at 13.4 percent compared with 14.8 percent in 2019, underscored by prudent monetary policy using novel approaches to counter supply-side inflationary pressures. However, severe supply chain disruptions and surging commodity prices as well as exchange rate depreciation pressures pushed up inflation to 17.9 percent in 2021. Inflation is expected to further rise to 22.1 percent in 2022 on the back of the Russia-Ukraine crisis, which has greatly pushed up fuel and food prices around the world.

Figure 1. Real GDP Growth and Inflation (percent)

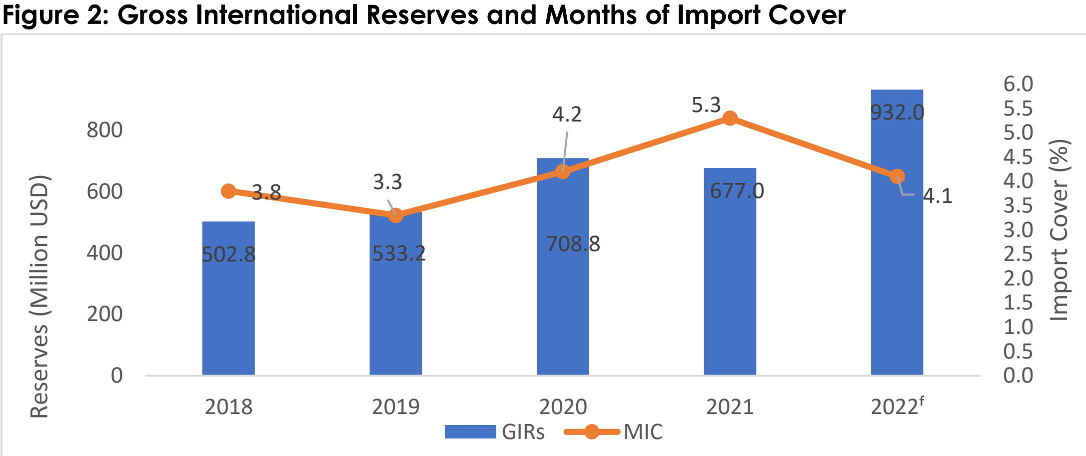


Source: Stats SL, BSL & IMF projections. Note: f=forecast/projection

Note: Figure 1 presents the graph of the real gdp growth and inflation from 2018 to 2022. However, the numbers for 2022 are estimated projections for both real gdp growth and inflation.

On the external front, the current account deficit widened to 15.6 percent of GDP in 2020 from 13.5 percent of GDP in 2019, mainly due to a wider deficit in the trading account. However, the stock of gross foreign exchange reserves improved to $708.8 million (equivalent to 4.2 months of import cover), compared with $533.2 million (equivalent to 3.3 months of import cover) in 2019.

Figure 2: Gross International Reserves and Months of Import Cover

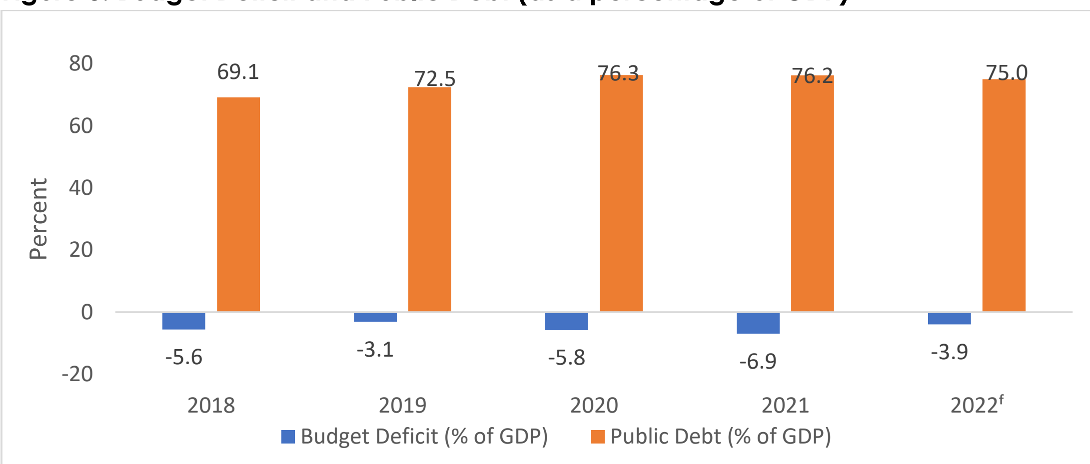


Source: Stats SL, BSL & IMF projections. Note: f=forecast/projection

Notes: Figure 2 presents the graph of the Gross International Reserves and Months of Import Cover for the period 2018 to 2022. The numbers for gross international reserves and months of import cover for 2022 are estimated projections.

The COVID-19 outbreak also greatly constrained government fiscal operations, with increased health and social expenditures. Consequently, the budget deficit widened to around 5.8 percent of GDP in 2020 from 3.1 percent in 2019, and further widened to 6.9 percent in 2021, on account of revenue shortfalls arising from lower economic activities. Moreover, the stock of public debt increased to 76.3 percent of GDP in 2020 from 72.5 percent in 2019. Sierra Leone's debt is classified as being at high risk of debt distress, largely due to heightened solvency and liquidity risks arising from the COVID–19 pandemic. The country is implementing an Extended Credit Facility (ECF) arrangement with the International Monetary Fund. The ECF plans to support the government's reform agenda of creating fiscal space to finance policy priorities of the National Development Plan (NDP).

Figure 3: Budget Deficit and Public Debt (as a percentage of GDP)



Source: Stats SL, BSL & IMF projections. Note: f=forecast/projection

Notes: Figure 3 depicts the graph of the budget deficit and public debt expressed as a percentage of GDP for the period 2018 2022. The numbers in 2022 are estimated projections for both variables (budget deficit and public debt) also expressed as a percentage of GDP.

The high debt burden coupled with limited fiscal and monetary policy space could constrain Sierra Leone's effort to increase growth to its pre-crisis level in the near term. The ECF program, which was introduced before the pandemic, continues to guide policy and budgeting in Sierra Leone. In particular, the 2020 budget was anchored on the NDP. Despite credits and grants from international financial institutions in 2020 to help the country meet the urgent balance of payments and fiscal needs from the pandemic, the country needs increased external financial assistance to support a resilient recovery. External assistance could aim to create fiscal space through debt relief, restructuring, suspension of debt service payments, and concessional lending. In the medium to long term, the country should also complement ongoing domestic revenue mobilization efforts by deepening ongoing financial sector reforms to support domestic credit market growth.[6] Rich in minerals, Sierra Leone has relied on the mining sector in general, and diamonds and iron ore in particular, for its economic base. In the 1970s and early 1980s, the economic growth rate slowed because of a decline in the mining sector. Finally, exchange rate challenges and government budget deficits led to sizable balance-of-payments deficits and inflation. Sierra Leone's short-term prospects depend upon continued adherence to domestic reforms and continued external donor assistance.

3.0 METHODOLOGY AND DATA

3.1 Monetary Policy Framework

The current Bank of Sierra Leone (BSL) monetary policy framework is monetary targeting regime that focuses on the growth rate of a chosen monetary aggregate. In the case of BSL, reserve money is the primary operating target. The intermediate target or nominal anchor is broad money. The monetary targeting framework is based on the premise that in the long term, price growth is affected by money supply growth.

The Bank's primary monetary policy objective is to deliver price stability-low and stable inflation and, subject to that, to support the Government's economic objectives including those for growth and employment. The Bank's mission, therefore, is to "formulate and implement monetary and supervisory policies to foster a sound economic and financial environment. It is acknowledged that monetary policy cannot contribute directly to economic growth and employment creation in the long run. However, by creating a stable financial environment, monetary policy fulfills an important pre-condition for economic development (BSL monetary policy framework, 2016).

3.2 Methodology and Model Description

Drawing from theoretical foundations, we analyze the response of output, inflation, and demand to monetary policy and productivity shocks in Sierra Leone using a Bayesian Dynamic Stochastic General Equilibrium (DSGE) Model. Models of this type are popular in describing monetary policy in both academic and policy settings (Salisu & OlaOluwa, 2021). Their suitability in estimating shocks is also well-established in

[6] https://www.afdb.org/en/countries-west-africa-sierra-leone/sierra-leone-economic-outlook#:~:text=Outlook%20and%20risks&text=Inflation%20is%20projected%20to%20ease,2021%20and%2013.5%25%20in%202022.

existing studies (e.g., see (Christiano , Eichenbaum, & Evans , 2005); (Peiris & Saxegaard, 2007)). The DSGE model is a system of equations that are related to economic theories and is normally used for policy analysis and forecasting. As stated in (Sbordone, Tambalotti, Rao, & Walsh, 2010), "One of the fundamental features of DSGE models is the dynamic interaction between three interrelated blocks[7]—in the sense that expectations about the future are a crucial determinant of today's outcomes". In this regard, we employ a Bayesian Linear DSGE model to analyze the impact of monetary policy and productivity shocks on inflation, interest rate, and exchange rates in Sierra Leone.

3.3 Model Specification

We extend the Keynesian DSGE framework for a small open economy. In our model households consume and invest in baskets consisting of domestically produced and imported goods. We allow the imported goods to enter both aggregate consumption and investment. This is needed when matching the joint fluctuations in both imports and consumption given the volatility of imports relative to consumption patterns. We model an economy in which the growth rate of the trade-weighted exchange rate is exogenous and is affected by inflationary pressure. Therefore, we have assigned a trade-weighted exchange rate as the exchange rate.

A. Households

The output gap is specified in the output gap equation below, which is an Euler equation, stating the intertemporal first-order condition for a dynamic choice problem facing the representative household. The output gap is specified as a function of the future expected output interest rate, inflation, and government policy shock.

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

The output gap is modelled as an unobserved control variable, where: r_t is the interest rate and it is modelled as an observed control variable, while p_t is the inflation rate, which is modelled as an observed control variable. The shock process here evolves the following specification

$$g_{t+1} = \rho_g g_t + \xi_{t+1} \qquad (2)$$

The variables g_t is a first-order autoregressive state variable.

B. Firms

Here, it is assumed that the final domestic good is a composite of a continuum of i differentiated goods, each supplied by a different firm. Since the central bank has a

[7]According to Sbordone, Tambalotti, Rao, and Walsh, 2010, the DSGE model is structured around three blocks: the demand block, supply block and the rate.

time-varying inflation p_t in the model, we allow for interest rate inertia to the current inflation target, but also the inflation expectation term in the Phillips curve. The process for the first-order condition of the profit maximization problem yields the following augmented log-linearized Phillips curve:

$$p_t = \beta E_t(p_{t+1}) + \kappa x_t + \phi e_t \quad (3)$$

where p_t denotes log deviation from steady-state, and denotes inflation in the domestic sector. We now turn to the import and export sectors.

Recall the canonical New Keynesian DSGE model of inflation (p_t), output gap (x_t) and the interest rate (r_t) includes an exogenous (observed=domestic exchange rate=foreign exchange rate) variable. As such, we have further extended the model by adding an AR (1) for the unobserved state variable(est) and an equation linking the unobserved (est) to the observed(e_t), thereby specifying how the unobserved state (est) is transformed into the observed control variable(e_t). Recalling that all the observed variables in a DSGE model must be modelled as endogenous control variables. This requirement implies that there is no reduced form for the endogenous variables as a function of observed exogenous variables – indicating from the theory that exogenous variables should be modelled. Mechanically, the solution is to define a control variable that is equal to a state variable that models the exogenous process. We clarify this issue by allowing for the above identity to hold then

$$e_t = es_t \quad (4)$$

where, e_t is the growth rate of the exchange rate, which we have modelled as an observed exogenous variable. Note that we have, therefore, modelled an economy in which the growth rate of the trade-weighted exchange rate is exogenous and which it affects inflation. Henceforth, we would refer to the trade-weighted exchange rate as the exchange rate. Note that the evolution or transmission of the exchange rate est shock as a state variable with an AR (1) process is defined as follows;

$$\mathrm{es}_{t+1} = \rho_{es}\mathrm{es}_t + \mathrm{v}_{t+1} \quad (5)$$

This assumption is informed by our knowledge of the Sierra Leone economy, where the prevailing domestic exchange rate is largely taken as given and highly influenced by external factors and the informal sector.

C. Central Bank

We approximate the behaviour of the central bank by following (Smets & Wouters , 2002) approach - where the central bank is assumed to adjust the short-term interest rate in response to the CPI inflation rate, the inflation target, and the output gap (measured as actual minus trend output). This equation of the output gap links the interest rate with the inflation rate and the exchange rate and the government sector.

$$r_t = \frac{1}{\psi} p_t + u_t \quad (6)$$

$$r_t = \rho_r r_{t-1} + \frac{1-\rho_r}{\psi} p_t + u_t \quad (7)$$

Moreover, the policy inertia of the lagged interest rate is also a function of the price level as depicted in equation (7). As such, we specify the monetary policy shock as following an AR (1) process as specified below:

$$u_{t+1} = \rho_u u_t + \epsilon_{t+1}; \quad (8)$$

3.4 Estimation Procedure and Assumptions

This study adopts a Bayesian Linear DSGE procedure to estimate the model. We fit this model using data on interest rate r, inflation rate p, and the growth rate of the exchange rate e. The equation ($e = es$) links the observed variable e to the unobserved state variable es. Before our estimations, we compute the annualized inflation rate using the quarterly time series. In addition to this, our parameter estimates are obtained by imposing restrictions on selected parameters. Introducing restrictions is known to make unidentified parameters in a model identified -see (Salisu & OlaOluwa, 2021). In other words, prior restriction of parameters attempts to overcome identification issues in DSGE models.

Therefore, we define constraints that best suit our model by setting the parameters thus:

$\beta = 0.5$, $\psi = 1.5$. While theoretical monetary policy rules assume a beta (β) of 0.5 and Psi (ψ) of 2, various studies have adopted several values within this range. For example, (Kollmann , 2017) set beta (β) at 0.99 which is consistent with (Ratto, Roeger , & Veld , 2009) where it was set as 0.996. Theoretically, the discount rate β must lie between 0 and 1 with common values in the range (0.90, 0.99).

The parameter (k) (price-adjustment parameter) is mostly considered to be small and positive. Though the autocorrelation parameters are expected to lie between (-1, 1), they are more likely to be positively closer to 1 than 0. The parameter $1/\psi$ is expected to be greater than 1 to enhance model stability. In this respect, the parameter ψ must lie between 0 and 1.

In light of the above theoretical considerations, we now make some assumptions concerning the distribution of the unknown parameters as indicated. We assume a beta (β) distribution with shape parameter as (95, 5) thus placing the prior mean at 0.95 and most of the prior mass between 0.9 and 1. In the case of kappa (k) a beta distribution with shape parameters (30, 70) is used, while the same hold for phi (φ), thus placing the prior mean at 0.3. While the rest of the autoregressive parameters, a beta distribution with shape parameters (75, 25) is used.

3.5 Data: Sources, Description, and Summary Statistics

For the estimations of our DSGE model, we employ quarterly data covering the period 2011q1 to 2018q4. The variables used for the study are monetary policy rates(r), nominal exchange rates (exr), trade weighted exchange rates (exrall), and GDP deflator (GDPdef). The data are sourced from the Bank of Sierra Leone (BSL) Statistics Warehouse and IMF International Financial Statistics.

3.6 Convergence Diagnostics

We perform convergence diagnostics for the model by using the Markov Chain Monte Carlo (MCMC) simulation. If the MCMC simulation did not converge, then the estimates cannot be trusted. To do this, we graphed the behavior of the individual parameters as well as produced the effective sample size (ESS) summary statistics. To ensure there is convergence efficiency, the trace plot should not exhibit any time trend and should have constant mean and variance as well as a decaying autocorrelation. The density of the chain should not vary throughout the MCMC sample. The constancy of the density distribution can be assessed by examining the 1-half and 2-half density plots and should not exhibit many differences. If they differ significantly, then the chain has not converged. Concerning the efficiency of the summary statistics (ESS), the closer the ESS estimates to the MCMC sample size, the better, and the lower the auto-correlation spikes are, the higher the efficiency the better. In this respect, we started our Bayesian DSGE estimation using the without-block option. Using the Bayesian DSGE without the block option, the results indicate that there is evidence of high autocorrelation in the MCMC iterations (see appendix 1). This also corroborated with a very low average efficiency of about 0.002 percent from the effective sample size summary statistics (see appendix 2). Furthermore, the efficiency performance for all the parameters (from the effective sample size of the summary statistics) was all less than 1 percent (see appendix 2). Thus an indication of a convergence problem in the MCMC iteration. In light of the above, we further check whether the efficiency of the MCMC sampling can be enhanced using the block option. In this respect, we graphed the behavior of the relevant diagnostics using the block of the structural parameters and the block of the state variables. This procedure is observed to enable us to choose the parameters (structural and state parameters) with the best performance. From the density functions of the structural parameters (beta, kappa, and phi), we observe that the density function for beta is better and the same goes for its autocorrelation, hence the choice of beta (see appendix 4). In the case of the block for state variables, we observed that the density function for rhoe is better relative to the other state variables, hence the choice of rhoe (see appendix 4). This, therefore, informed the choice of the two variables (beta and rhoe) in our Bayesian DSGE with block option. Simply put, the parameters selected are based on the behavior of the density functions.

The best from each category (control variables and state variables) is selected and these are beta and rhoe followed by {sd(e.es)} (see appendix 4). Based on the results from the various diagnostics, we observed that using the block option significantly improves the efficiency of the MCMC sampling.

4.0 Result and Discussions.

In this section, we present the result and discussions of the Bayesian estimation of our DSGE model using the second scenario (the block option). In this respect, we observed that using the block option with increased burn-in iterations produced a more efficient result, hence the discussion of the results is based on this approach as presented in Table 1. We observe that the efficiency of the parameters improved compared with the Bayesian DSGE model without the block option (appendix 1). More importantly, the effective sample sizes also turn out to improve for all the parameters relative to the one without the block (see Table 2 compare to appendix 2). Estimates from Table 1 further suggest no evidence of high autocorrelation in the MCMC iterations. The results also suggest an improved MCMC acceptance rate of 0.3922 and a maximum efficiency rate of about 22 percent. The beta, kappa, and phi parameters (0.93, 0.29, and 0.22 respectively) were all very close to our prior assumptions. The result from the parameter phi, suggests that a 1 percent depreciation in the exchange rate raises the level of inflation by 0.22 percent.

Table 1. Bayesian DSGE Estimation with Block Option

Variables	Mean	Std. dev	MCSE	Median	Equal-tailed [95% Cred. Interval]	
beta	0.9329	0.0266	0.0024	0.9359	0.8752	0.9752
kappa	0.2892	0.0412	0.0028	0.2890	0.2131	0.3730
phi	0.2221	0.0360	0.0027	0.2203	0.1522	0.2919
rhou	0.6105	0.0226	0.0016	0.6094	0.5682	0.6551
rhog	0.7970	0.0354	0.0022	0.7975	0.7182	0.8627
rhoe	0.6968	0.0505	0.0014	0.6965	0.5979	0.7936
sd (e. u)	27.0866	3.4907	0.3302	26.7756	21.2585	35.4304
sd (e. g)	0.8928	0.2684	0.0167	0.8499	0.4703	1.5362
sd (e. es)	3.6548	0.4765	0.0102	3.6064	2.8391	4.7097

Notes: Table 1 presents the Bayesian DSGE estimation with Block Option with increased burn-in iterations of 5000.

The estimation used quarterly data with a sample period from 2011Q1 to 2018Q4. The Bayesian estimates are based on an MCMC sample size of 10,000 after an increased burn-in iterations of 5000 and the number of observations being 32. The table also reports Monte Carlo standard errors, medians, and equal-tailed credible intervals (CrIs). The acceptance rate specifies the proportion of proposed parameter values accepted by the MCMC algorithm. The MCMC acceptance rate improved to 0.3922. Therefore an acceptance rate of 0.39 in our estimation means that 39 percent out of 10,000 proposal parameter values were accepted by the algorithm. The minimum, average and maximum efficiency rates are 0.01, 0.05 and 0. 22 percent respectively. The higher maximum efficiency rate is 0.22 percent, which implies lower autocorrelation. The state variables included are u (rhou), g (rhog), and e (rhoe), which represent monetary policy shock, productivity shock and demand shock; while beta, kappa and phi are the control variables also known as structural parameters. The estimated standard deviations of the shocks are also displayed. The shocks to the state variables u, g and e are denoted by e.u, e.g, and e.es and have standard deviations of 27.08, 0.89 and 3.65 respectively.

Table 2: Effective Sample Size Summary Statistics

Variables	ESS	Corr. Time	Efficiency
beta	118.47	84.41	0.0118
kappa	216.12	46.27	0.0216
phi	173.51	57.63	0.0174
rhou	193.97	51.55	0.0194
rhog	262.46	38.10	0.0262
rhoe	1402.46	7.13	0.1402
sd (e. u)	111.74	89.49	0.0112
sd (e. g)	259.57	38.52	0.0260
sd (e. es)	2200.16	4.55	0.2200

Note: Table 2 presents the effective sample size summary statistics with MCMC sample size of 10,000 and a maximum efficiency rate equal to 0.22 percent. The abbreviation ESS denotes the effective sample statistics.

Table 3a. Posterior Summary Statistic

Posterior mean of beta

	Mean	Std. dev	MCSE	Median	Equal-tailed [95% Cred. Interval]	
expr1	1.0729	0.0311	0.0029	1.0685	1.0254	1.1426

Notes: Table 3a presents the posterior summary statistics with a posterior mean of beta which denotes an inflation-adjusted parameter of $1/\beta$, in the Taylor rule, which is denoted as (expr1 = 1/{beta}). The MCMC sample size is 10,000.

Table 3b. Posterior mean of phi

	Mean	Std. dev	MCSE	Median	Equal-tailed [95% Cred. Interval]	
expr1	4.6278	0.7986	0.0580	4.5400	3.4257	6.5683

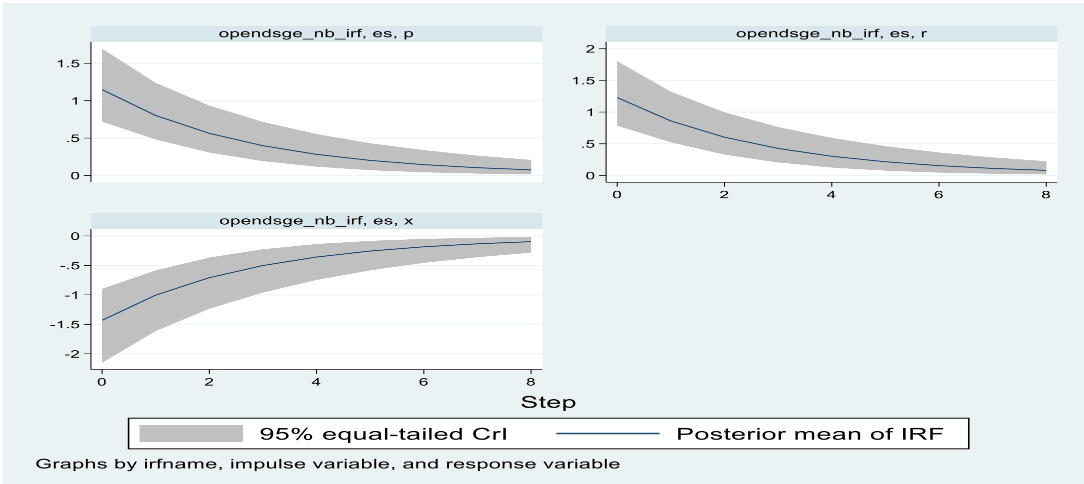
Notes: Table 3b. presents the posterior summary statistics with a posterior mean of phi denoted as (expr1 = 1/{phi}). The MCMC sample size included is 10,000.

Taking from Table 1, we also observe that the autoregressive parameters for the state variables are positive, with the state variables u (rhou), g (rhog), and e (rhoe) showing autocorrelation of 0.61, 0.80, and 0.70 respectively. In terms of the shocks, the estimates suggest that productivity shock (0.80 percent) tends to be highly persistent relative to the monetary policy shock (0.61 percent) and demand shock (0.70 percent). This implies that economic agents tend to respond quickly to monetary policy shock relative to productivity and demand shocks. From a theoretical perspective, productivity shock is usually considered a permanent shock, which comes with more rigidities that make the shock more persistent than others.

Taking from the convergence diagnostics, we observe that the trace plots indicate a reasonably good mixing, as the autocorrelations decay at a moderate pace although beta seems to exhibit slightly higher autocorrelations than other parameters (see appendix 4). The trace does not seem to exhibit any time trend and has constant mean and variance. Similarly, the density for both the first and second half as well as the overall densities do not vary much from the density of the full MCMC sample. Thus an indication that our model has no convergence problem.

We also analyze the posterior mean for beta, which is the inflation-adjusted parameter, $1/\beta$, in the Taylor rule. The results suggest that the posterior mean is about 1.07, which is also very close to the prior mean of 1.5, often seen in most literature (see Table 3 above). From the graphs, the trace plot exhibits a reasonably good mixing and the autocorrelations decay at a moderate pace. Also, evidence from the density plot shows that the first and second-half densities are similar to the density of the full sample (see appendix 5). Thus, an indication of convergence. Furthermore, we compare the prior distribution and the posterior distribution for some of the parameters to determine whether they are informative. In this respect, we plot the prior and posterior parameters of kappa, beta, and phi, and results from the densities suggest that the data is informative. (See appendix 6). Taking from Figures 1, 2, and 3, we also analyze the impulse responses to demand shock, monetary policy shock, and productivity shock respectively.

Figure *1: Response of output, inflation, and interest rates to demand shock (shock to es)*



Notes: Figure 1 shows the impulse response function of the response of output, inflation and interest rates to demand shock at 95 percent confidence interval.

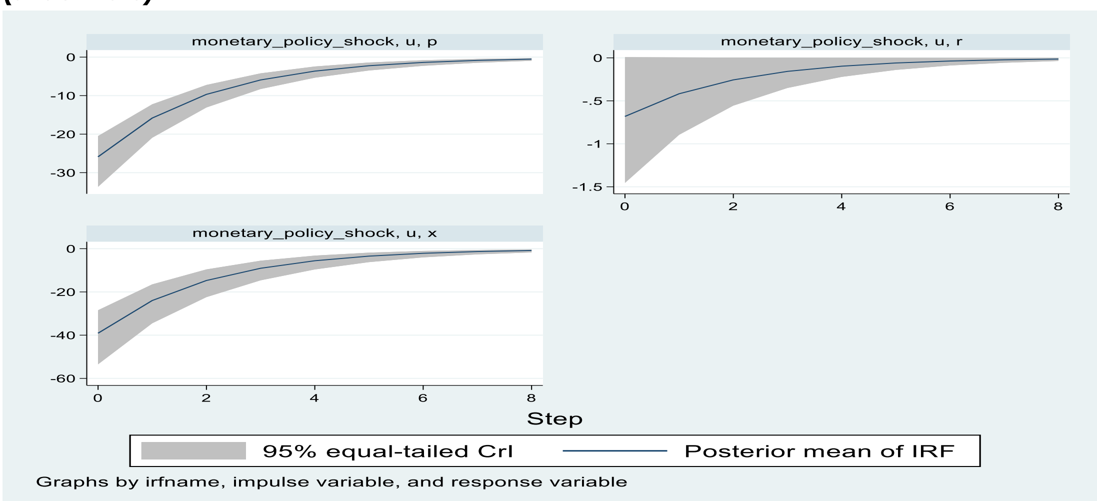
We start with the analysis of the response of inflation to demand shock (see Figure 1). In this respect, we observe that the initial response of inflation to demand shock is immediate and that a one standard deviation shock to aggregate demand is likely to raise the level of inflation by about 1.2 percent (see Figure 1 top left). This implies that demand shock is inflationary. Though we could see that the impact of the demand shock is positive, the shock is however not persistent throughout the eight-quarter horizon. It begins to phase out as it moves towards its steady state horizon.

The response of interest rate to demand shock is also positive (see Figure 1 top right). There is an immediate initial response, but phases out as it moves towards the eighth lag. An important implication of this is that monetary policy authorities are likely to raise the level of the monetary policy rate (r) in response to demand shock to close the output gap and bring inflation within the desired policy target.

In the case of the response of the output gap to demand shock, the results suggest that one standard deviation appears to closing the output gap. This implies that the increase in policy rate in response to the demand shock, is rather closing the output gap, which will ultimately bring inflation down to target. Though the impact is initially high but it is not persistent as it phases out gradually towards the eighth lag which reinforces the above assertion (see Figure 1 bottom left).

In this respect, a surprise depreciation in the exchange rate appears to discourage production, investment as well as the supply of social services particularly for an import-dependent economy. This is likely to discourage future investment as the cost of imported inputs will increase, which will subsequently lead to an increase in the cost of production, hence discouraging production. In this respect, producers may tend to wait until the exchange rate stabilizes before they could import materials as the component of the shock is exchange rate.

Figure 2: Response of output, inflation, and interest rates to Monetary Policy shock (shock to u)

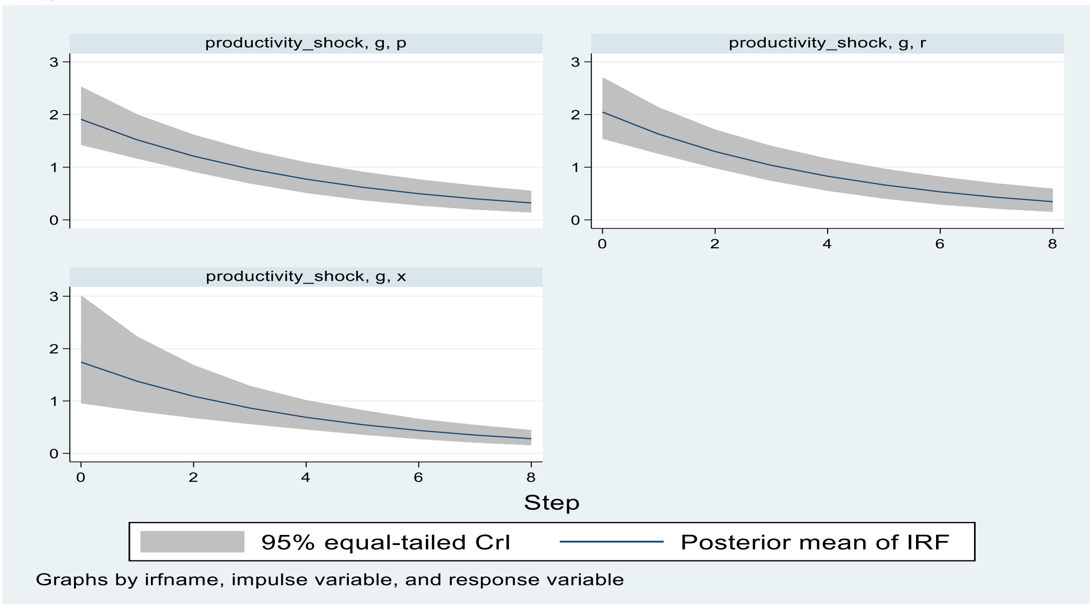


Notes: Figure 2 shows the impulse response function of the response of output, inflation and interest rates to monetary policy shock at 95 percent confidence interval.

Turning to the analyses of the impulse response to a monetary policy shock, we observe that the variables (inflation, interest rate, and output gap) have an immediate decline in response to monetary policy shock (see Figure 2). This implies that a unit shock to monetary policy causes inflation to fall. Furthermore, when the output gap becomes negative, this is an indication of a contractionary shock. However, the impact is temporary as the lines gradually return to their baseline of steady state (see Figure 2). Simply put, both lines return to their steady state as the effect of the shock dissipates. The result is statistically significant as it falls within the confidence bounds. These results resonate with the idea that a positive shock to monetary policy is expected to affect inflation and output, but only temporarily. As such monetary policy shock, like creating a situation of a liquidity trap, which leads to negative interest rates and renders monetary policy impotent with possible negative effects on the output gap in the absence of strong fiscal impulse

In terms of the impulse response to productivity shock, we observe that the impact is positive and permanent. (See Figure 3). Inflation increases sharply but starts to dissipate by the fourth quarter but is eventually higher than pre-shock levels. As such, productivity shocks have a permanent effect on inflation in Sierra Leone.

Figure 3: Response of output, inflation, and interest rates to Productivity shock (shock to g)



Notes: Figure 3 shows the impulse response function of the response of output, inflation and interest rates to productivity shock at 95 percent confidence interval.

In response to the productivity shock, the interest rate increases sharply and starts declining and returns to its initial value by the sixth quarter, thereafter it starts to decline but does not return to pre-shock levels even after the eighth quarter horizon. This shows that productivity shocks have a permanent effect on monetary policy reactions. Following the productivity shock, output rises sharply, and remains elevated unto the third quarter and thereafter begins returning to steady-state levels by the sixth quarter but remains higher than the pre-shock levels, which is an indication that productivity shocks as we have already stated above have a permanent effect on output in Sierra Leone.

5.0 CONCLUSION AND RECOMMENDATION

This paper analyses the effect of monetary policy, productivity and demand shocks on output, inflation, and interest rate in Sierra Leone using a Bayesian Dynamic

Stochastic General Equilibrium (DSGE) Model. We commence the estimation of the model with two scenarios to determine the option with the most efficient result. The first scenario is the Bayesian DSGE approach without the block option and the second is the Bayesian DSGE with the block option. Estimates suggest that the second option using Bayesian DSGE with block option with increased burn-in iterations of 5000 produced a more efficient result.

Estimates from the model suggest that the impact of monetary policy shocks temporarily causes a decline in inflation and output. Though the initial response is immediate, it gradually returns to its steady state after a certain period.

The impact of productivity shock is however permanent as it causes an immediate increase in output and inflation, though gradually declines but remains higher than pre-shock levels.

The model further indicates that the initial response of inflation to demand shock is immediate and that a one standard deviation shock to aggregate demand is likely to temporarily raise the level of inflation. Simply put, demand shocks are found to be temporarily inflationary but their overall effect on inflation, interest rates, and output is also transitory. The result suggests that the initial response is immediate, but phases out as it moves towards the eighth lag. An important implication of this is that monetary policy authorities are likely to raise the level of the monetary policy rate (r) in response to a demand shock.

This reinforces the fact that though the impact of demand shock is significant but not persistent as it fizzles out gradually overtime. It is also important to note that the component of the shock of the response of output to demand shock is the exchange rate. In this respect, a surprise depreciation in the exchange rate appears to discourage production, investment as well as the supply of social services. An implication of this is that exchange rate depreciation tends to discourage production, investment, and the supply of social services particularly for an import-dependent economy. This is likely to discourage future investment because the cost of imported inputs will increase, which will subsequently lead to an increase in the cost of production, hence discouraging production. Thus, we recommend the formulation and implementation of policies that are geared towards stabilizing the exchange rate, given its impact on productivity and by extension economic development.

Also, we believe that the monetary authorities in Sierra Leone have a role to play in terms of strengthening the financial sector reforms to improve monetary policy transmission. This is because the result clearly shows that monetary policy transmission is weak and its impact dissipates rather quickly. Policy measures such as the use of market-based instruments such as lender of last resort loans limited to liquidity support for illiquid but solvent banks which should be fully collateralized and granted at penalty rates, overdraft loans to support payment system, reduction of required reserves, the use of bond instruments to improve on bank's balance sheet as well as current income in combination with other instruments (bond replacing nonperforming assets) and prudential supervision systems are more likely to foster sound credit decisions. A gradual deepening of money and securities markets is also likely to enhance effective and efficient conduct of monetary policy; which in turn helps to promote the achievement of macroeconomic and financial stability. Putting in place an active and well-functioning money market, as well as instruments that influence the marginal cost of funds to banks and strong bank supervision are all measures in the right direction.

Finally, the fiscal and monetary policy authorities should implement policies that are geared towards enhancing real sector growth. This is because the Sierra Leone economy is highly susceptible to imported inflation. As such, any real sector growth that enhances the domestic production of imported goods will help control inflationary pressures that arise from external shocks. In addition, fiscal policy affects aggregate demand and supply directly through the taxes and incentives they create, by public investment, transfers to household and firms.

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Appendices

Appendix 1: Bayesian DSGE Estimation without Block Option

Variables	Mean	Std. dev	MCSE	Median	Equal-tailed [95% Cred. Interval]	
beta	0.9993	0.0003	0.0041	0.9999	0.9986	0.9998
kappa	0.2726	0.0125	0.0033	0.2716	0.2499	0.3004
phi	0.3365	0.0163	0.0048	0.3422	0.3057	0.3598
rhou	0.1131	0.0147	0.0030	0.1131	0.0832	0.1413
rhog	0.9964	0.0008	0.0014	0.9965	0.9943	0.9978
rhoe	0.7170	0.0453	0.0107	0.7186	0.6261	0.8004
sd (e. u)	3.6544	0.1320	0.0393	3.6438	3.4465	3.9013
sd (e. g)	0.7021	0.0149	0.0026	0.0688	0.0453	0.1035
sd (e. es)	1.2456	0.0634	0.0176	1.2521	1.1064	1.3507

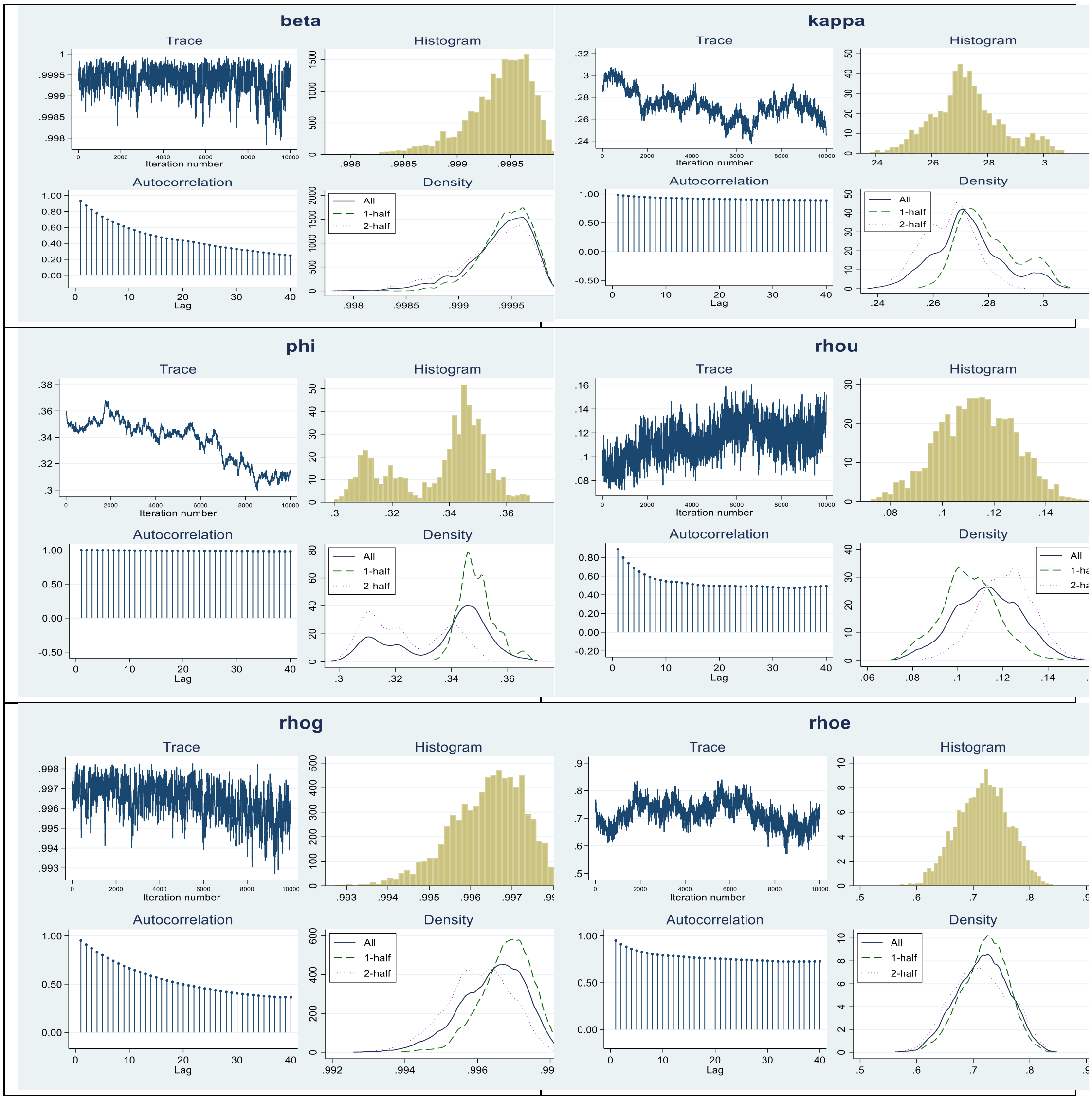
Notes: Appendix 1 presents the Bayesian DSGE estimation without Block Option burn-in iterations of 2,500. The estimation used quarterly data with a sample period from 2011Q1 to 2018Q4. The Bayesian estimates are based on an MCMC sample size of 10,000 and the number of observations is 32. There is a high autocorrelation after 500 lags. The table also reports Monte Carlo standard errors, medians, and equal-tailed credible intervals (CrIs). The MCMC acceptance rate 0.3729. 6. The minimum, average and maximum efficiency rates are 0.0011, 0.0024 and 0. 0579 percent respectively.

Appendix 2: Effective Sample Size Summary Statistics

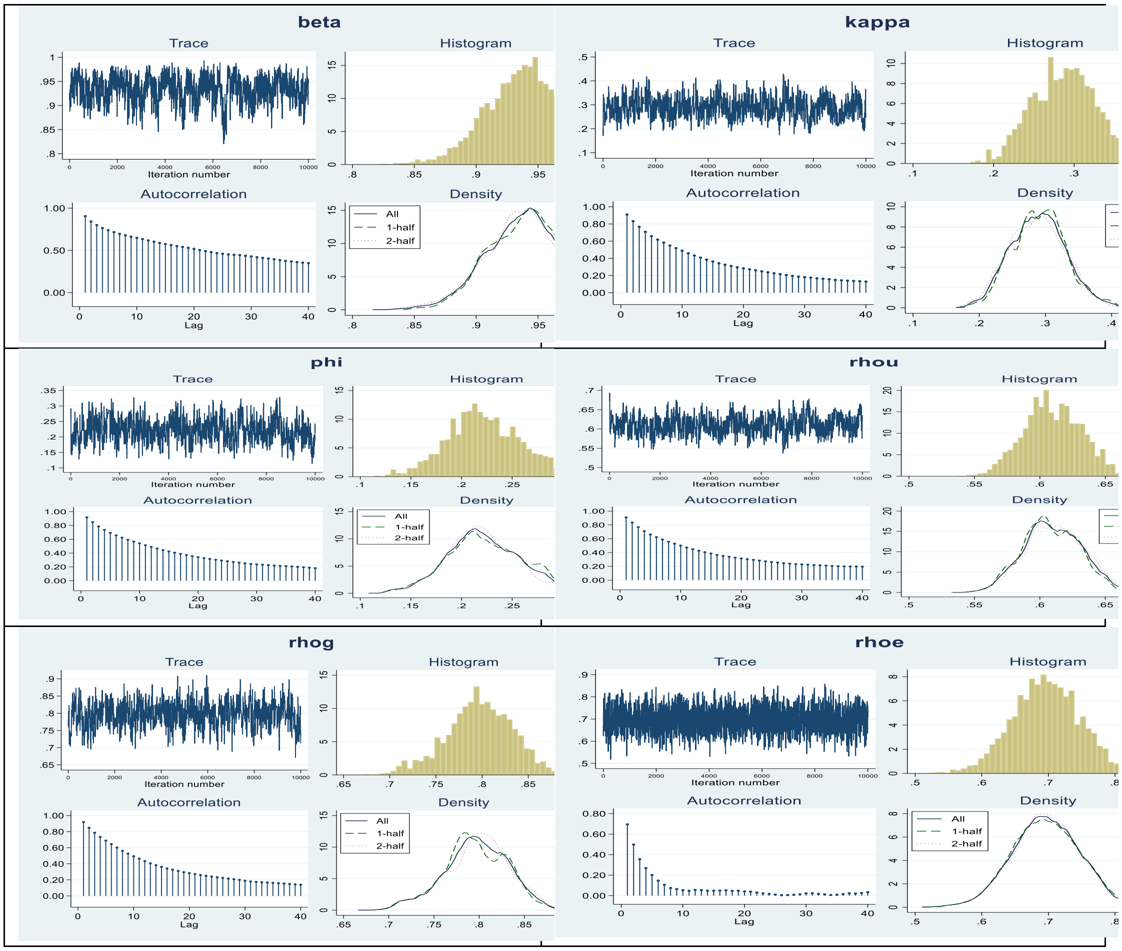
Variables	ESS	Corr. Time	Efficiency
beta	57.97	172.51	0.0058
kappa	14.37	695.85	0.0014
phi	11.18	894.47	0.0011
rhou	23.91	418.23	0.0024
rhog	36.11	276.92	0.0036
rhoe	17.88	559.18	0.0018
sd (e. u)	11.25	889.26	0.0011
sd (e. g)	30.78	324.85	0.0031
sd (e. es)	12.91	774.65	0.0013

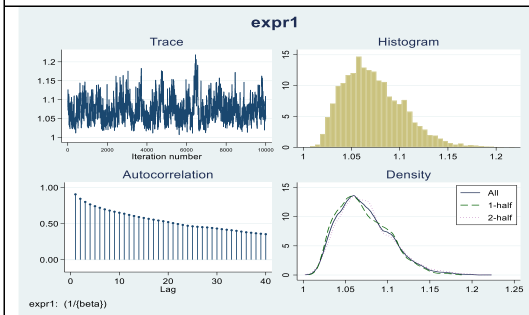
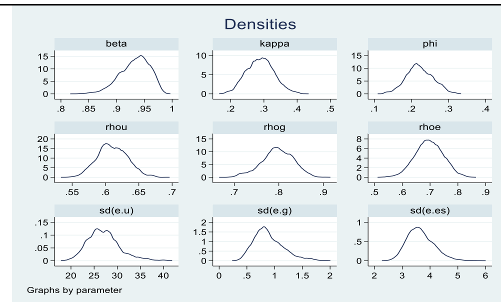
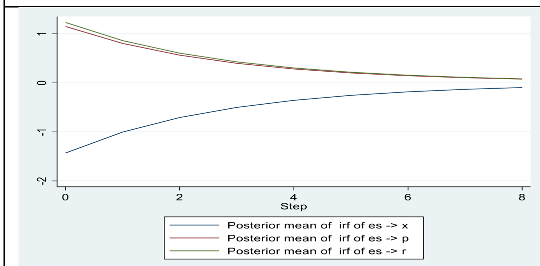
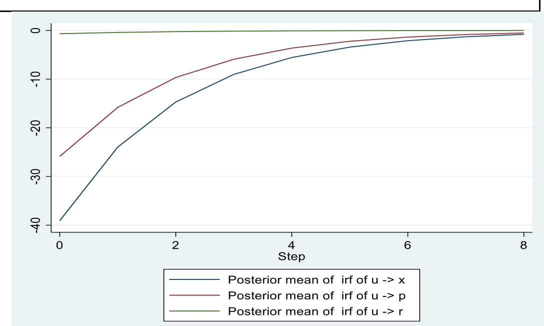
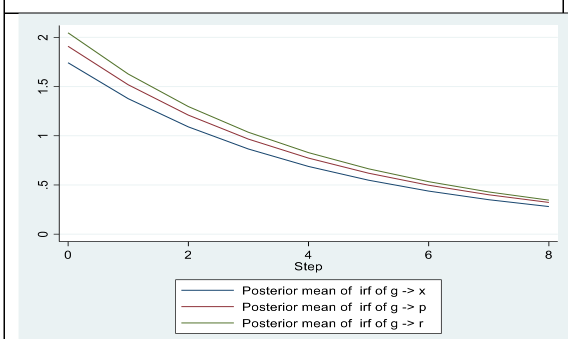
Notes: Appendix 2 presents the effective sample size summary statistics with MCMC sample size of 10,000 and the minimum, average and maximum efficiency rates are 0.0011, 0.0024 and 0. 0057 percent respectively.

Appendix 3: Bayesian DSGE without Block Option (Convergence Diagnostic-Graphical Approach) The behavior of the parameters (beta, kappa, phi, rhou, rhog, rhoe).



Appendix 4: Bayesian DSGE with Block Option (Convergence Diagnostic-Graphical Approach) - The behavior of the parameters (beta, kappa, phi, rhou, rhog, rhoe).



Appendix 5: Posterior kernel density for beta	**Appendix 6: posterior kernel densities for all model parameters**
	
Appendix 7: Combined Graphs of Impulse Responses to Demand Shock	**Appendix 8: Combined Graphs of Impulse Responses to Monetary Policy Shock**
	
Appendix 9: Combined Graphs of Impulse Responses to Productivity Shock	
	

Appendix 10: IRF Table to Monetary Policy Shock

Step	(1) irf	(1) Lower	(1) Upper	(2) irf	(2) Lower	(2) Upper
0	-39.0937	-53.4776	-28.4578	-25.8833	-33.6637	-20.4904
1	-23.9643	-34.4897	-16.4982	-15.8109	-20.927	-12.2503
2	-14.7104	-22.3953	-9.57998	-9.67138	-13.0741	-7.22389
3	-9.0424	-14.6244	-5.54215	-5.92402	-8.28236	-4.20737
4	-5.56598	-9.58109	-3.20155	-3.63364	-5.34182	-2.43872
5	-3.43082	-6.20799	-1.82474	-2.23184	-3.46804	-1.40559
6	-2.11765	-3.99895	-1.04345	-1.37271	-2.2561	-.806051
7	-1.3089	-2.60679	-.594648	-.845458	-1.46917	-.465334
8	-.810127	-1.72156	-.339349	-.521435	-.950479	-.26551

Step	(3) irf	(3) Lower	(3) Upper	(4) irf	(4) Lower	(4) Upper
0	-.681557	-1.45454	.008574	-39.0937	-53.4776	-28.4578
1	-.417437	-.894618	.005367	-23.9643	-34.4897	-16.4982
2	-.256012	-.555737	.003263	-14.7104	-22.3953	-9.57998
3	-.157222	-.350088	.001986	-9.0424	-14.6244	-5.54215
4	-.096683	-.221232	.001242	-5.56598	-9.58109	-3.20155
5	-.059535	-.140097	.00072	-3.43082	-6.20799	-1.82474
6	-.036709	-.088786	.000416	-2.11765	-3.99895	-1.04345
7	-.022665	-.057037	.00024	-1.3089	-2.60679	-.594648
8	-.014013	-.03664	.000139	-.810127	-1.72156	-.339349

Step	(5) irf	(5) Lower	(5) Upper	(6) irf	(6) Lower	(6) Upper
0	-25.8833	-33.6637	-20.4904	-.681557	-1.45454	.008574
1	-15.8109	-20.927	-12.2503	-.417437	-.894618	.005367
2	-9.67138	-13.0741	-7.22389	-.256012	-.555737	.003263
3	-5.92402	-8.28236	-4.20737	-.157222	-.350088	.001986
4	-3.63364	-5.34182	-2.43872	-.096683	-.221232	.001242
5	-2.23184	-3.46804	-1.40559	-.059535	-.140097	.00072
6	-1.37271	-2.2561	-.806051	-.036709	-.088786	.000416
7	-.845458	-1.46917	-.465334	-.022665	-.057037	.00024
8	-.521435	-.950479	-.26551	-.014013	-.03664	.000139

Appendix 11: IRF Table for the Demand Shock

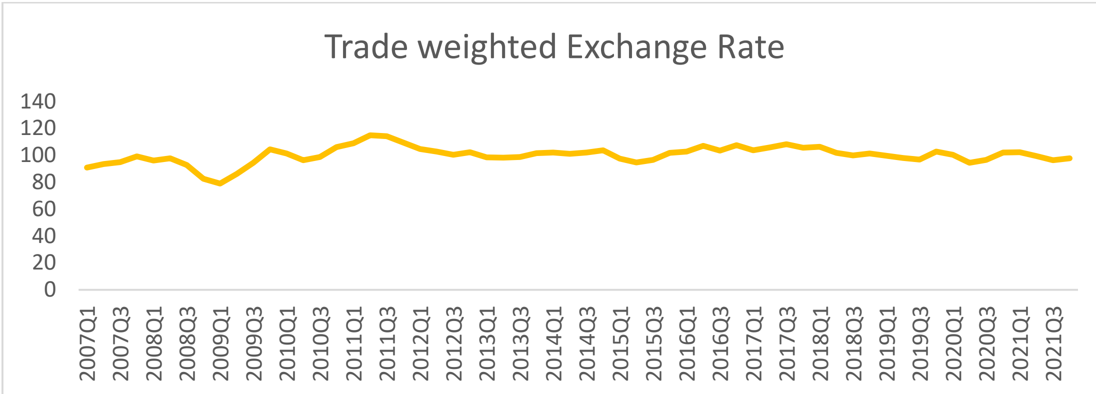
Step	(1) irf	(1) Lower	(1) Upper	(2) irf	(2) Lower	(2) Upper
0	-1.43118	-2.15131	-.897528	1.14802	.720565	1.69503
1	-1.00366	-1.61241	-.58521	.802316	.48252	1.23745
2	-.707511	-1.23346	-.367374	.563621	.307413	.934137
3	-.501295	-.959242	-.226113	.397953	.191618	.715069
4	-.356961	-.745062	-.138444	.28238	.117854	.552805
5	-.25543	-.582264	-.084094	.201351	.071554	.430403
6	-.183655	-.454652	-.051098	.14426	.043219	.337801
7	-.132669	-.358886	-.030909	.103842	.026121	.263867
8	-.096278	-.281918	-.018557	.075091	.015787	.207809

Step	(3) irf	(3) Lower	(3) Upper
0	1.22984	.784977	1.80152
1	.859766	.525033	1.32097
2	.604169	.329939	.996484
3	.426714	.20567	.762209
4	.302882	.12568	.591308
5	.216036	.077222	.462253
6	.154828	.046487	.36095
7	.111481	.028	.283635
8	.080638	.016945	.223768

Appendix 12: Summary Statistics

	EXR	R	GDPDEF	EXRALL
Mean	5787.936	14.63636	136.9792	100.1015
Median	4469.210	14.33333	136.0600	100.7450
Maximum	10839.80	24.50000	223.5600	114.8500
Minimum	2969.547	9.500000	71.99000	78.95000
Std. Dev.	2462.643	4.206134	47.47634	6.358036
Skewness	0.641452	0.500895	0.278106	-0.6879
Kurtosis	2.008986	2.400501	1.948564	4.922429
Jarque-Bera	6.569876	2.498801	2.829782	13.97139
Probability	0.037443	0.286677	0.242952	0.000925
Sum	347276.1	644.0000	6575.000	6006.090
Sum Sq. Dev.	3.58E+08	760.7374	105938.1	2385.053
Observations	60	44	48	60

Appendix 13: Trade Weighted Exchange Rate



ANALYSIS OF MONETARY POLICY AND PRODUCTIVITY SHOCKS IN NIGERIA: A BAYESIAN DSGE APPROACH

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Abstract

This study constructs a DSGE model that allows the monetary authorities to determine the appropriate response in the presence of demand, technology, and monetary policy shocks employing quarterly data from 1995:Q1 to 2021:Q1 The results are presented across two eras – pre-COVID and the entire sample. The results reveal that the effect of all the shocks has an initial positive effect on the interest rate in Nigeria though the short-term persistence of productivity shock is higher than all three shocks. A policy implication from the study is that the CBN will likely increase interest rates in response to productivity, demand, and own shocks, however, the rate hikes in response to productivity shocks are higher than those to demand and monetary policy shocks. The study recommends the need for the CBN to employ alternative monetary policy instruments aside from the interest rate in a bid to stimulate the economy in the face of productivity shocks.

Keywords: Bayesian DSGE models, interest rate, demand shocks, productivity shocks, monetary policy

JEl: Classification: C11, E23, E31, E47, E52

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Disclaimer: This paper presents the views of the authors and does not necessarily reflect those of the Central Bank of Nigeria (CBN) or the Securities and Exchange Commission (SEC).

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1.0 INTRODUCTION

In this paper, we propose a revision of the closed-economy DSGE model of Tawose et al. (2021) for analysing monetary policy and productivity shocks in Nigeria to capture the influence of informative priors within an open-economy framework. Also, this paper modifies the small macroeconomic open economy model constructed by Olofin (2014), which is only a partial equilibrium model as it does not include all the main blocks of an economy – households, firms, and government. We are motivated by the need to construct a model that allows the monetary policy authorities to determine the appropriate response in the presence of different shocks (demand shocks, supply shocks, technology shocks). This is particularly important in the COVID-era where external shocks such as supply chain disruptions, crude oil prices, and exchange rate changes exert significant influence on the Nigerian economy. In addition, the need to capture the productivity effects of widespread adoption of disruptive technologies (teleconferencing and FinTechs) which accompanied the pandemic on the structure of the Nigerian economy is instructive for monetary policy.

Nigeria's position as a small-open exporter of crude oil, makes the economy susceptible to oil price shocks, as highlighted by the 2016 and 2020 recessions, largely occasioned by the 2014-2016 oil glut and 2020 oil price crash, respectively. The attendant consequences of these shocks prompted several policy rates changes by the Central Bank of Nigeria (CBN) to cushion its effect on the price level and output, achieving varying degrees of success. Thus, incorporating the role of oil price in the reaction function of the CBN is not out of place (see Salisu et al., 2018).

Furthermore, the importance of the exchange rate for import-dependent economies like Nigeria is well documented in the literature (see Adebiyi and Mordi, 2012; Buyandelger, 2015), as changes in foreign prices can be easily fed into domestic prices. To stabilise the foreign exchange market (FEM) and achieve convergence between the different rates in the Nigerian FEM, the CBN introduced the managed float Investors and Exporters (I&E) window in 2017 which has been relatively stable. However, the retail segment of the FEM (Bureau de Change, BDC) has depreciated by over 40% since 2017, which has led to a substantial increase in inflation, hindering the ability of the CBN to meet its price stability mandate. The occurrence of the COVID-19 pandemic which plunged the economy into recession and heightened inflationary pressures alongside the uncertainties surrounding the implications of the Russia-Ukraine crisis for the economy further highlights the need to account for external influences in monetary policy analysis. All these factors impress the need for an adequately specified open-economy model to inform the CBN on the impact of the shocks above and provide appropriate policy responses to achieve its mandate.

To achieve this objective, we employ an open-economy Bayesian DSGE due to its ability to easily incorporate initial values that account for the peculiarities of the Nigerian economy, for which the data alone may be inadequate. Relative to the ML DSGEs, the Bayesian DSGE model can provide more efficient estimations of the model parameters and more consistent estimates of the oil price and exchange rate shocks driving economic developments (Smet and Wouters, 2004), all of which are imperative for effective monetary policy decision making.

Our paper differs from the others in four distinctive ways. First, to the best of our knowledge, there is no study on the Nigerian economy that employs Bayesian DSGE to provide evidence of changes in productivity shocks in the pre-COVID and COVID-19 era. Second, we apply an open-economy DSGE model that accounts for the combined effect of oil price and exchange rate shocks on the Nigerian economy as most studies in the literature, concentrate on just either oil price or exchange rate shock. Third, we specify an augmented New Keynesian Phillips curve equation that accounts for the combination of both forward-looking and backward-looking price-setting behaviour, similar to Gali and Gertler (1999). Fourth, we extend the traditional monetary policy reaction function to accommodate interest rate smoothing properties as past policy rates have been found to influence interest rate decisions of Central Banks.

Our results show that the productivity shock is the most persistent in the Nigerian economy in relation to the interest rate and output gap, closely followed by demand shock, while the monetary policy shock is the most transient. Concerning prices, monetary policy shock had the most potent initial impact, revealing the absence of a price puzzle for Nigeria, while the productivity and demand shocks were initially inflationary, with productivity accounting for higher price increases. Our results are robust to different price measures.

The rest of the study is presented as follows: Section two presents some literature review and section three outlines our data and model in detail. While section four presents results, section five concludes the study.

2.0 LITERATURE REVIEW

Several studies have been carried out on the usefulness and otherwise of the effectiveness of monetary policy shocks on several economies including Nigeria. These analyses are also being performed using a varied number of approaches including the Bayesian DSGE. On the role of macroeconomic shocks in ten African countries, Rasaki and Malikane (2015) note that external shocks, particularly external debt, exchange rate, foreign interest, and commodity prices, are the dominant drivers of fluctuations in Africa. The presence of price and liquidity puzzles were investigated for indebted small open economies by Muhanji, Malikane, and Ojah (2013) who note that many African countries report a price puzzle. Also, in small open economies, Buyandelger (2015) finds that the exchange rate acts as a shock absorber for domestic productivity and foreign demand shock.

The first study developed on the Nigerian economy that employs the Bayesian DSGE model, Olofin et al (2014), analyses the effects of three policy options built around the assumptions of the changes made to the monetary policy rate using a partial equilibrium DSGE model. Though relevant, the study only captures a sub-segment of the Nigerian economy. Some such studies on the Nigerian economy include analysis of monetary and fiscal policy changes in informal labour markets (See Adu, Alege, & Olurinola, 2021), remittances and monetary policy transmission (Apanisile, 2021), and external shocks on the domestic economy (Ojeyinka & Yinusa, 2022). Highlighting the appropriate channel of monetary policy transmission given anticipated and unanticipated monetary policy shocks Akinlo and Apanisile (2019), however, fail to estimate the effect of these shocks on macroeconomic outcomes, which would be tested in this paper using the same approach. Ojeyinka and Yinusa (2022) note that external shocks, particularly oil price, foreign output, and foreign inflation impact demand (output gap and inflation) positively. This present study confirms the authenticity of these findings in line with exchange rate shocks to corroborate or refute the same while highlighting any patterns of change in consumption.

3.0 DATA AND METHODOLOGY

3.1 Theoretical Basis

The theoretical basis of DSGE models is grounded in the new consensus macroeconomics. It employs new consensus macroeconomic theory for policy analysis. Notwithstanding the sharp critique following the 2007 financial crisis, the model has several key advantages. DSGE models are prominently used for forecasting, policy analysis, and storytelling. They are used to predict and explain the dynamic behaviour of aggregate time series over the business cycle having recorded several advantages over time. DSGE models are known to have decent in-sample and out-of-sample forecasting performance suitable for policy analysis. The models are micro-founded, as they are rooted in economic theory and their parameters are structural, thus when compared with traditional VARs or simultaneous equation models, they are invariant to policy shocks. Finally, DSGE results and policy scenarios are easily communicated (Nachane, 2018).

3.2 Brief Description of the Model

We build on the Woodford's (2003) model in order to incorporate interest rate smoothing (see also, Salisu et al., 2022) backward-looking price setting (se also, Olofin et al., 2014), and exchange rate (as a proxy for the external sector) (see also, Olofin et al., 2014). The effect of interest rate smoothing is captured in this model as the CBN has been observed to adjust its monetary policy rate, the MPR, in a sequence of relatively small steps in the same direction. As observed, interest rate remained constant for varying periods consecutively and its increase was only staggered despite varying changes in the price level such as observed between 1995Q2 and 1998Q4 when interest rate was held at 13.5% with increases in the consumer price index from 18.81 points to 29.56 points, respectively. This pattern can also be observed severally during the period covered by this study and is captured by including the first lag of the policy rate as an additional regressor in the policy rule in equation 3c. In the case of the backward-looking price setting behaviour, earlier research maintain that such behavior is a better approximation of reality than forward-looking behaviour (Fuhrer, 1997; Linde, 2002).

Thus, we present Nigeria as a small open economy with evidence of interest rate smoothing and backward-looking price setting behavior. Drawing from the theoretical foundations, this study analyses the effect of nominal (monetary policy and demand) shocks and real (productivity) shocks on select macroeconomic variables (inflation, interest rate, and output). The demand shock is captured by the exchange rate at the BDC segment of the FEM. The BDC exchange rate was selected over the interbank and rates at the I&E window as it exhibits elements of variability and the data spans the timeframe covered by the study.

The Bayesian approach is selected as it is guided by theory and institutional knowledge. Also, Bayesian analysis fits the solved DSGE model to a vector of aggregate time series. Bayesian estimations are based on the likelihood functions generated by the DSGE models and prior distributions can be used to incorporate additional information into the parameter estimation (An and Schorfheide, 2007). Nevertheless, the model must be correctly specified and potential lack of identification of parameters of interest resolved. Just like a 'regular' DSGE model, the Bayesian DSGE model is used for policy analysis and forecasting. Again, it highlights the dynamic interaction between several interrelated blocks, capturing the effects of past actions on today and future outcomes. The blocks included are the households, firms, and the Central Bank. Thus, the Bayesian model is used to analyse the effect of the Central bank of Nigeria's own, productivity, and demand shocks on the output gap, interest rate, and inflation in Nigeria as well as provide policy implications of the effects of interest rate smoothing and backward-looking price setting scenario on the actions of the CBN. The individual blocks are discussed below briefly.

3.2.1 Households

In this paper, households optimisation is captured by the Euler equation represented in equation 1 representing the linear version, which states that the current output is a function of expected output, expected inflation and current nominal interest rate (i.e., the monetary policy rate).

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

3.2.2 Firms

The price equation, that is, the Phillips curve, in its linear form is stated in equations 2. It shows the association between the level of output and current and expected value of deviation of inflation from its steady-states.

$$p_t = \beta E_t(p_{t+1}) + \kappa x_t \quad (2)$$

where β is the pricing decision of the firm.

3.2.3 The Central Bank

The interest rate equation, captured in equation 3a, explains the reaction of the central bank in response to inflation and other factors not incorporated, to ensure price stability.

$$r_t = \frac{1}{\psi} p_t + u_t \quad (3a)$$

where r_t is the steady-state value of the interest rate and u_t is a state variable that captures all movements in the interest rate not driven by inflation. $\frac{1}{\psi}$ captures the degree to which the central bank responds to inflation.

Equation 3a is modified to include interest rate smoothing effects and is as shown in the linear version of the policy equation as presented in equation 3b below.

$$r_t = \rho_r r_{t-1} \frac{1-\rho_r}{\psi} p_t + u_t \quad (3b)$$

Where r_{t-1} represents the interest rate smoothing effect and ρ_r is a state variable.

This effect is captured as the Nigerian monetary authorities tend to adjust their rate in a sequence of relatively small steps in the same direction (see, Salisu et al., 2022). A backward-looking price-setting component is also included to ensure determinacy and test whether the nominal interest rate responds aggressively or otherwise to past inflation rates (see Carlstrom and Fuerst, 2000).

The backward-looking price setting behaviour is captured in the consumption (household) equation. Using the linear version of the household equation, the backward-looking component is shown thus:

$$p_t = \rho_p p_{t-1} + (1-\rho_p)[\beta E_t(p_{t+1}) + \kappa x_t] \tag{3c}$$

Where ρ_p is a no shock state variable and p_{t-1} captures backward looking price setting behaviour.

The combination of the effects of interest rate smoothing and backward-looking price setting highlights the extent of rigidity of the monetary authority in the implementation of monetary policy.

3.2.4 Structural Shocks

This model captured the effect of three shocks monetary policy shock (u_t), productivity shock (g_t), and demand shock (es_t) represented by equations 4, 5, and 6, respectively. The equations for these state variables are stated in logarithms as follows:

$$lnU_{t+1} = \rho_u ln(U_t) + e_{t+1} \tag{4}$$

$$lnG_{t+1} = \rho_g ln(G_t) + \epsilon_{t+1} \tag{5}$$

$$lnES_{t+1} = \rho_{es} ln(ES_t) + v_{t+1} \tag{6}$$

This block is significant as it is used to complete the model, describing the evolution of the state variables ($U_t, G_t$and ES_t). As shown above, the state variable are autoregressive processes in logarithmic forms. Thus, the variables e_{t+1}, ϵ_{t+1} and v_{t+1} are shocks to the state variables and are used to determine the appropriate response of monetary policy to shocks to monetary policy, productivity and demand, respectively.

3.3 Model Specification

The DSGE model was further modified, solved, and estimated as linearized equations as shown below. The demand shock, represented by the exchange rate (es_t) is included in the price equation to capture the initial effect of changes in the exchange rate on price and its indirect effect on consumption (equation 9), with the shock process highlighted in equation 13. The productivity shock (g_t) feeds into the consumption equation to capture the effect of changes in productivity on household consumption. Surprises in monetary policy (u_t) are highlighted in the interest rate equation and the shock process is contained in equation 11. For ease of follow through, the linearized equations, including the modifications, have been repeated as follows:

$$p_t = \rho_p p_{t-1} + (1-\rho_p)[\beta E_t(p_{t+1}) + \kappa x_t + \phi es_t] \tag{7}$$

$$e_t = es_t \tag{8}$$

$$x_t = E_t(x_{t+1}) - \{r_t - E_t(p_{t+1}) - g_t\} \tag{9}$$

$$r_t = \rho_r r_{t-1} \frac{1-\rho_r}{\psi} p_t + u_t \quad (10)$$

$$u_{t+1} = \rho_u u_t + \epsilon_{t+1} \quad (11)$$

$$g_{t+1} = \rho_g g_t + \xi_{t+1} \quad (12)$$

$$es_{t+1} = \rho_{es} es_t + v_{t+1} \quad (13)$$

3.4 Estimation Procedure

The simulation method used is the Markov chain Monte Carlo (MCMC) method with the number of iterations measured by an MCMC size of 46,000 draws. The length of the burn-in period is 6,000 with 103 observations in the dataset. The Metropolis-Hastings sampling algorithm is used. To analyse convergence diagnostics, the trace, histogram, autocorrelation, and density plots are employed.

3.5 Data Sources, Description, and Summary Statistics

Quarterly data was sourced from the Central Bank of Nigeria (CBN) and the International Financial Statistics (IFS) spanning the period 1995Q2 to 2021Q1. The exchange rate and the GDP deflator were utilised in their growth rates. While in the main model, the NEER was utilised to capture the exchange rate, the rate at the bureau de Change (BDC) segment of the foreign exchange market was used for robustness purposes. The lending rate was differenced to circumvent the problem of nonstationarity in that series. Other variables include interest rate (lending rate) and consumer price index, with the CPI also employed for robustness purposes. The details of data selection, processing, and sources are shown in Table 1.

Table 1: Variable definition and measurement

Variable	Measurement	Data Source
Interest rate	In percent (%)	IFS
GDP Deflator	$\frac{nominal\ GDP}{real\ GDP} * 100$	CBN
NEER	Growth rate (%)	IFS
BDC exchange rate	Growth rate (%)	CBN
CPI	In units	CBN

Note: The interest rate here is the lending rate. The NEER, CPI, and BDC represent Nominal Effective Exchange Rate, Consumer Price Index, and Bureau de Change respectively.

Table 2 shows the basic statistical features of the data over the period. The exchange rate at the BDC segment of the FEM revealed high volatility averaging ₦186.58/US$ within the study period and depreciating to ₦476.56/US$. In addition, NEER also reveals a high level of volatility ranging from a low index point of 44.96 to the highest point of 764.20, averaging 190.09 index points. Prices were also relatively unstable as GDP deflator and CPI averaged 91.02% and 116.23 index points, with a high variation of 67.67 and 79.31, respectively. Nevertheless, CPI was more volatile than GDP deflator over the period. Interest rate averaged negative 0.09% with a possibility of a drag on changing interest rates as interest rate varied marginally as captured by the measure of variability at -877.63.

Table 2: Summary Statistics

	Interest rate	GDP Deflator	NEER	BDC	CPI
Mean	-0.0885	91.0182	190.0851	186.5840	116.2302
Standard deviation	0.7767	61.5957	205.6599	108.9604	92.1804
Coefficient of variation	-877.6270	67.6741	108.1936	58.3975	79.3085
Minimum	-3.9967	14.0513	44.9550	80.9300	18.8120
Maximum	3.4067	237.8008	764.2026	476.5600	372.5137
Observation	103	103	104	103	103

Note: NEER, BDC, and CPI denote Nominal Effective Exchange Rate, Bureau de Change, and Consumer Price Index, respectively.

3.6 Priors for Distributions

The priors used in the estimation of the model are presented in table 3. The distribution of these priors is determined by theory and institutional knowledge. Typically, the beta must lie between 0 and 1, with common values ranging between 0.90 and 0.99. The kappa is usually thought to be small and positive. The autocorrelation parameters must lie between -1 and 1 but are characteristically assumed to be positive and closer to 1 than to 0. Furthermore, to maintain stability, the coefficient of inflation to monetary policy rate must be between 0 and 1. The priors were thus selected to match the theoretical considerations highlighted above.

Table 3: Prior for distributions

Parameter	Interpretation	Range	Density function	Para(1)	Para(2)
ρ_r	Interest rate smoothening parameter	(0,1)	Beta	0.70	0.30
φ	Coefficient of inflation to monetary policy rate	(0,1)	Beta	0.50	0.50
ρ_p	Backward-looking price setting	(0,1)	Beta	0.30	0.70
β	Discount factor	(0,1)	Beta	0.95	0.05
κ	Price adjustment parameter	(0,+∞)	Beta	0.30	0.70
ϕ	Pricing decision of the firm	(0,+∞)	Beta	0.30	0.70
ρ_u	AR(1) for the monetary policy shock	(-1,1)	Beta	0.75	0.25
ρ_g	AR(1) for the productivity shock	(-1,1)	Beta	0.75	0.25
ρ_e	AR(1) for the demand shock	(-1,1)	Beta	0.75	0.25
σ_u	Standard deviation of the monetary policy shock	(0,+∞)	Inverse-gamma	0.01	0.01
σ_g	Standard deviation of the productivity shock	(0,+∞)	Inverse-gamma	0.01	0.01
σ_{es}	Standard deviation of the demand shock	(0,+∞)	Inverse-gamma	0.01	0.01

4.0 RESULTS AND DISCUSSION

4.1 The Entire Sample - Pre-COVID and COVID-19 periods (1995Q1 – 2021Q1)

The results of the posteriors reveal that the persistence value of the monetary policy is 0.57%, productivity, 0.63%, and demand, 0.64%. This implies that the effect of the exchange rate is more persistent in Nigeria followed by productivity and monetary policy. This is not surprising as Nigeria is a consuming and/or importing nation. Hence, the effect of the exchange rate will be more persistent. Monetary policy shock is less persistent.

Table 4: Model Estimation Results

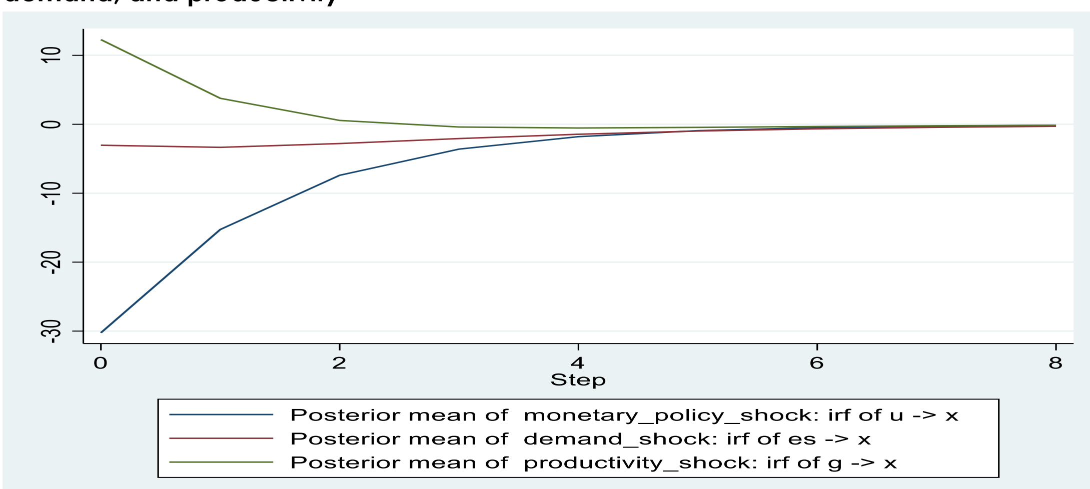
Parameters	Model (without block)		Model (with block)	
	Mean	95% interval	Mean	95% interval
ρ_r	0.9633	[0.9563, 0.9698]	0.8718	[0.8185, 0.9110]
φ	0.7156	[0.6800, 0.7546]	0.5669	[0.4794, 0.6527]
ρ_p	0.2799	[0.2328, 0.3257]	0.1663	[0.1169, 0.2224]
β	0.7110	[0.6046, 0.8157]	0.9497	[0.8994, 0.9831]
κ	0.8602	[0.8280, 0.8899]	0.3836	[0.3014, 0.4733]
ϕ	0.3303	[]0.2693, 0.3907	0.1727	[0.1173, 0.2380]
ρ_u	0.0468	[0.0371, 0.0574]	0.5666	[0.5290, 0.6112]
ρ_g	0.9890	[0.9849, 0.9925]	0.6294	[0.5323, 0.7253]
ρ_e	0.3163	[0.2826, 0.3520]	0.6365	[0.5328, 0.7347]
σ_u	2.0167	[1.9757, 2.0592]	5.0855	[3.5763, 7.3212]
σ_g	0.6900	[0.6045, 0.7738]	7.6819	[4.7109, 11.7814]
σ_{es}	3.2921	[3.2394, 3.3512]	16.1795	[13.8592, 18.9259]
Log-MLH	-2292.7688		-1121.234	
Acceptance rate	0.203		0.4065	

Note: MCMC runs of 46,000 iterations with 6,000 burn-ins were used. Log-MDD stands for log marginal-likelihood and the acceptance rate is the random-walk Metropolis-Hastings sampling.

Figure 1 shows the response of the output gap to shocks emanating from monetary policy, demand, and productivity. The result reveals that the output gap responds positively and significantly to shock in productivity. Productivity shock tends to have a longer effect on the output gap than monetary and demand shocks, but the effect fizzles out before the sixth forecast horizon. On the other hand, the output gap responds negatively and significantly to shocks in demand and monetary policy. The output gap may likely increase initially by 30.0% but fizzles out in the fourth quarter.

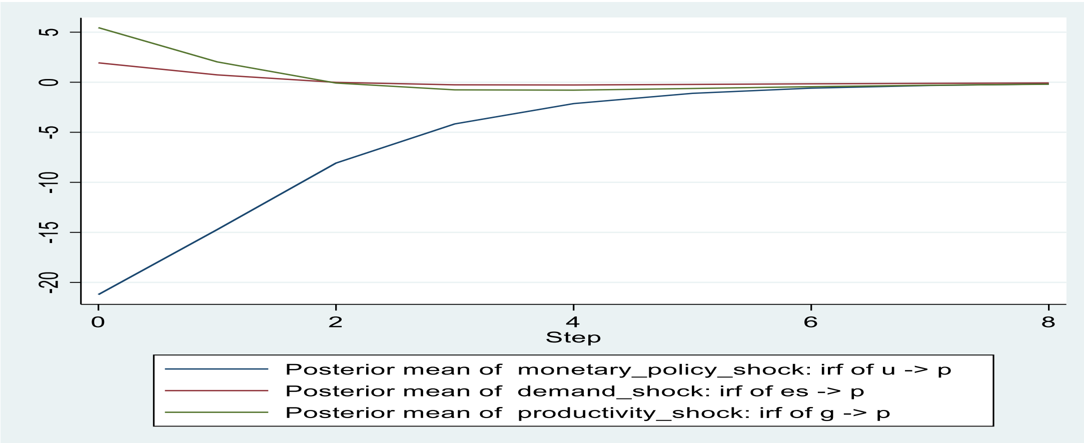
Monetary policy and demand shocks cause the output gap to widen though the effect is transient as it dies out in the fourth quarter following the shock. This initial negative effect is however dampened by the positive effect of productivity shock on the output gap. Also, the effect of the productivity shock lingers for a slightly higher period than those of the other two shocks. Thus, productivity tends to have a longer effect on the output gap than monetary and demand shocks. Though the results of the posterior means reveal that the persistence of the demand shock is higher than that of the productivity shock by 0.01% the effect of the exchange rate shock fizzles out faster than that of the productivity shock, thus, emphasising the importance of the effect of the productivity shock on output gap in Nigeria.

Figure 1: The response of output gap to shocks emanating from monetary policy, demand, and productivity



Using the GDP deflator as a measure of price, the CBN smooths interest rate by 0.87% supporting the staggered way interest rate changes after a shock; further stressing the fact that the CBN is selectively dovish to changing the interest rates. Thus, interest rate lag plays a vital role in Nigeria over other fundamentals. Monetary policy shock tends to have a higher initial effect on inflation as price declines by about 21% given an increase in monetary policy rate thus revealing the absence of the price puzzle (Figure 2). Therefore, the action of the CBN can be regarded as being non-inflationary. At the initial stage, both demand and productivity shocks are inflationary though minute. Also, the effect dies out before the 8th quarter following the introduction of the shock.

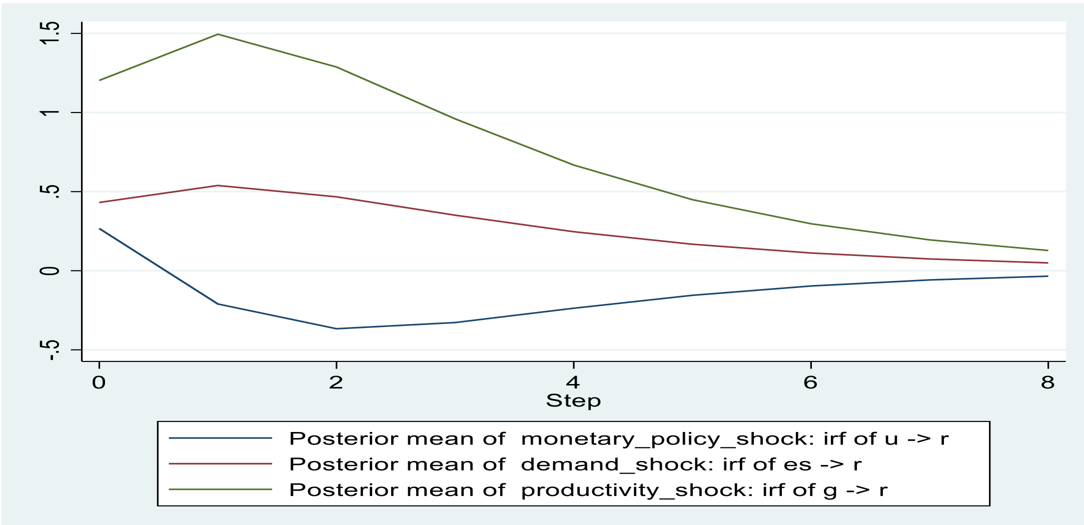
Figure 2: The response of inflation to shocks emanating from monetary policy, demand, and productivity



The imposition of all the shocks has an initial positive effect on the interest rate in Nigeria though the short-term persistence of productivity shock is higher than all three shocks (Figure 3). However, the effects are persistent and seem to converge to a steady state in the long run. The initial impact of all the shocks is positive with productivity shock causing the greatest initial change in interest rates (Figure 3). A productivity shock causes a rise in inflation, which then leads the CBN to raise the interest rate, however slowly as evidenced by the result of the smoothing parameter. This is believed to encourage producers to borrow funds and thus boost the economy. It will also curb inflation as individuals will be encouraged to save. In addition, a demand shock is seen to increase interest rates, which is congruent with the actions of monetary authorities to ensure price stability in agreement with the loanable fund theory.

While the effect of productivity and demand shocks on interest rate remains positive over eight quarters, the effect of own shock causes a decline in interest rate from the first quarter following the shock with a gradual increase in interest rate from the third to the eighth quarter, until it goes back to equilibrium. This is necessary because of the impact of productivity shock on income and consumption. Furthermore, because productivity is inflationary, the CBN might want to sustain the interest rate over a longer period than other shocks.

Figure 3: The response of interest rate to shocks emanating from monetary policy, demand, and productivity



4.2 Pre-COVID 19 (1995Q1 – 2019Q4)

The results obtained in the pre-COVID era are similar to those observed over the entire sample and are reported in Table 5 and Figure 4(a, b, and c).

Table 5: Model Estimation Results

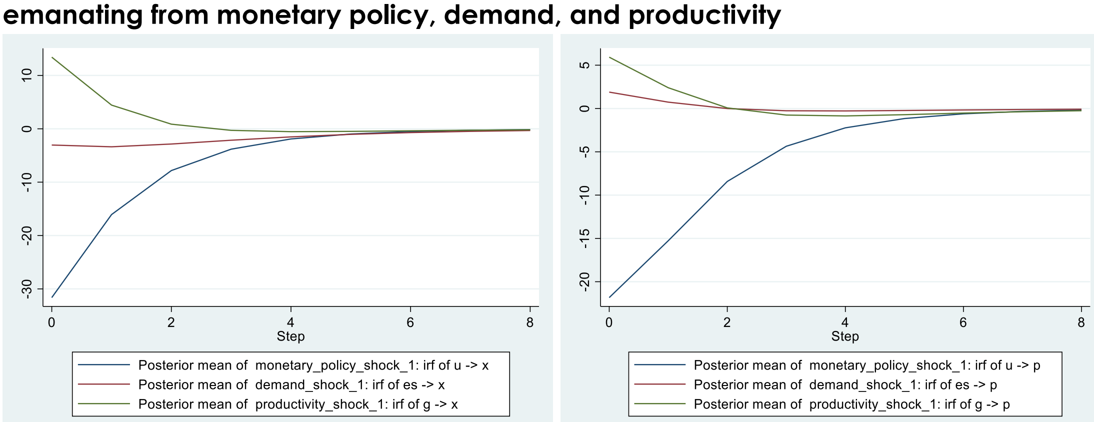
Parameters	Model (without block)		Model (with block)	
	Mean	95% interval	Mean	95% interval
ρ_r	0.9753	[0.9704, 0.9797]	0.8817	[0.8235, 0.9210]
φ	0.3620	[0.3190, 0.4079]	0.5406	[0.4530, 0.6258]
ρ_p	0.0345	[0.0230, 0.0469]	0.1681	[0.1176, 0.2281]
β	0.4551	[0.4106, 0.5003]	0.9638	[0.9295, 0.9873]
κ	0.8353	[0.8041, 0.8659]	0.3694	[0.2825, 0.4608]
ϕ	0.5583	[0.5343, 0.5825]	0.1615	[0.1073, 0.2181]
ρ_u	0.2611	[0.2433, 0.2793]	0.5667	[0.5162, 0.6135]

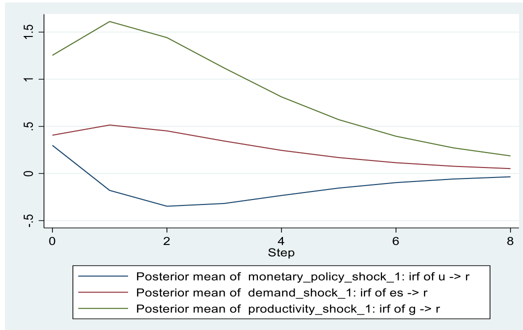
ρ_g	0.9840	[0.9788, 0.9888]	0.6639	[0.5577, 0.7551]
ρ_e	0.1335	[0.1129, 0.1548]	0.6450	[0.5449, 0.7456]
σ_u	1.7123	[1.6551, 1.7730]	5.1242	[3.2880, 7.9036]
σ_g	1.0175	[0.9845, 1.0517]	7.8412	[4.3910, 13.6941]
σ_{es}	4.2151	[4.1162, 4.3192]	16.6503	[14.3728, 19.2981]
Log-MLH	-1909.1279		-1074.724	
Acceptance rate	0.147		0.3912	

Note: MCMC runs of 46,000 iterations with 6,000 burn-ins were used. Log-MDD stands for log marginal-likelihood and the acceptance rate is the random-walk Metropolis-Hastings sampling.

This could point to the fact that the data spanning the pre-COVID era is greater than that covering the COVID era and thus is bound to overshadow the effects of the behaviour in the COVID era. Another reason could be the benefits of the monetary policy interventions, which could have spurred productivity and sustained the Nigerian economy during the Pandemic. Thus, we conclude that the results are robust and thus the findings can be generalized for the Nigerian economy.

Figure 4: The response of output gap (a), inflation (b), and interest rate (c) to shocks emanating from monetary policy, demand, and productivity





4.3 Robustness Test

4.3.1 Using an alternative measure of inflation

Robustness was carried out on the model and this involves the use of the CPI as a measure of price (to replace the use of the GDP deflator in the main model). The results obtained using the CPI as contained in table 6 and Figure 5 (a, b, and c), were found to be similar to those obtained using the GDP deflator (table 4 and Figures 1, 2, and 3). This supports the conclusion that the Nigerian data is robust to explain the economic phenomenon.

Table 6: Model Estimation Results

Parameters	Model (without block)		Model (with block)	
	Mean	95% interval	Mean	95% interval
ρ_r	0.9784	[0.9735, 0.9828]	0.8365	[0.7774, 0.8849]
φ	0.0874	[0.0688, 0.1102]	0.5500	[0.4613, 0.6399]
ρ_p	0.2171	[0.1771, 0.2586]	0.1877	[0.1344, 0.2486]
β	0.8982	[0.8197, 0.9600]	0.9490	[0.8968, 0.9834]
κ	0.6300	[0.5552, 0.7175]	0.3923	[0.3092, 0.4811]
ϕ	0.1803	[0.1283, 0.2376]	0.1464	[0.0981, 0.2040]
ρ_u	0.3518	[0.2672, 0.4221]	0.5739	[0.5227, 0.6190]

ρ_g	0.8069	[0.7715, 0.8435]	0.6313	[0.5315, 0.7287]
ρ_e	0.3482	[0.2763, 0.4115]	0.6430	[0.5371, 0.7500]
σ_u	3.9379	[3.7988, 4.0758]	4.2741	[3.0549, 5.9387]
σ_g	3.0698	[2.9927, 3.1569]	6.0485	[3.9307, 8.9899]
σ_{es}	5.5990	[5.4097, 5.7878]	16.2186	[14.0323, 18.7355]
Log-MLH	-1490.3537		-1071.4889	
Acceptance rate	0.1779		0.4151	

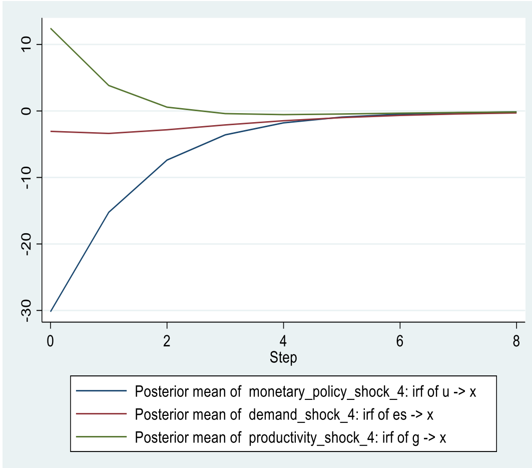
Note: MCMC runs of 46,000 iterations with 6,000 burn-ins were used. Log-MDD stands for log marginal-likelihood and the acceptance rate is the random-walk Metropolis-Hastings sampling.

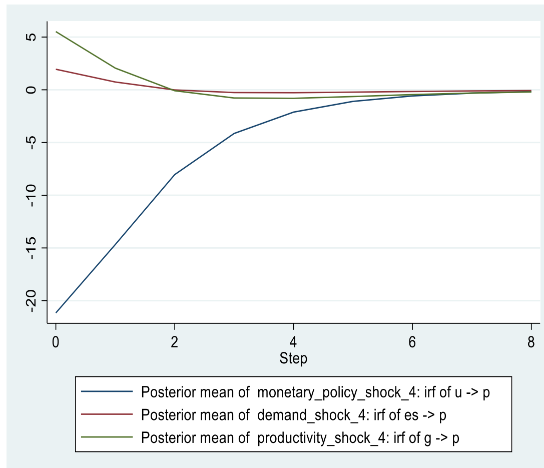
However, a few observations have been highlighted:

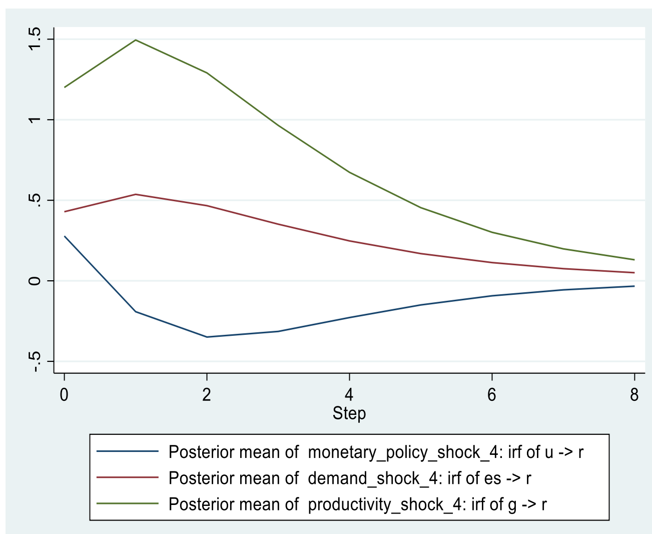
- The effect of interest rate smoothing is slower using the CPI than using the GDP deflator as when using the CPI, the CBN changes the interest rate at a faster rate given a shock though the difference is minute at 0.07%. Thus, when using the CPI as a measure of price, the CBN tends to be more rigid.
- Also, the CBN tends to rely on the backward-looking price setting option when using the CPI as the measure of price than when the GDP deflator is in use.
- Productivity and monetary policy shocks are nevertheless generally smaller when using CPI as a measure of price than when using the GDP deflator. The opposite is the case with the demand shock, that is, the impact of the demand shock affects demand via the CPI measure more than via the GDP deflator.

In conclusion, the results do not change when either the price measures of CPI or GDP deflator are used in the model.

Figure 5: The response of output gap (a), inflation (b), and interest rate (c) to shocks emanating from monetary policy, demand, and productivity







4.3.2 Using an alternative measure of exchange rate

Another robustness was carried out, employing the exchange rate at the BDC segment of the foreign exchange market. The BDC exchange rate was used to replace the trade weighted exchange rate in the main model. The results obtained using the BDC exchange rate are contained in table 7 and Figure 6 (a, b, and c). The pricing decision of firms are lower using the BDC exchange rate than using the NEER (Table 4), which could be an indicator of relative price stability in Nigeria compared to price changes in markets of foreign competitors. Here, Nigerian firms are in no hurry to change their prices, which could signify the import of relevance among firms as they struggle to remain competitive. In addition, the price adjustment parameter is relatively low using the BDC exchange rate than using the trade weighted measure of exchange rate, revealing that prices are sticky downwards and thus firms do not change their prices as soon as there is a change in exchange rate (depreciation or appreciation); and thus are slow to adjust their prices in line with market realities. Furthermore, the effect of backward looking price setting is downplayed by the impact of the BDC exchange rate. Overall, the results of the robustness and the main analysis suggests that the results of these analyses are verified to be true and are not affected by outliers from the model's assumptions.

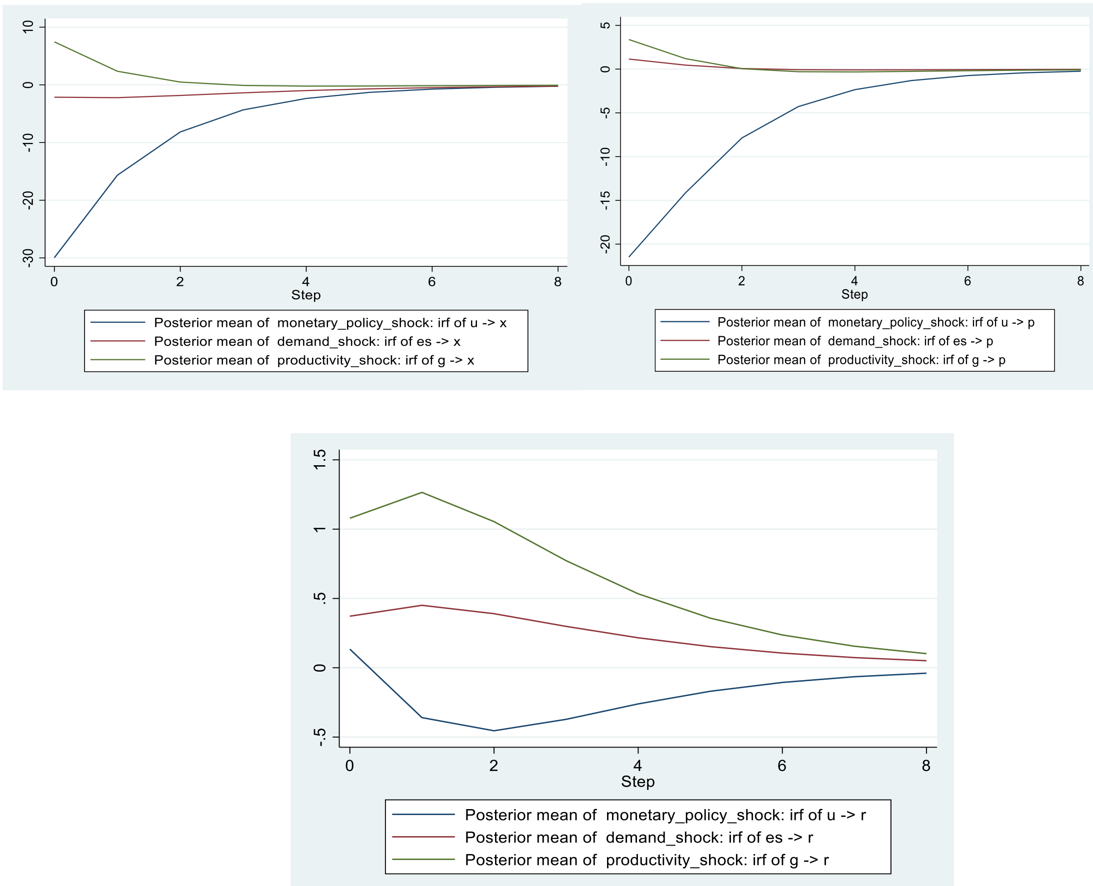
Table 7: Model Estimation Results

Parameters	**Model (without block)**		**Model (with block)**	
	Mean	**95% interval**	**Mean**	**95% interval**
ρ_r	0.8565	[0.8343, 0.8774]	0.8185	[0.7542, 0.8736]
φ	0.7790	[0.7362, 0.8201]	0.5539	[0.4674, 0.6420]
ρ_p	0.0988	[0.0705, 0.1313]	0.1187	[0.0813, 0.1637]
β	0.9647	[0.9302, 0.9887]	0.9513	[0.9017, 0.9838]
κ	0.5322	[0.4562, 0.5902]	0.3680	[0.2854, 0.4517]
ϕ	0.3237	[0.2526, 0.4018]	0.2660	[0.1921, 0.3501]
ρ_u	0.4759	[0.4455, 0.5105]	0.5790	[0.5407, 0.6194]
ρ_g	0.9523	[0.9371, 0.9663]	0.6380	[0.5320, 0.7250]
ρ_e	0.3449	[0.2952, 0.3946]	0.6693	[0.5760, 0.7565]
σ_u	3.3608	[3.1753, 3.5485]	7.2064	[4.8949, 10.0568]
σ_g	0.8465	[0.7400, 0.9565]	4.9758	[3.1648, 7.3979]
σ_{es}	3.8136	[3.6313, 4.0078]	6.2189	[5.4311, 7.1211]
Log-MLH	-1138.1966		-1002.4905	
Acceptance rate	0.2519		0.4122	

Note: MCMC runs of 46,000 iterations with 6,000 burn-ins were used. Log-MDD stands for log marginal-likelihood and the acceptance rate is the random-walk Metropolis-Hastings sampling.

When comparing the results in Figures 1, 2, and 3, and figures 6 (a, b, and c), we conclude that the results do not change when either the trade weighted or the BDC measure of exchange rate are used in the model.

Figure 6: The response of output gap (a), inflation (b), and interest rate (c) to shocks emanating from monetary policy, demand, and productivity



5.0 Conclusion

In this paper, we assess the impact of productivity, demand, and monetary policy shocks on the interest rate, output gap, and inflation spanning the 1995Q2 to 2021Q1 periods. The study modifies the Woodford (2003) DSGE model of an open economy by including the demand shock and accounting for interest rate smoothing and backward-looking price setting. The results were found to be robust irrespective of the measure of price used in the analysis (GDP deflator or CPI) as well as in the pre-COVID and COVID era. Findings revealed that the effect of all the shocks have an initial positive effect on the interest rate in Nigeria though the short-term persistence of productivity shock is higher than all three shocks. Also, the impact of productivity shock on interest rate is more persistent than that of demand and monetary policy shocks. Thus, a major policy implication from the study is that the CBN will likely increase interest rates in response to productivity, demand, and own shocks, however, the rate hikes in response to productivity shocks are higher than those to demand and monetary policy shocks. This paper thus recommends the need for the CBN to employ alternative monetary policy instruments aside from the interest rate in a bid to stimulate the economy in the face of productivity shocks. Nevertheless, the effect or otherwise of financial frictions in the Nigerian financial system could be understudied.

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Appendix

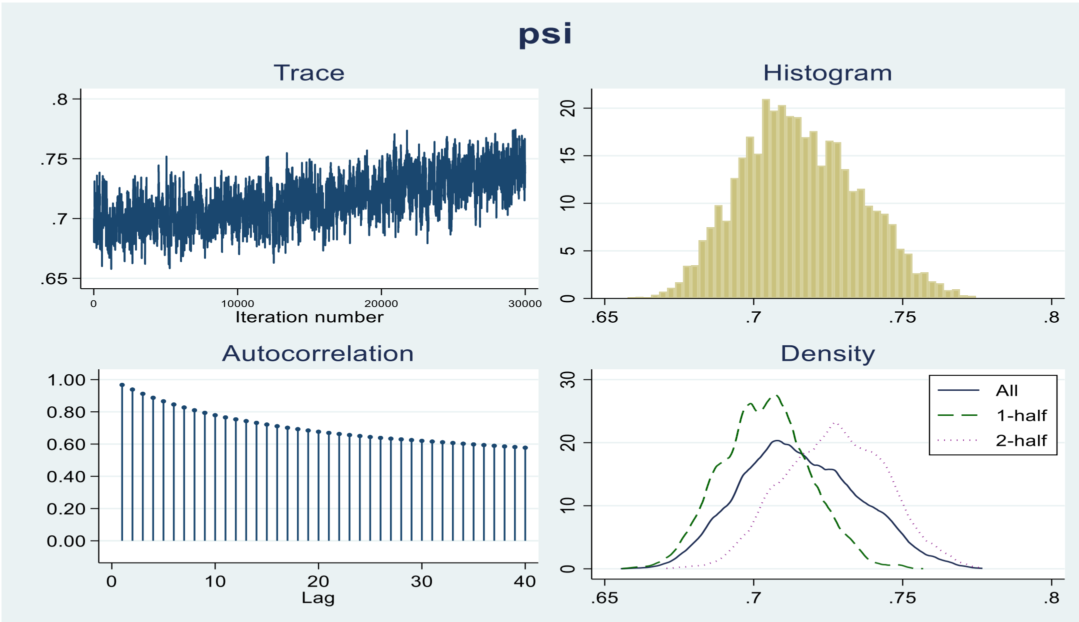
Appendix A.1: Results of main analysis – spanning 1995Q2 – 2021Q1

Without block option

```
Bayesian linear DSGE model                       MCMC iterations  =     35,000
Random-walk Metropolis-Hastings sampling         Burn-in          =      5,000
                                                 MCMC sample size =     30,000
Sample: 1995q3 thru 2021q1                       Number of obs    =        103
                                                 Acceptance rate  =       .203
                                                 Efficiency:  min =    .002023
                                                              avg =     .01176
Log marginal-likelihood = -2292.7688                          max =     .02532
```

	Mean	Std. dev.	MCSE	Median	Equal-tailed [95% cred. interval]	
rhor	.9633482	.0034767	.000141	.9634453	.9562775	.96975
psi	.7155564	.0196591	.002524	.7142099	.6800197	.7546337
rhop	.2798605	.0234477	.001426	.2799403	.2327517	.3256746
beta	.7109621	.0530027	.002173	.7108322	.6046185	.8156615
kappa	.8602134	.0155031	.000632	.8603486	.8280393	.8898445
phi	.3302954	.0310959	.00208	.3302349	.2693087	.390722
rhou	.0467688	.0051196	.000239	.046663	.037046	.0573694
rhog	.9890149	.001947	.000071	.9891091	.9848784	.9925055
rhoe	.3163364	.0176427	.001026	.3160189	.28258	.3520286
sd(e.u)	2.016678	.021998	.002729	2.016462	1.975733	2.05917
sd(e.g)	.6899681	.0422638	.002805	.6900947	.6044816	.773797
sd(e.es)	3.292063	.0292133	.00341	3.290543	3.23943	3.351163

Note: There is a high autocorrelation after 500 lags.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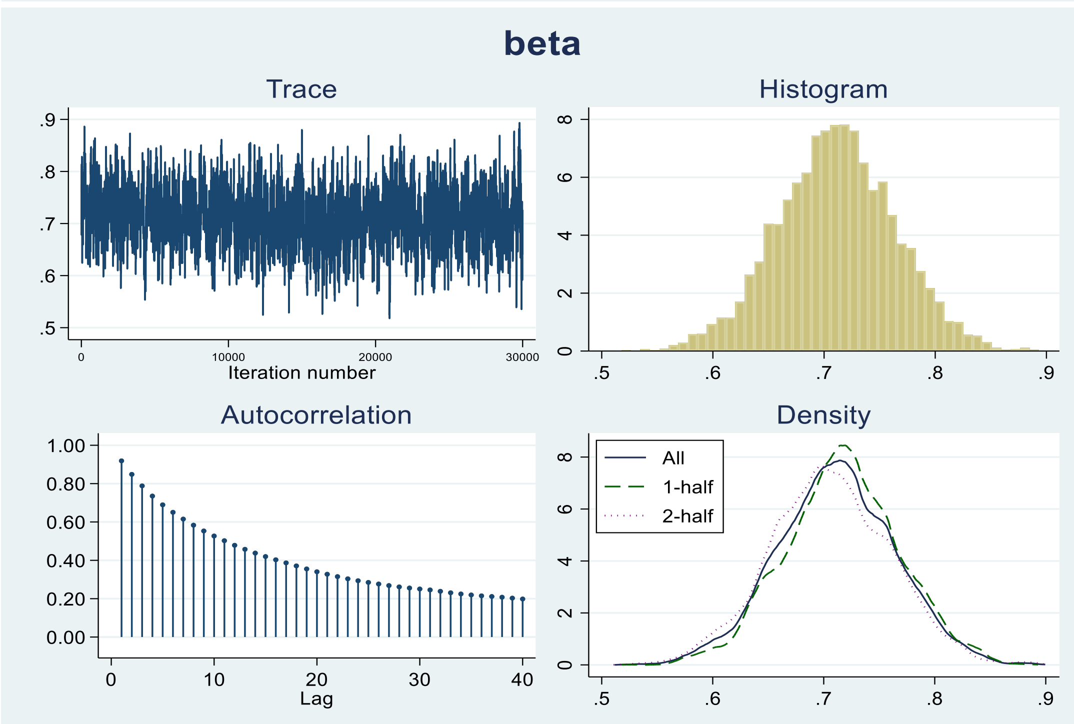
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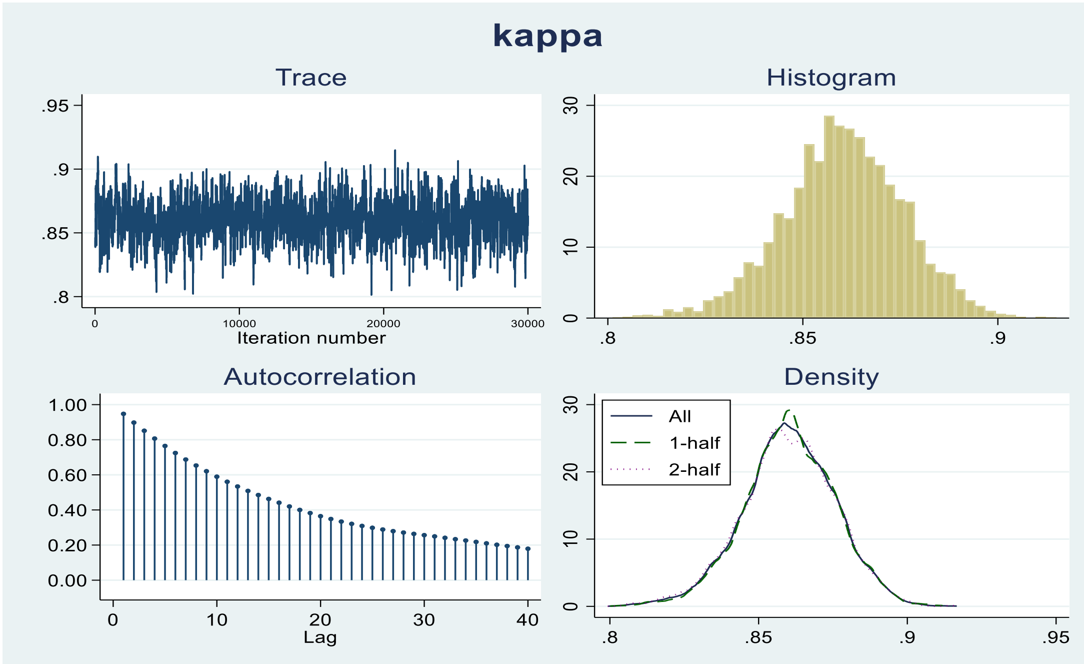
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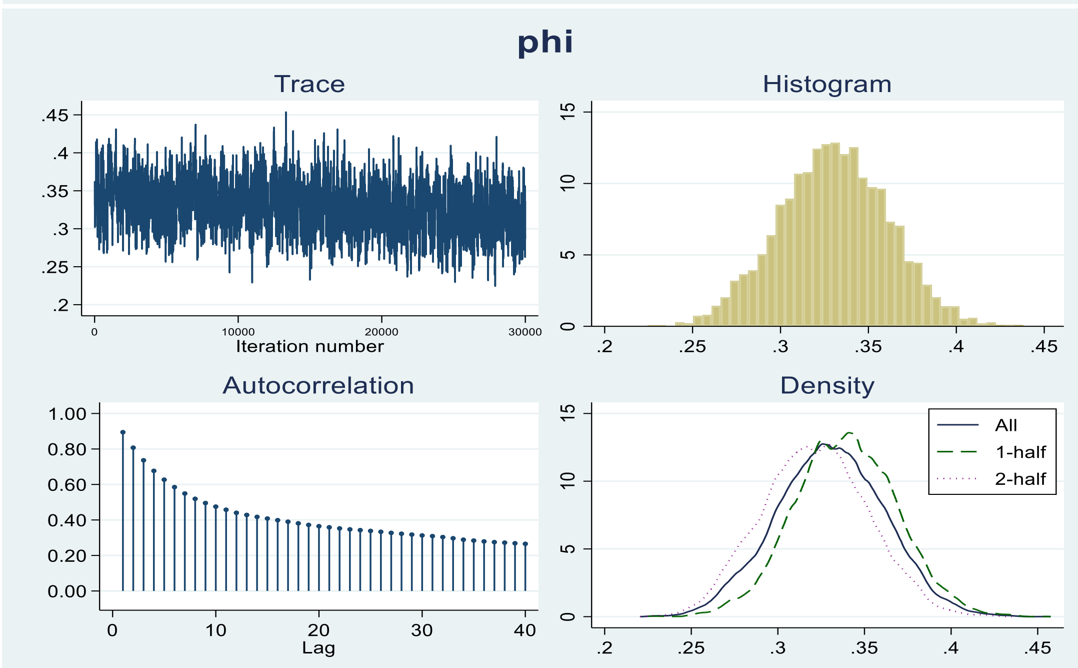
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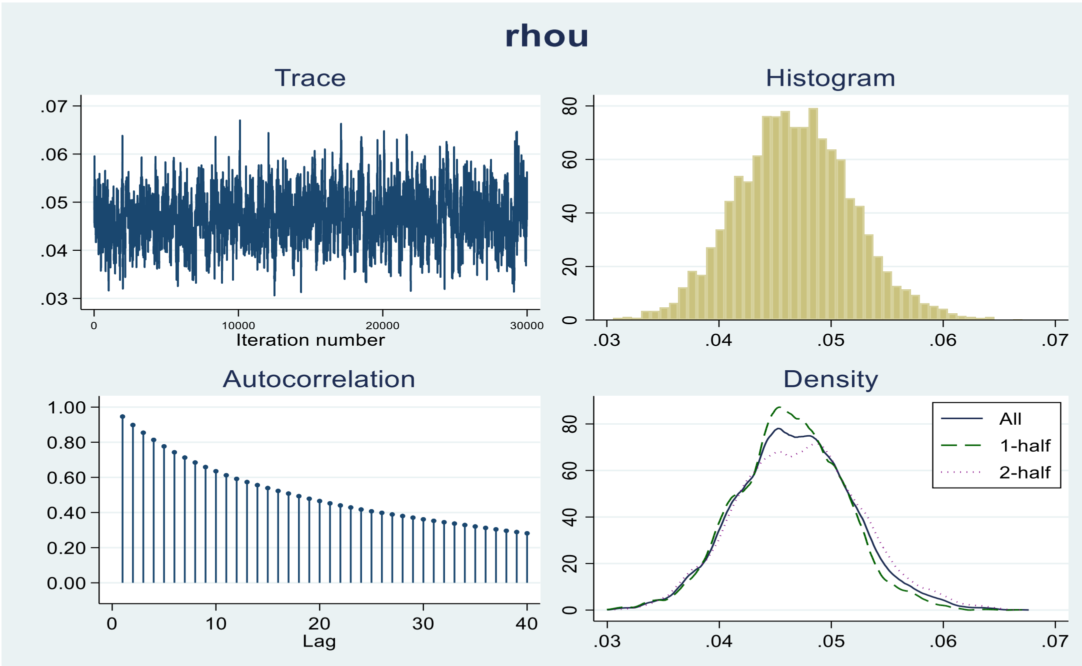
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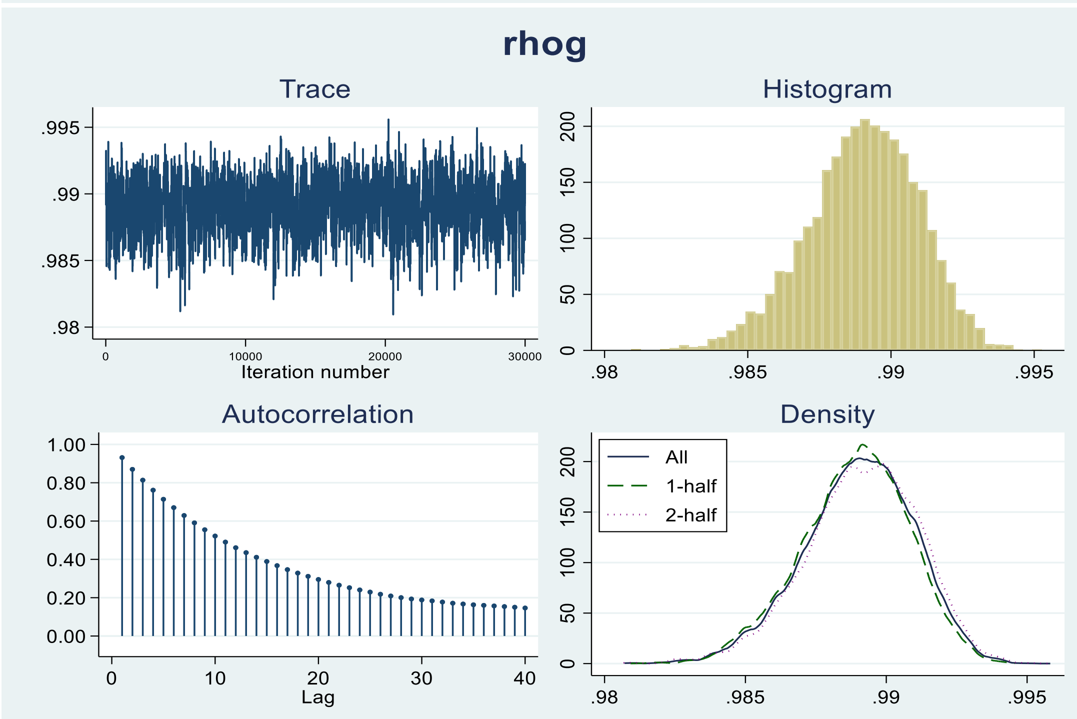
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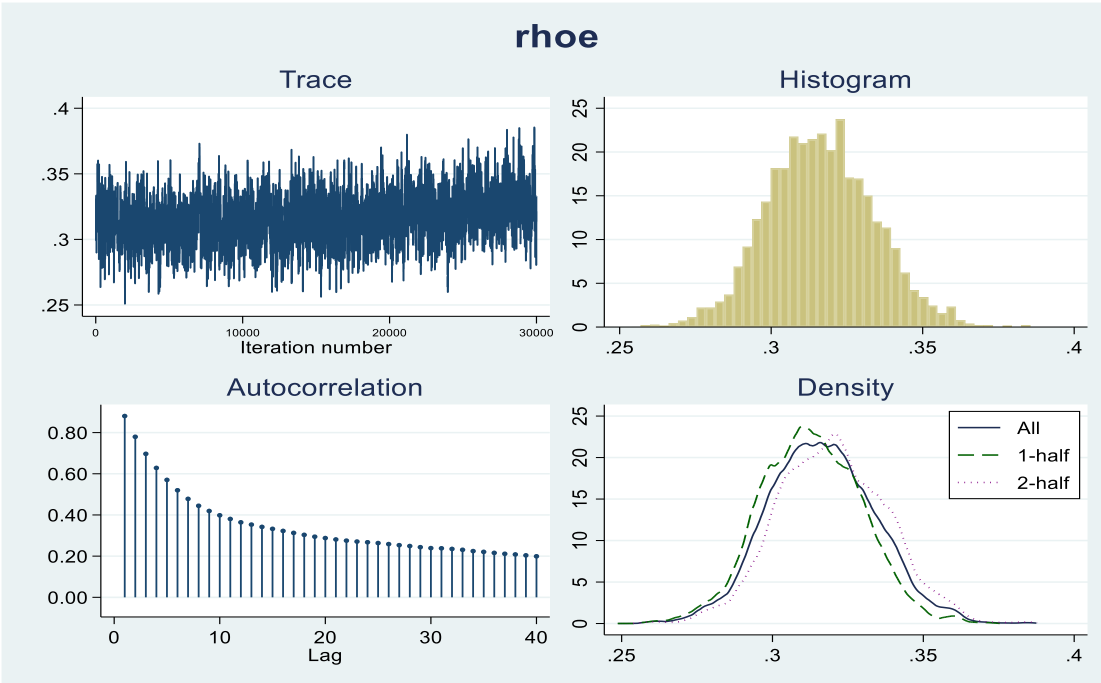
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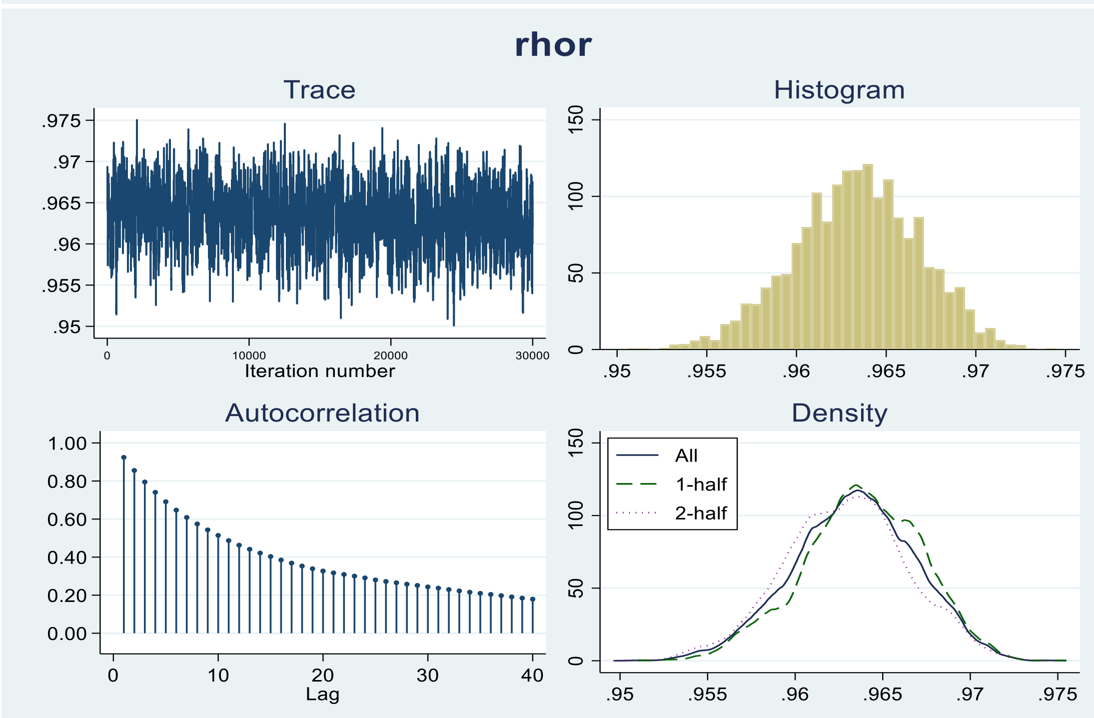
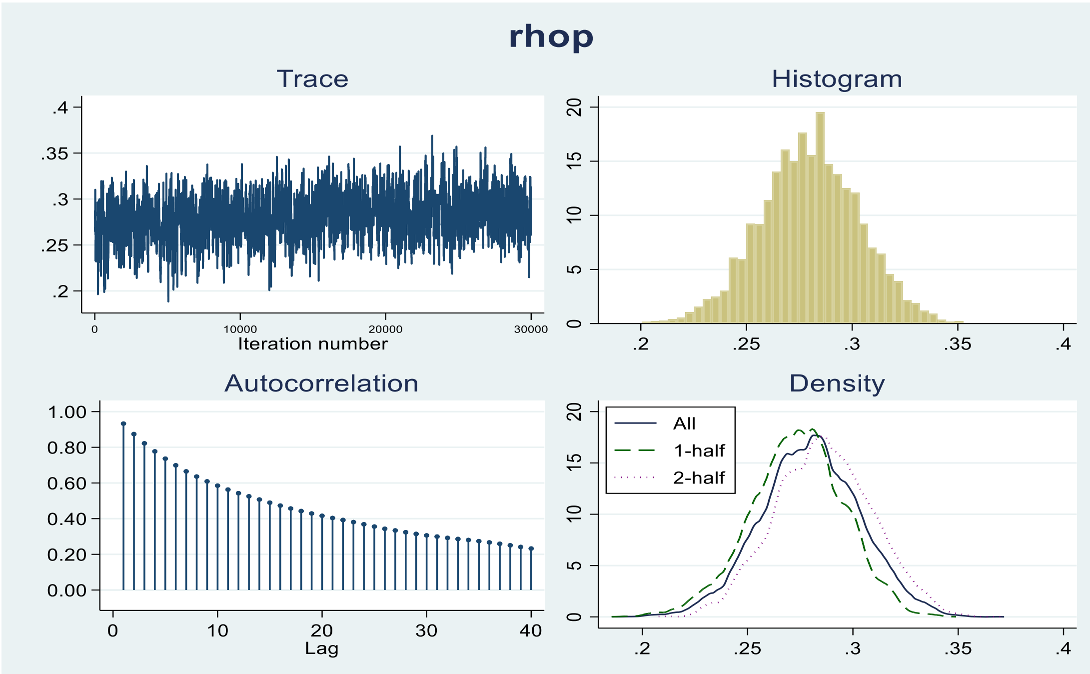
2-half


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



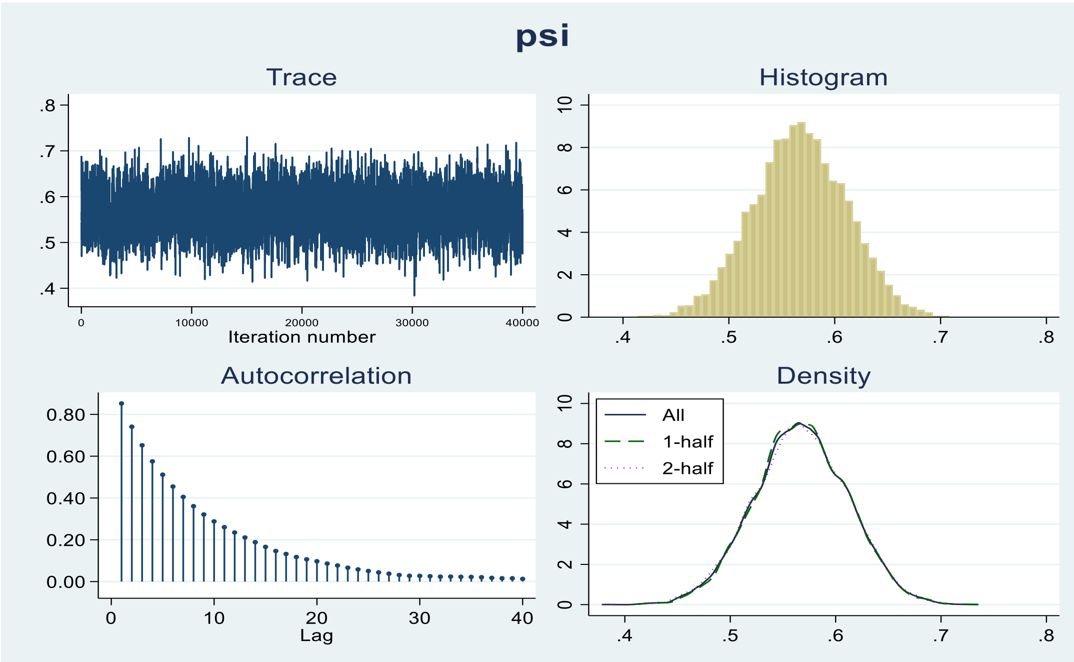

```
Efficiency summaries    MCMC sample size =     30,000
                        Efficiency:  min =    .002023
                                     avg =     .01176
                                     max =     .02532
```

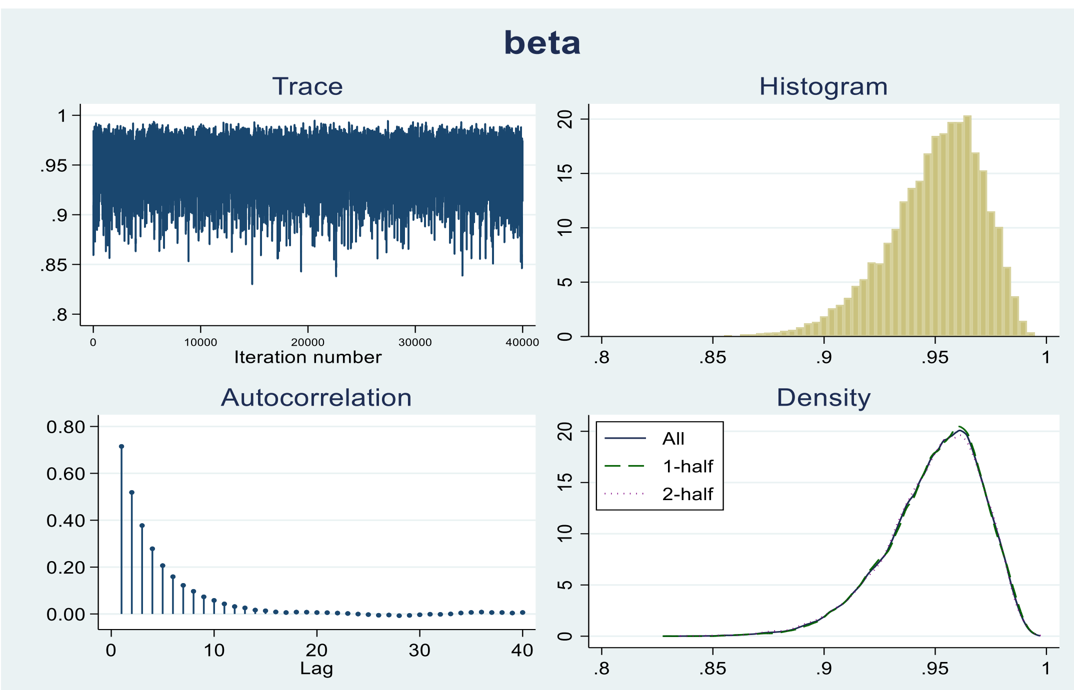
	ESS	Corr. time	Efficiency
rhor	604.46	49.63	0.0201
psi	60.69	494.31	0.0020
rhop	270.50	110.91	0.0090
beta	595.03	50.42	0.0198
kappa	601.15	49.90	0.0200
phi	223.48	134.24	0.0074
rhou	457.26	65.61	0.0152
rhog	759.47	39.50	0.0253
rhoe	295.87	101.40	0.0099
sd(e.u)	64.98	461.69	0.0022
sd(e.g)	226.95	132.19	0.0076
sd(e.es)	73.40	408.71	0.0024

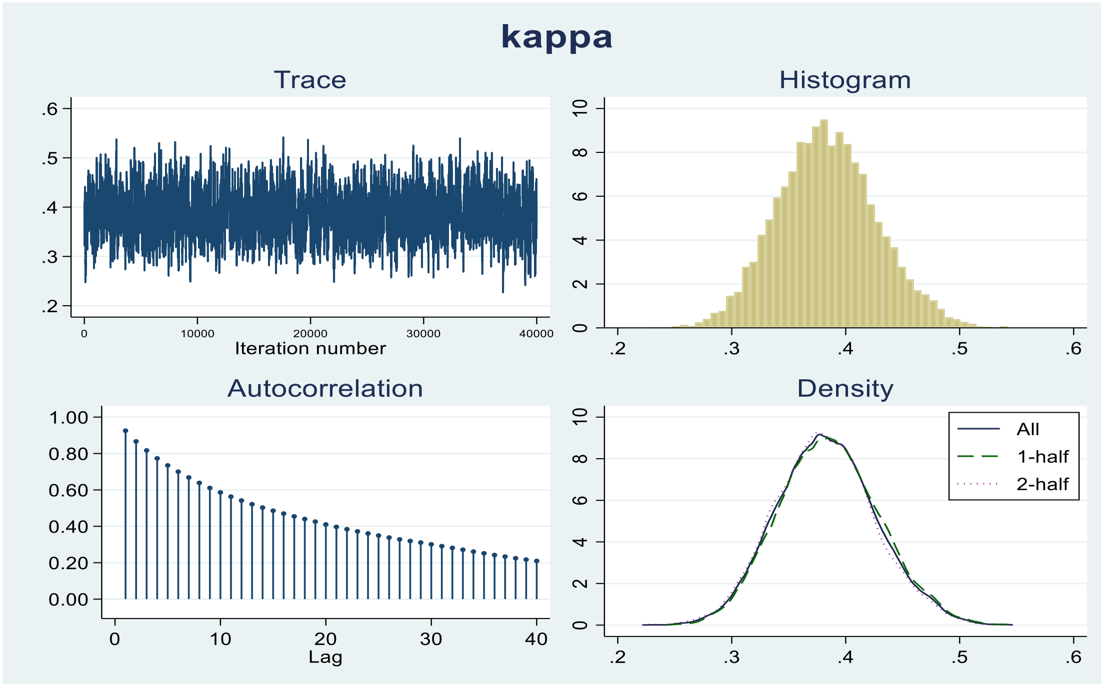
With block option and increase in mcmc size and burn in period

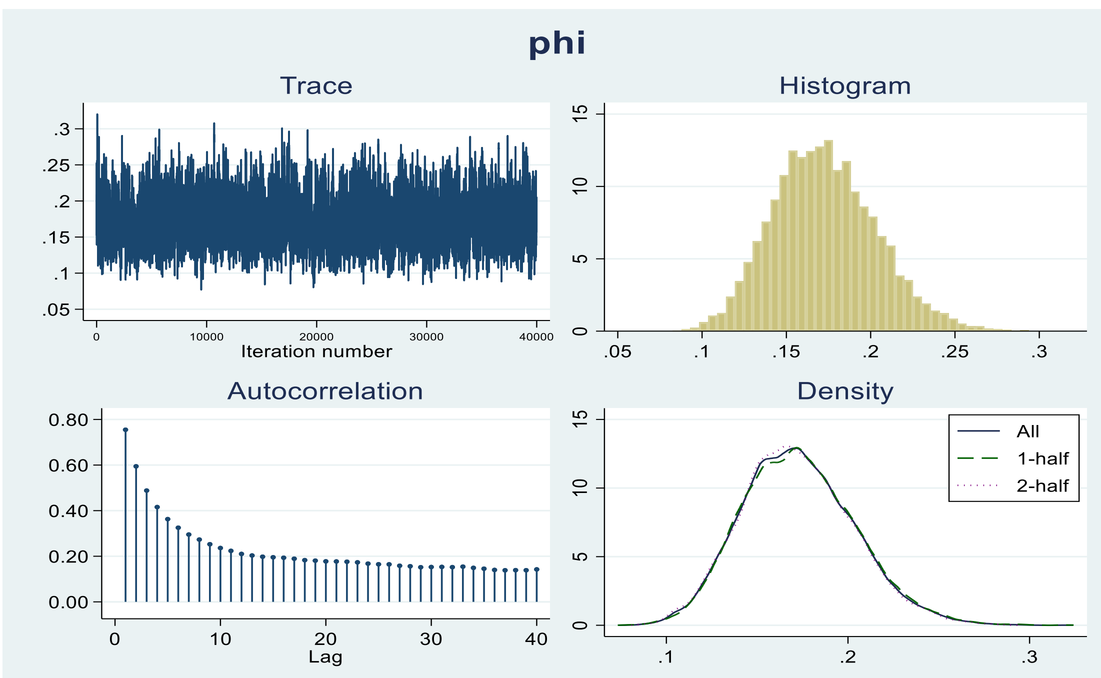
```
Bayesian linear DSGE model                          MCMC iterations  =     46,000
Random-walk Metropolis–Hastings sampling            Burn-in          =      6,000
                                                    MCMC sample size =     40,000
Sample: 1995q3 thru 2021q1                          Number of obs    =        103
                                                    Acceptance rate  =      .4065
                                                    Efficiency:  min =     .00627
                                                                 avg =     .03099
Log marginal-likelihood =  -1121.236                             max =      .1545
```

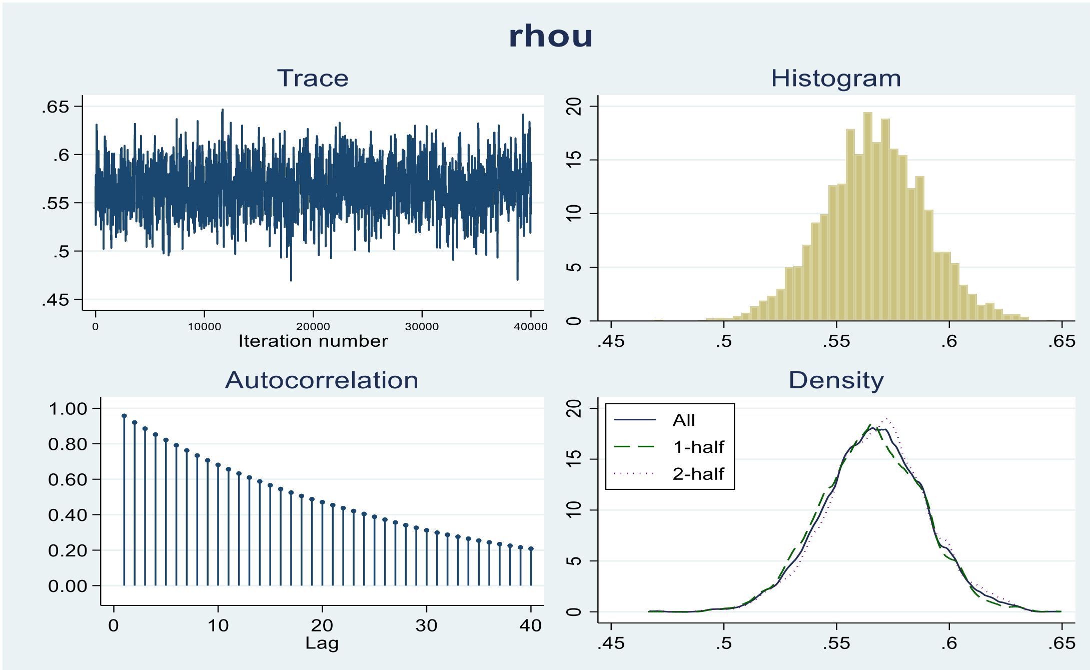
	Mean	Std. dev.	MCSE	Median	Equal-tailed [95% cred. interval]	
rhor	.8718131	.0235711	.001421	.8744827	.818486	.9109684
psi	.566939	.0445247	.000913	.566991	.4794043	.6526584
rhop	.1662964	.0268706	.001019	.1653081	.1168994	.2223709
beta	.9496932	.0217321	.000276	.9527508	.8993982	.9830786
kappa	.3835718	.0436521	.001497	.3824676	.3014102	.4733028
phi	.172653	.0308579	.000981	.170981	.1173209	.2379646
rhou	.5666094	.0227087	.000809	.5668315	.5209053	.6112033
rhog	.6293935	.0490842	.001479	.6292796	.532337	.7253149
rhoe	.6364779	.0512791	.002267	.6365571	.5328211	.7347017
sd(e.u)	5.085538	.9544747	.06027	4.963279	3.576329	7.321189
sd(e.g)	7.681903	1.76804	.100137	7.476663	4.710861	11.78136
sd(e.es)	16.17948	1.285484	.055212	16.11262	13.85917	18.92594

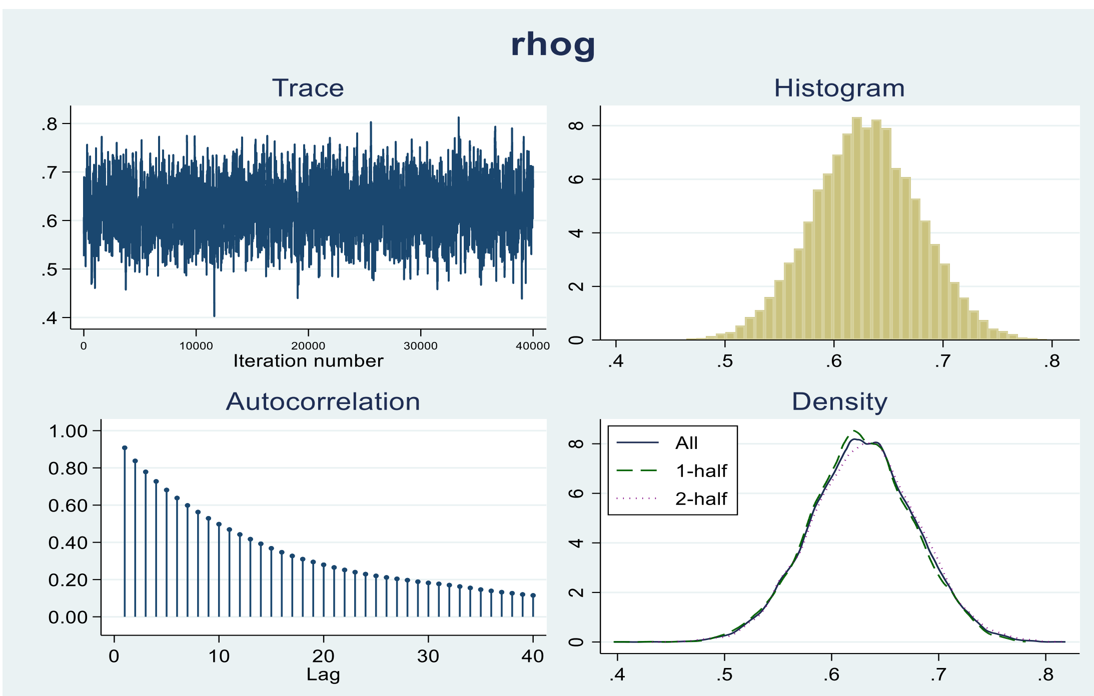

psi
Trace
Iteration number
Histogram
Autocorrelation
Lag
Density
All
1-half
2-half

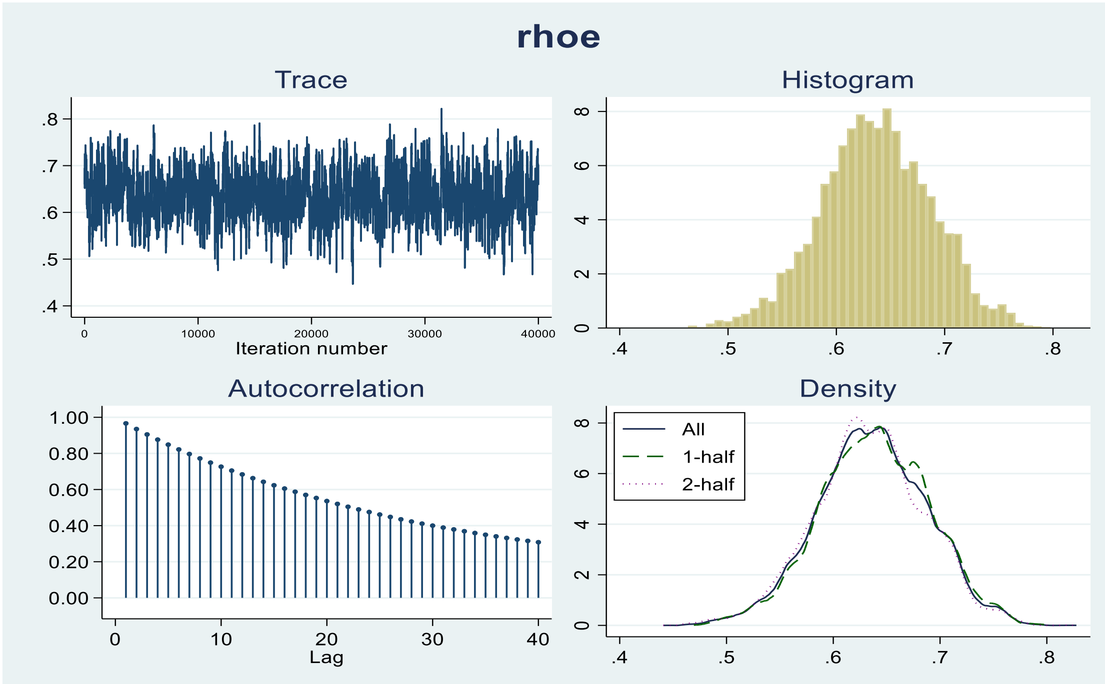

beta
Trace
Iteration number
Histogram
Autocorrelation
Lag
Density
All
1-half
2-half

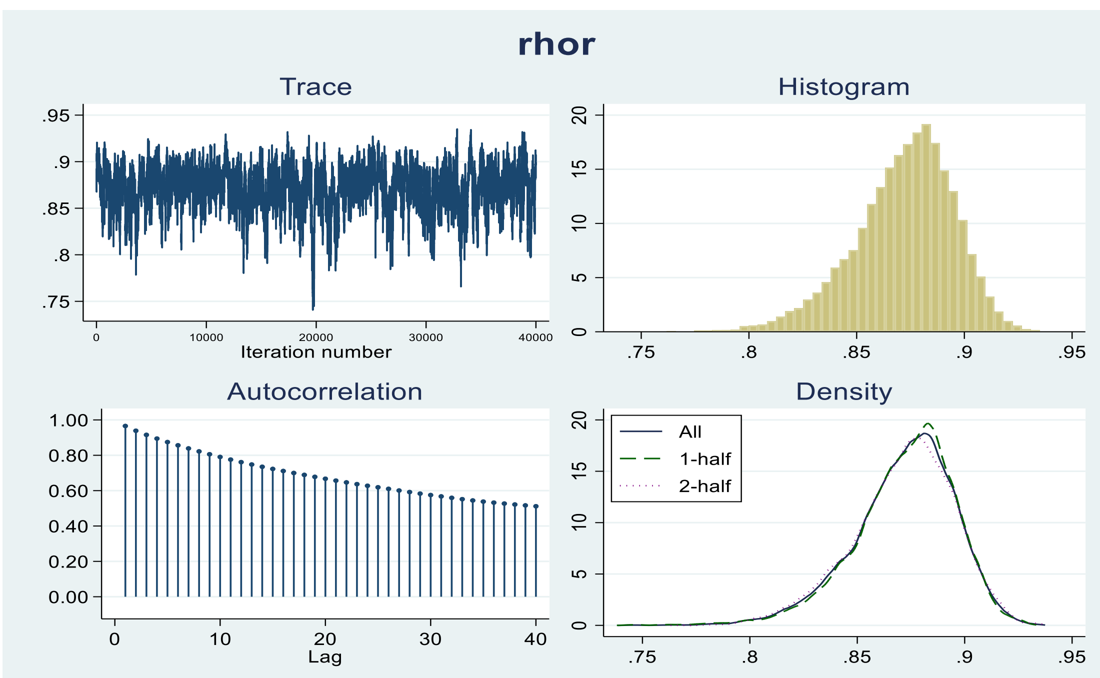

kappa
Trace
Histogram
Iteration number
Autocorrelation
Density
Lag
All
1-half
2-half

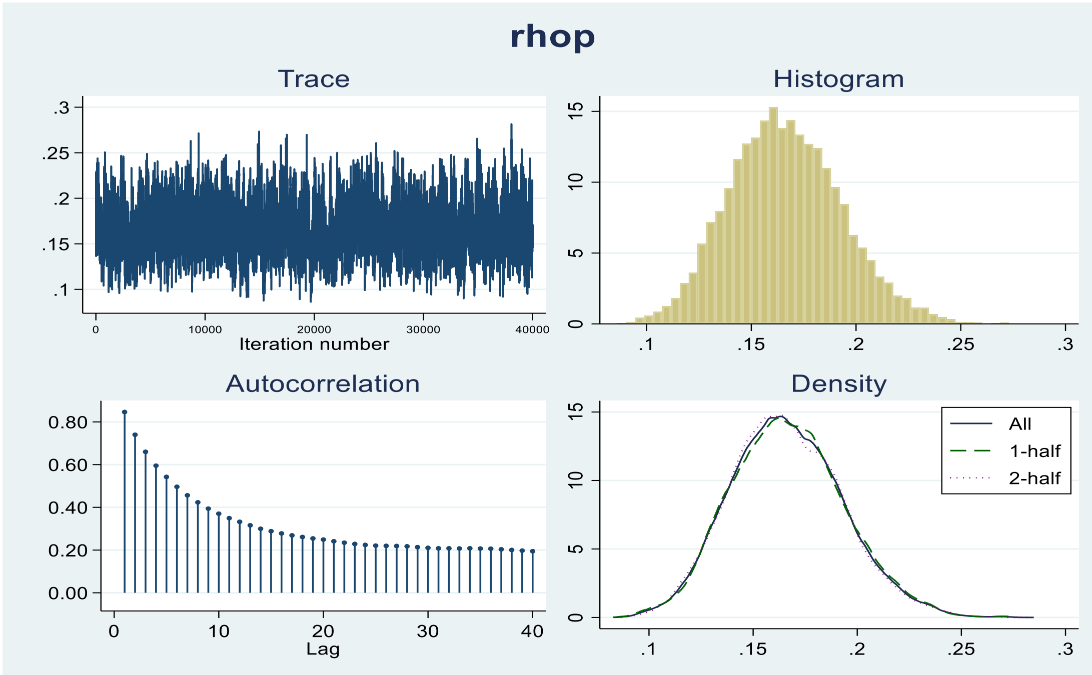

phi
Trace
Histogram
Iteration number
Autocorrelation
Density
Lag
All
1-half
2-half


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
Iteration number
Histogram
Autocorrelation
Lag
Density
All
1-half
2-half

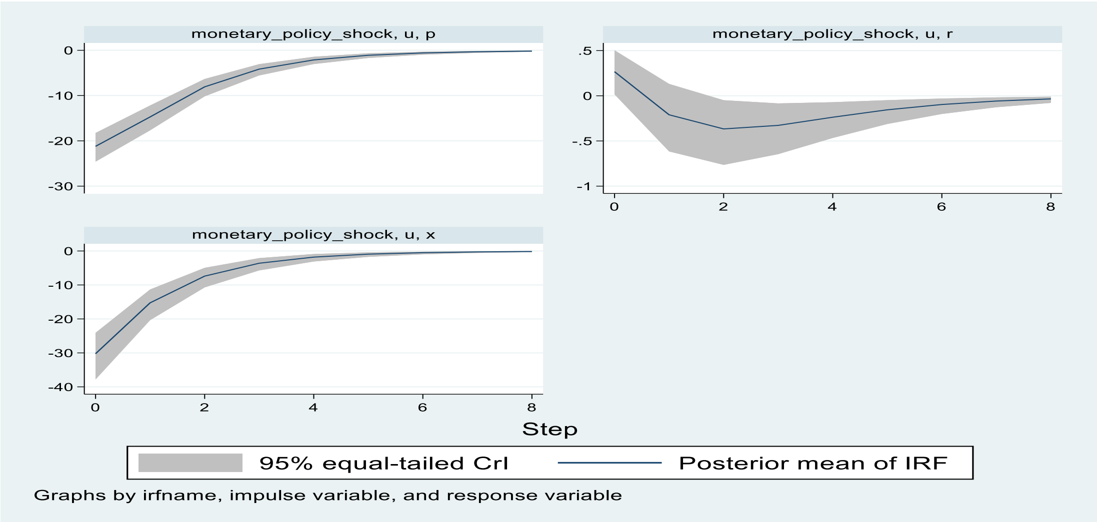

rhor
Trace
Iteration number
Histogram
Autocorrelation
Lag
Density
All
1-half
2-half




```
Efficiency summaries    MCMC sample size =     40,000
                        Efficiency:  min =     .00627
                                     avg =     .03099
                                     max =      .1545
```

	ESS	Corr. time	Efficiency
rhor	274.96	145.48	0.0069
psi	2379.99	16.81	0.0595
rhop	695.19	57.54	0.0174
beta	6178.60	6.47	0.1545
kappa	850.26	47.04	0.0213
phi	989.14	40.44	0.0247
rhou	788.51	50.73	0.0197
rhog	1100.96	36.33	0.0275
rhoe	511.49	78.20	0.0128
sd(e.u)	250.80	159.49	0.0063
sd(e.g)	311.74	128.31	0.0078
sd(e.es)	542.09	73.79	0.0136

Irf plots

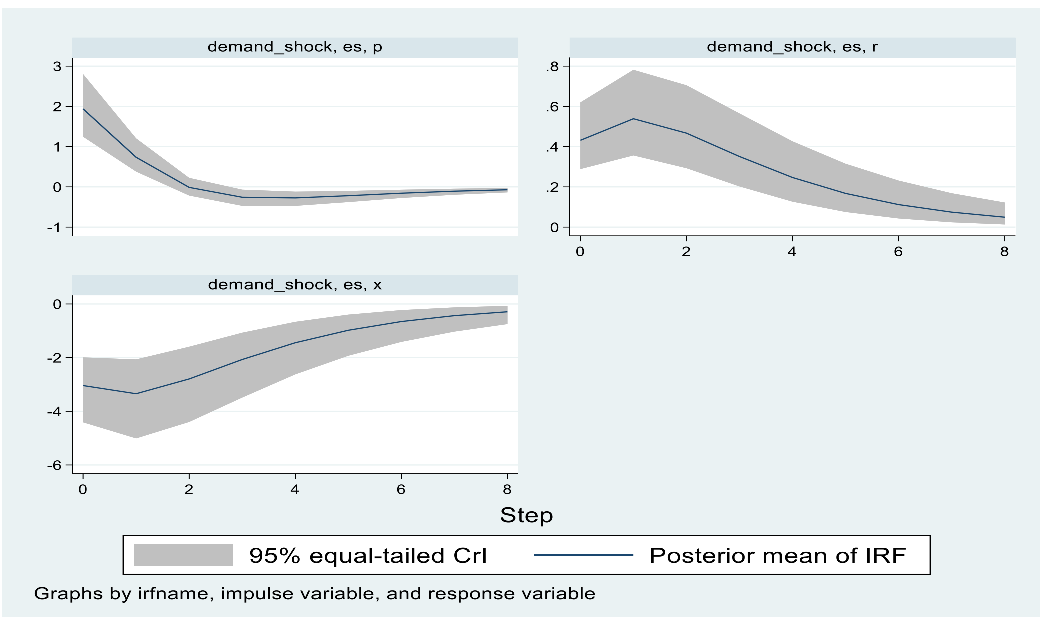


Irf table for impulse of u

Step	(1) irf	(1) Lower	(1) Upper
0	-30.2502	-37.814	-24.0871
1	-15.262	-20.3611	-11.3262
2	-7.39675	-10.7132	-4.95211
3	-3.59979	-5.70753	-2.0978
4	-1.79569	-3.09387	-.895009
5	-.924777	-1.72428	-.399941
6	-.49115	-.977504	-.18893
7	-.267583	-.565485	-.094563
8	-.148599	-.330894	-.04872

Step	(2) irf	(2) Lower	(2) Upper
0	-21.2143	-24.5986	-18.2687
1	-14.7211	-17.6817	-12.1932
2	-8.07561	-10.1757	-6.33878
3	-4.1636	-5.55871	-3.06669
4	-2.13164	-3.04104	-1.43634
5	-1.10797	-1.70087	-.670785
6	-.588969	-.972194	-.319249
7	-.320076	-.566065	-.156099
8	-.177164	-.333609	-.078418

Step	(3) irf	(3) Lower	(3) Upper
0	.267062	.015418	.503812
1	-.210317	-.616039	.131321
2	-.366641	-.764379	-.048879
3	-.327541	-.645959	-.084374
4	-.237053	-.466908	-.071001
5	-.155343	-.312155	-.048546
6	-.096509	-.201056	-.03006
7	-.05818	-.126615	-.017521
8	-.034476	-.07872	-.009821

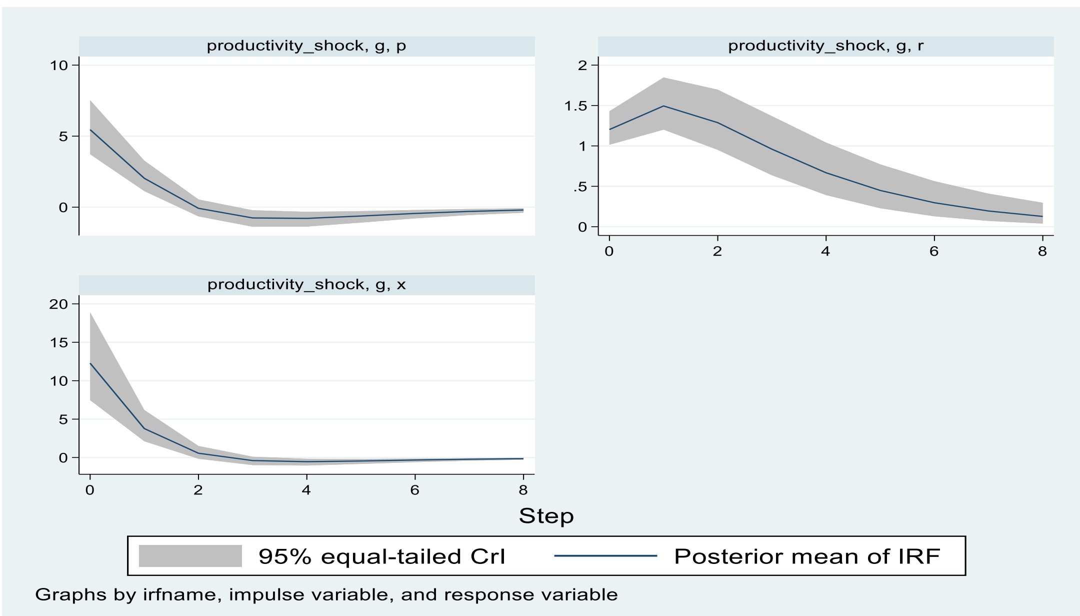


Irf table for the impulse of es

Step	(4) irf	(4) Lower	(4) Upper
0	-3.03979	-4.40985	-1.99079
1	-3.34456	-5.00908	-2.06502
2	-2.79348	-4.39623	-1.59298
3	-2.06853	-3.48706	-1.07004
4	-1.44385	-2.62296	-.665244
5	-.978536	-1.92855	-.395907
6	-.654082	-1.41138	-.227274
7	-.434939	-1.02811	-.127285
8	-.289092	-.74827	-.070612

Step	(5) irf	(5) Lower	(5) Upper
0	1.93828	1.24696	2.80387
1	.73619	.379735	1.20488
2	-.012405	-.215878	.223624
3	-.257911	-.471045	-.06851
4	-.273673	-.471652	-.118348
5	-.218747	-.377113	-.101026
6	-.156935	-.275628	-.070658
7	-.107107	-.195486	-.045089
8	-.071381	-.136387	-.027343

Step	(6) irf	(6) Lower	(6) Upper
0	.43142	.288457	.619739
1	.538675	.356375	.78165
2	.467039	.292876	.704962
3	.351007	.202217	.564806
4	.246564	.126443	.426137
5	.167518	.075213	.314813
6	.112036	.043015	.231164
7	.074466	.023961	.168308
8	.049447	.013243	.122124



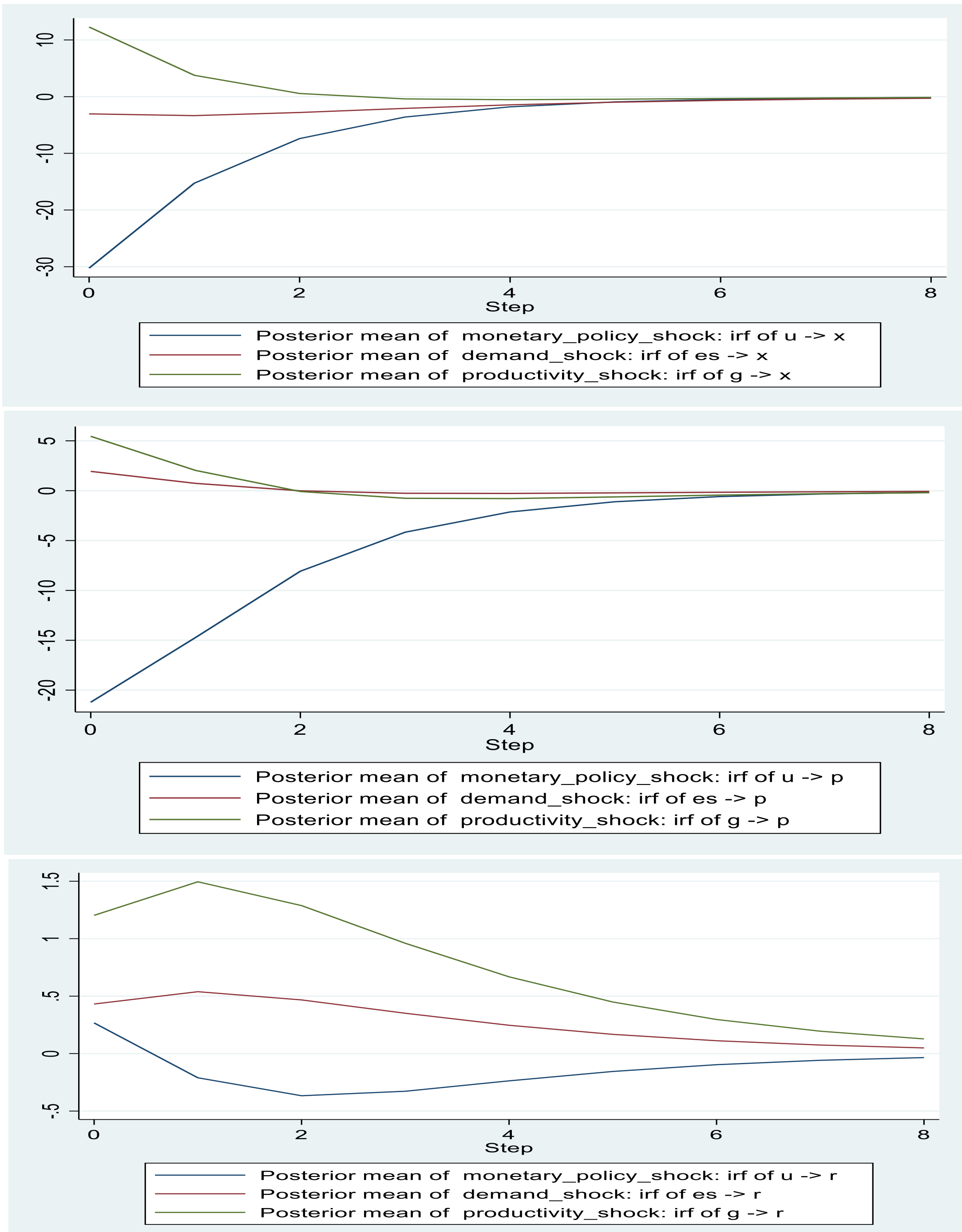
Irf table for the impulse of g

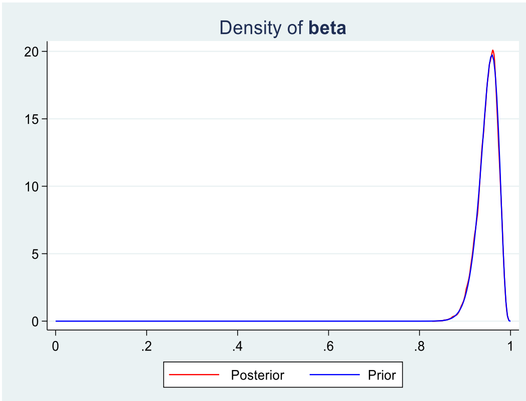
Step	(7) irf	(7) Lower	(7) Upper
0	12.2832	7.46887	18.8905
1	3.76987	2.11643	6.18258
2	.558525	-.162099	1.50191
3	-.394843	-.983926	.102702
4	-.538258	-1.0401	-.167482
5	-.447777	-.828662	-.181874
6	-.32255	-.596555	-.140832
7	-.218645	-.414228	-.095064
8	-.144105	-.285016	-.059271

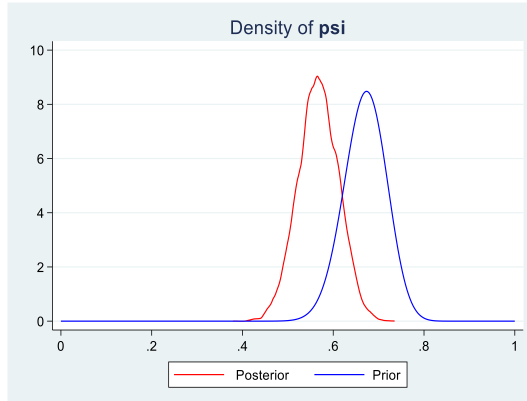
Step	(8) irf	(8) Lower	(8) Upper
0	5.45677	3.72313	7.52872
1	2.03435	1.12953	3.27541
2	-.080218	-.64932	.542722
3	-.759652	-1.37785	-.219871
4	-.789197	-1.36601	-.328967
5	-.623274	-1.08578	-.278724
6	-.442461	-.789221	-.198542
7	-.298815	-.556301	-.128974
8	-.197003	-.38819	-.078757

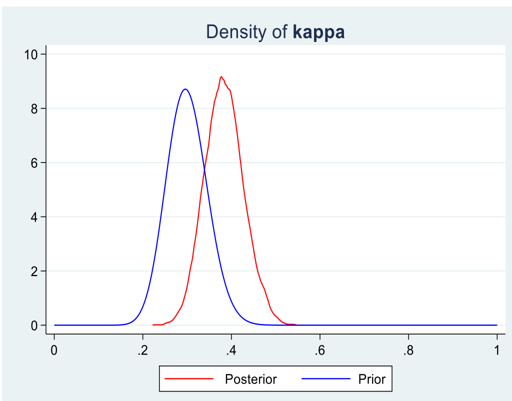
Step	(9) irf	(9) Lower	(9) Upper
0	1.20288	1.01475	1.42964
1	1.4949	1.20141	1.84718
2	1.28771	.951333	1.69567
3	.959953	.637163	1.36835
4	.667916	.391917	1.04127
5	.448961	.228661	.771716
6	.296801	.129297	.563607
7	.194863	.071488	.409101
8	.127751	.039193	.296346

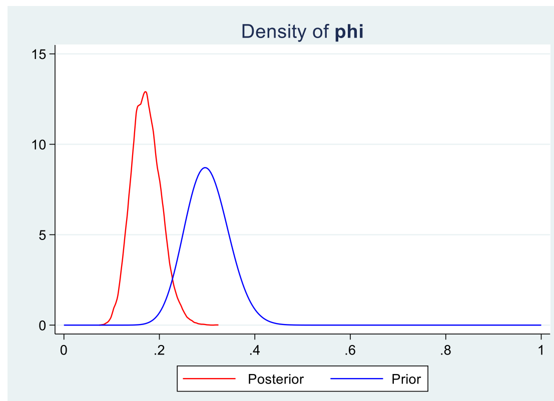
Combined plots

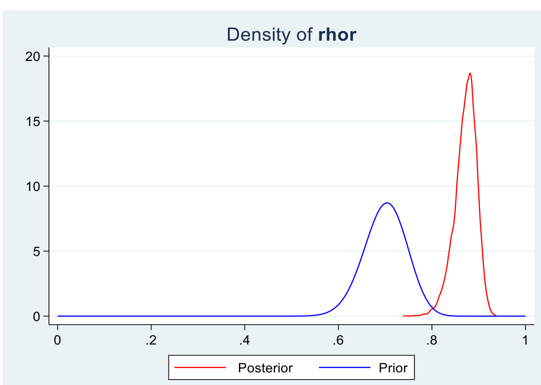

Step
Posterior mean of monetary_policy_shock: irf of u -> x
Posterior mean of demand_shock: irf of es -> x
Posterior mean of productivity_shock: irf of g -> x
Step
Posterior mean of monetary_policy_shock: irf of u -> p
Posterior mean of demand_shock: irf of es -> p
Posterior mean of productivity_shock: irf of g -> p
Step
Posterior mean of monetary_policy_shock: irf of u -> r
Posterior mean of demand_shock: irf of es -> r
Posterior mean of productivity_shock: irf of g -> r

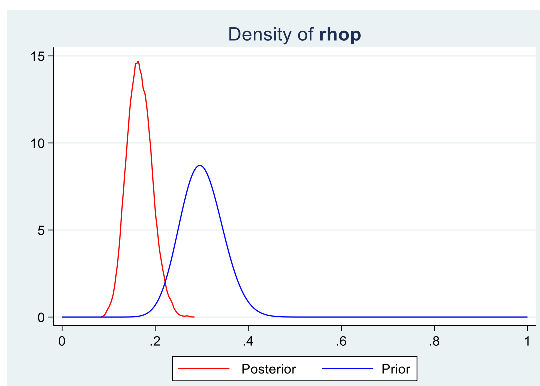












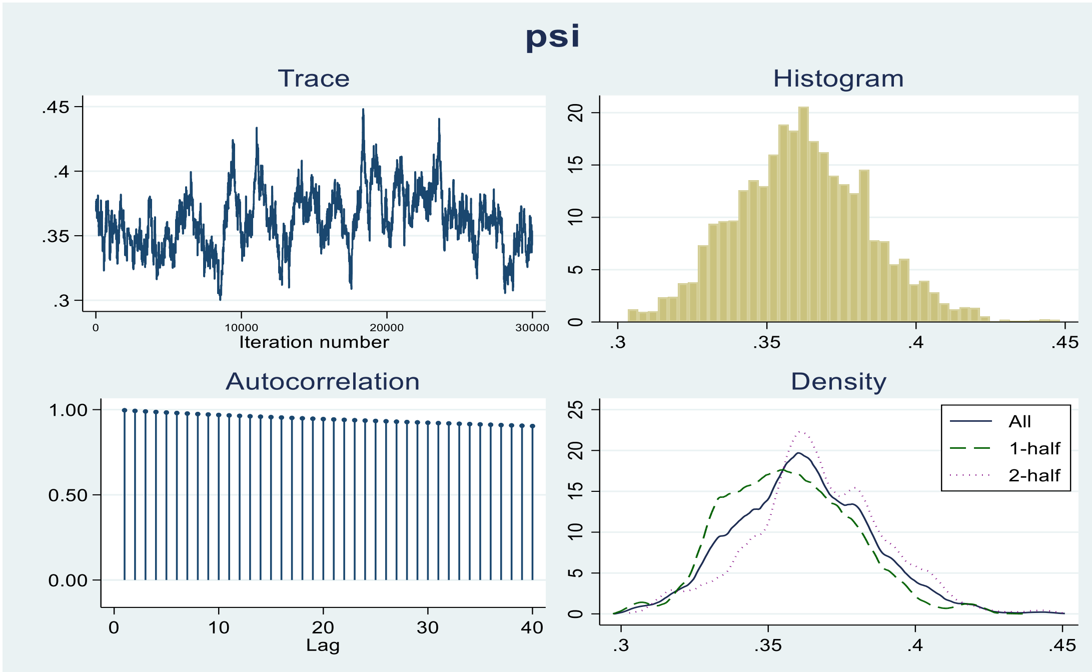
Almost all the posterior plots reveal that the data used for this study are imformative.

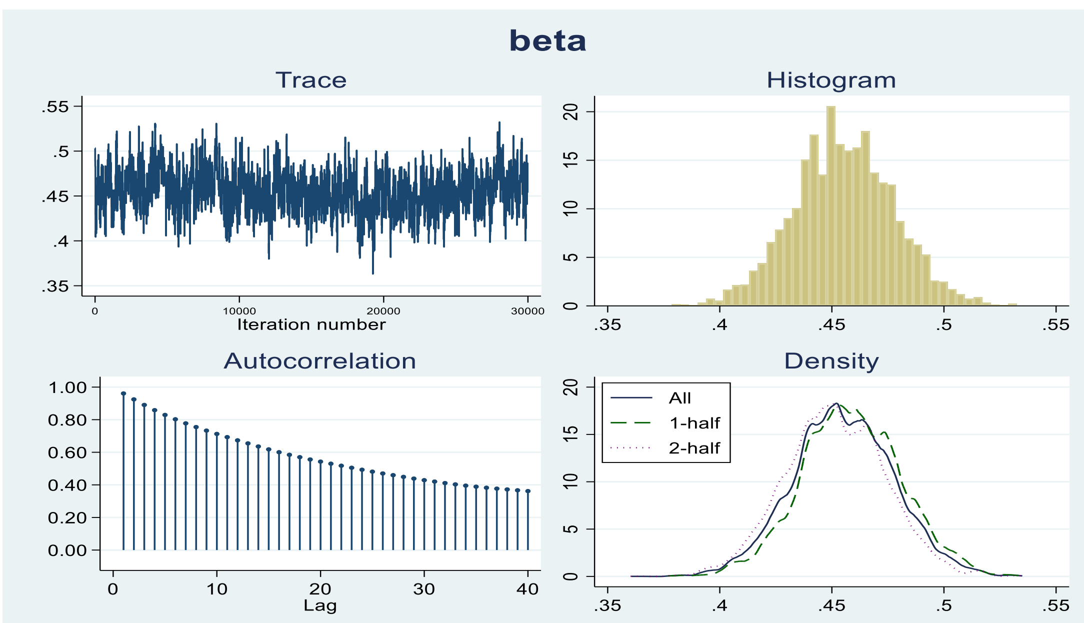
Appendix A.2: Results of pre-COVID analysis – spanning 1995Q2 – 2019Q4
Results for robustness (Pre-COVID Era)
Without block option

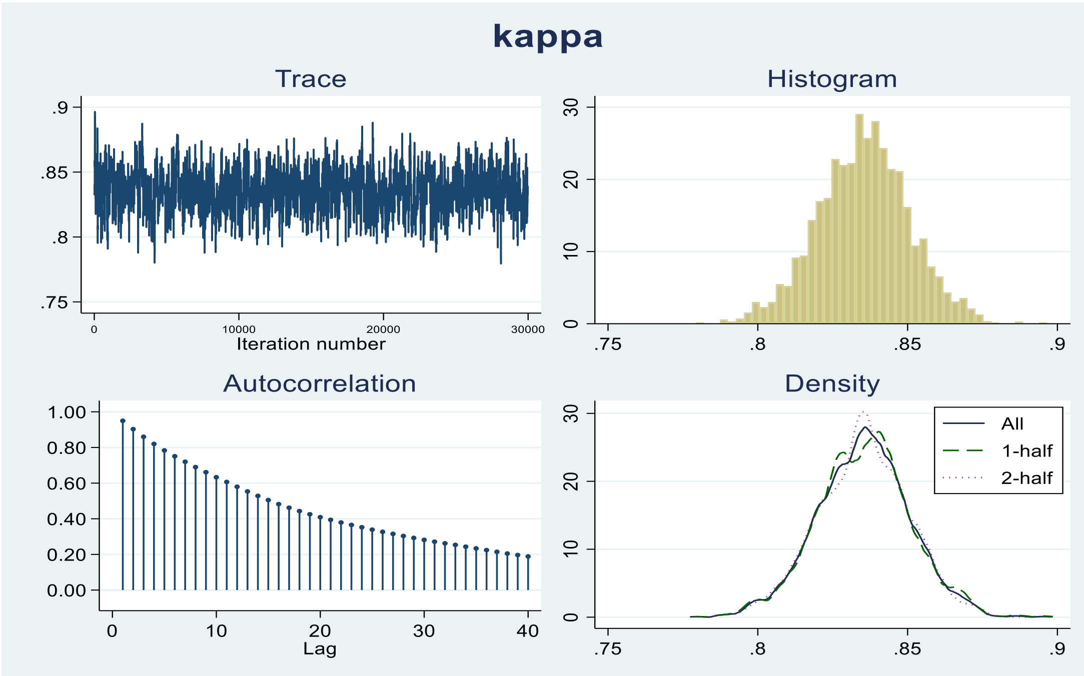
```
Bayesian linear DSGE model                          MCMC iterations  =     35,000
Random-walk Metropolis–Hastings sampling            Burn-in          =      5,000
                                                    MCMC sample size =     30,000
Sample: 1995q3 thru 2019q4                          Number of obs    =         98
                                                    Acceptance rate  =      .1469
                                                    Efficiency:  min =     .00166
                                                                 avg =     .01076
Log marginal-likelihood = -1909.1279                             max =     .04323
```

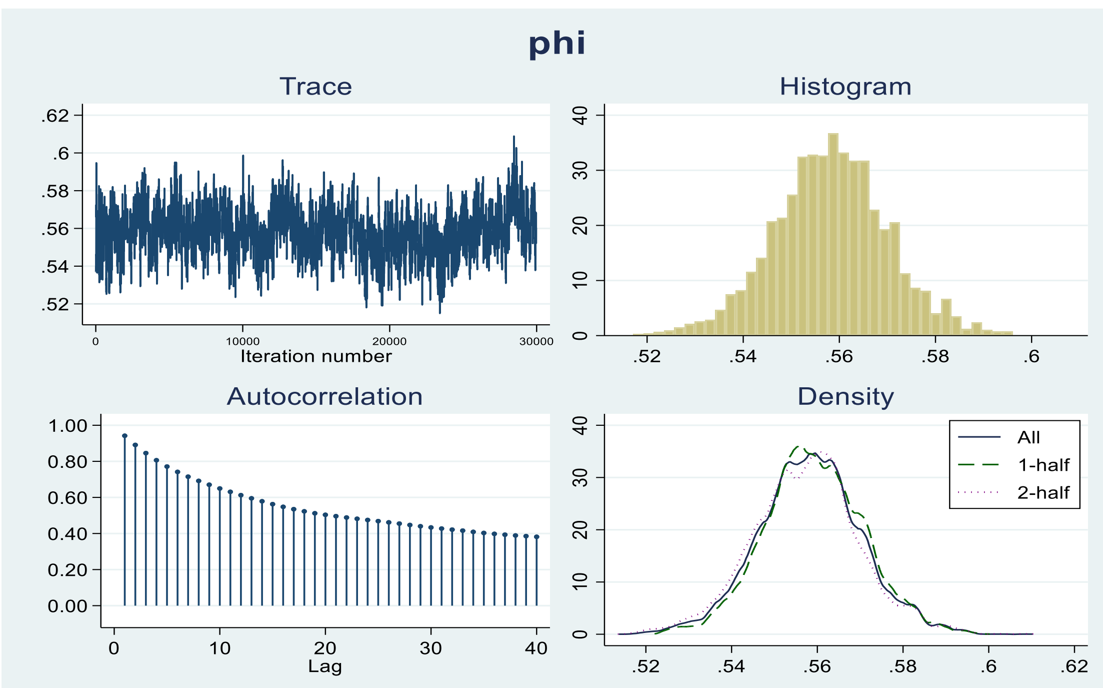
	Mean	Std. dev.	MCSE	Median	Equal-tailed [95% cred.	interval]
rhor	.9753326	.0023299	.000239	.9754036	.9704195	.9796886
psi	.3619526	.0225741	.003199	.3613037	.3190176	.407891
rhop	.0345152	.0061577	.000332	.0345588	.0229944	.046853
beta	.4550916	.0224825	.001662	.4547805	.4105687	.5003429
kappa	.835259	.0153813	.000609	.8353916	.8040901	.8659047
phi	.5582526	.0119911	.00104	.5583334	.5342615	.5825213
rhou	.2610731	.0093121	.000404	.2608735	.2432573	.2793181
rhog	.9840419	.0025687	.000192	.9841966	.9787943	.9888374
rhoe	.1334772	.010582	.000294	.1333071	.112874	.1548442
sd(e.u)	1.712321	.0293704	.003765	1.711717	1.65505	1.772966
sd(e.g)	1.017502	.0172769	.001749	1.017556	.9844728	1.051698
sd(e.es)	4.215058	.0509972	.00313	4.214519	4.116227	4.319225

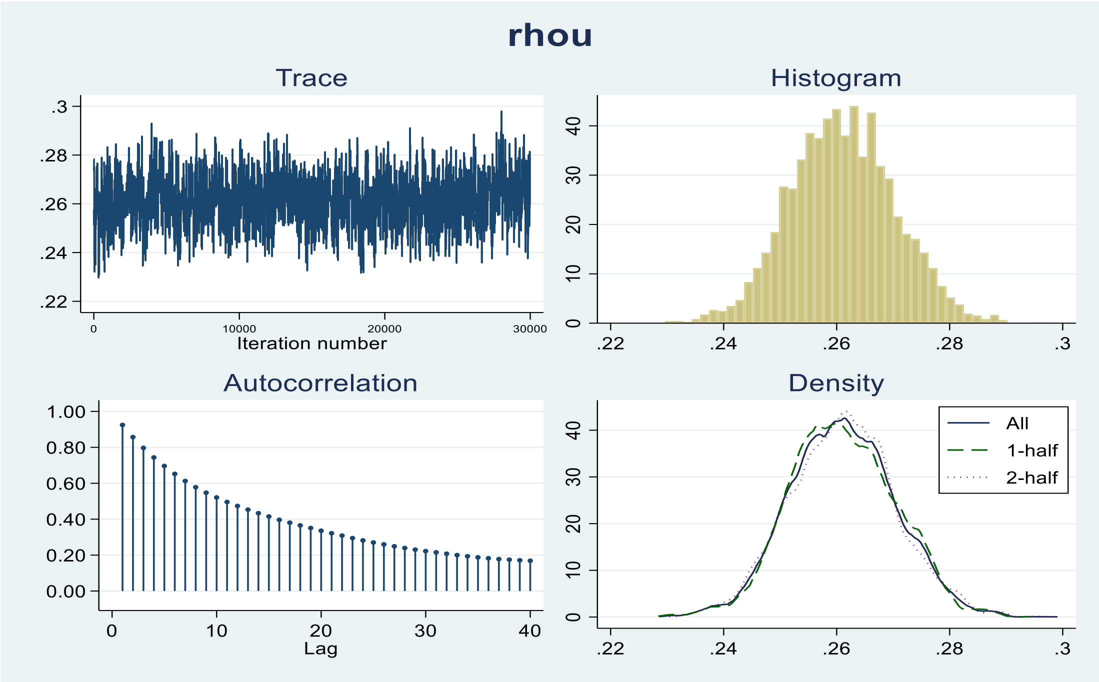
Note: There is a high autocorrelation after 500 lags.

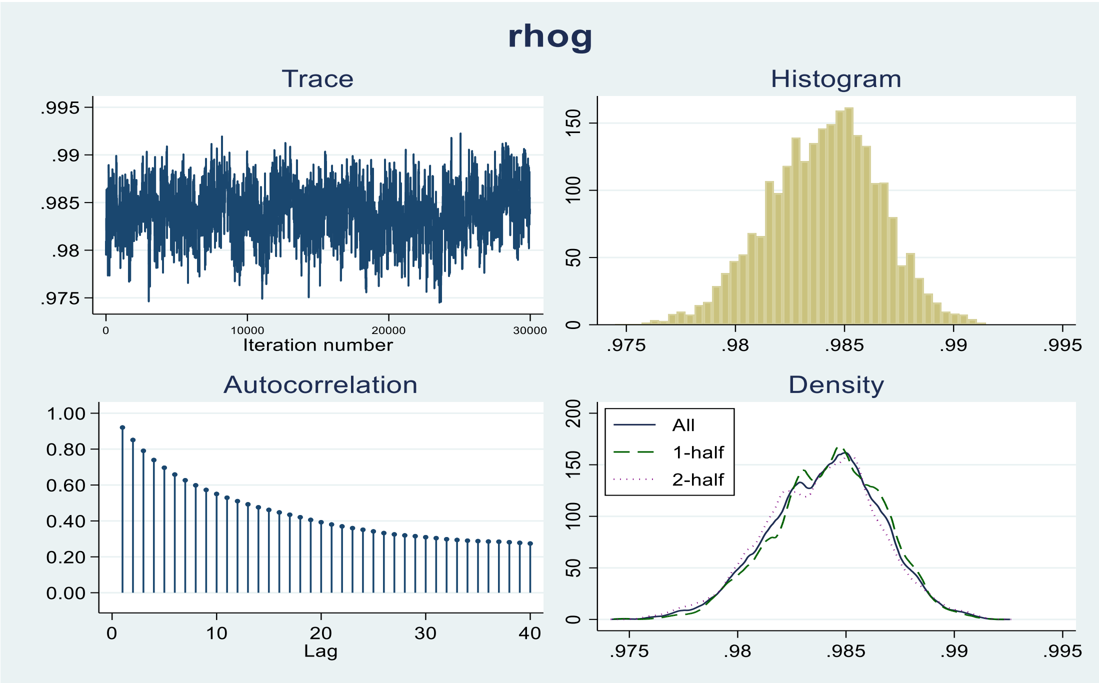

psi
Trace
Iteration number
Histogram
Autocorrelation
Lag
Density
All
1-half
2-half

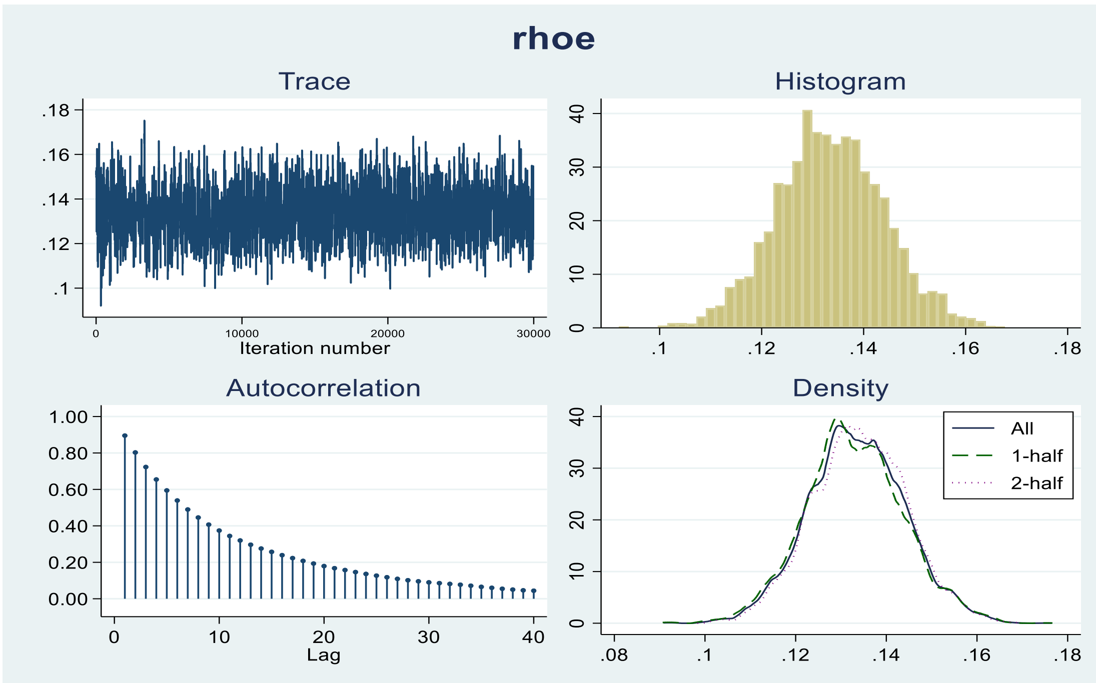

beta
Trace
Iteration number
Histogram
Autocorrelation
Lag
Density
All
1-half
2-half

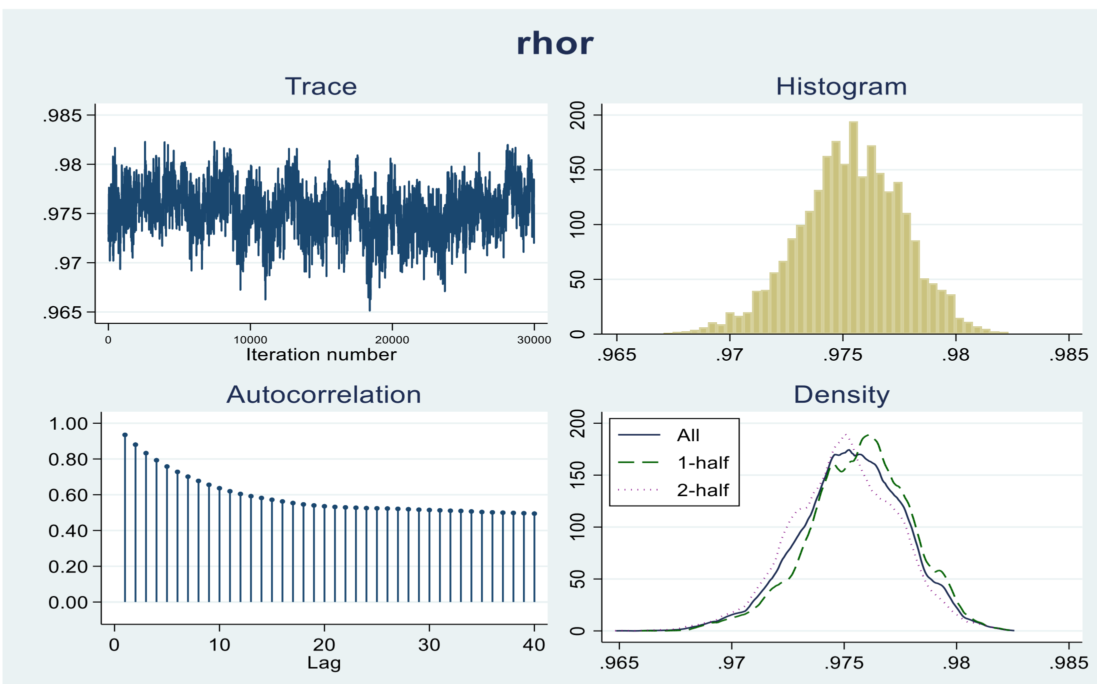

kappa
Trace
Iteration number
Histogram
Autocorrelation
Lag
Density
All
1-half
2-half

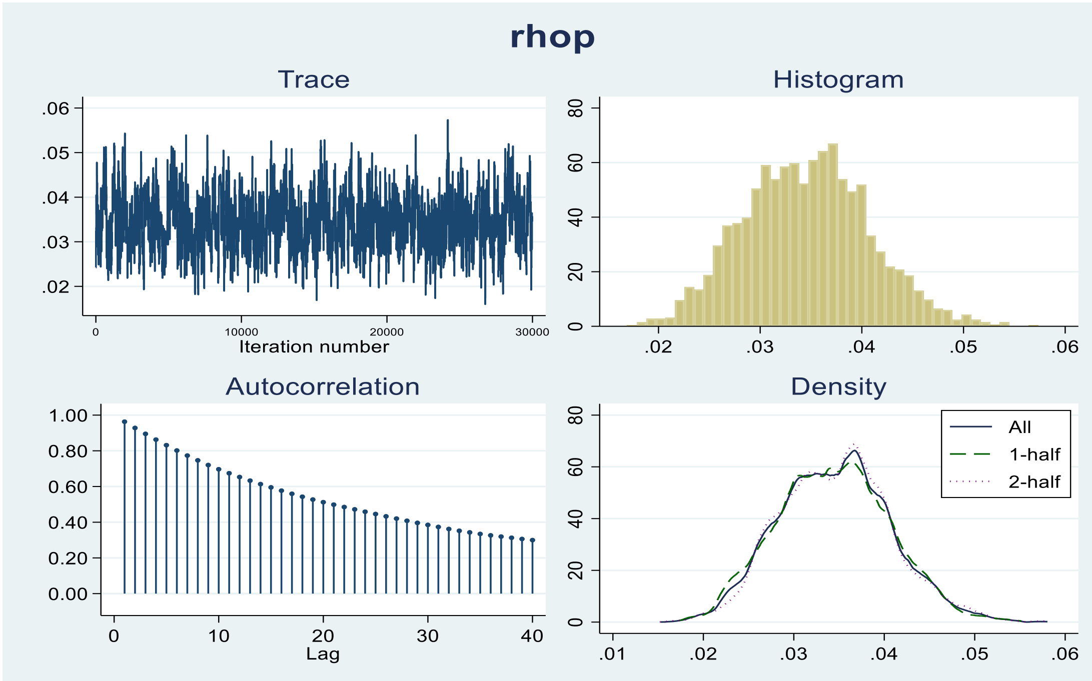

phi
Trace
Iteration number
Histogram
Autocorrelation
Lag
Density
All
1-half
2-half


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
Iteration number
Histogram
Autocorrelation
Lag
Density
All
1-half
2-half


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



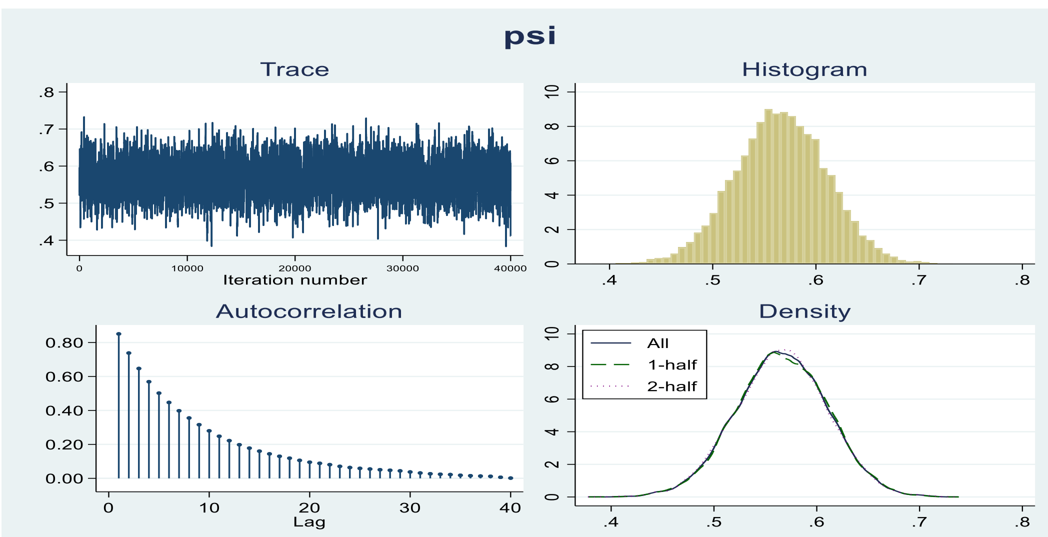

```
Efficiency summaries    MCMC sample size =     30,000
                        Efficiency:  min =     .00166
                                     avg =     .01076
                                     max =     .04323
```

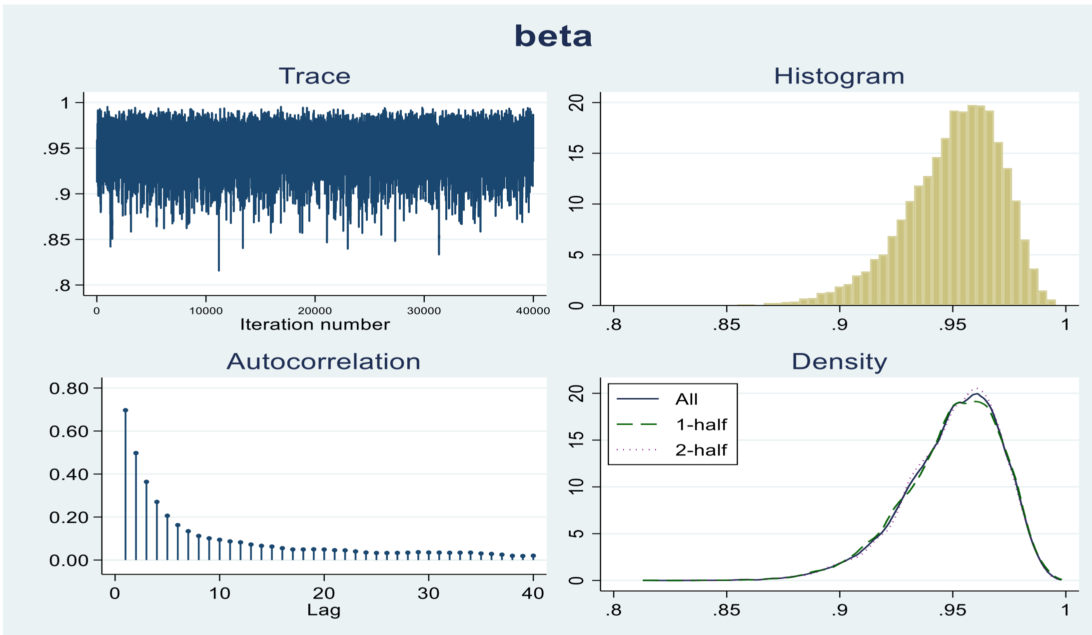
	ESS	Corr. time	Efficiency
rhor	95.32	314.74	0.0032
psi	49.80	602.36	0.0017
rhop	344.91	86.98	0.0115
beta	182.91	164.01	0.0061
kappa	637.60	47.05	0.0213
phi	132.87	225.78	0.0044
rhou	532.16	56.37	0.0177
rhog	178.63	167.95	0.0060
rhoe	1296.85	23.13	0.0432
sd(e.u)	60.87	492.86	0.0020
sd(e.g)	97.61	307.35	0.0033
sd(e.es)	265.48	113.00	0.0088

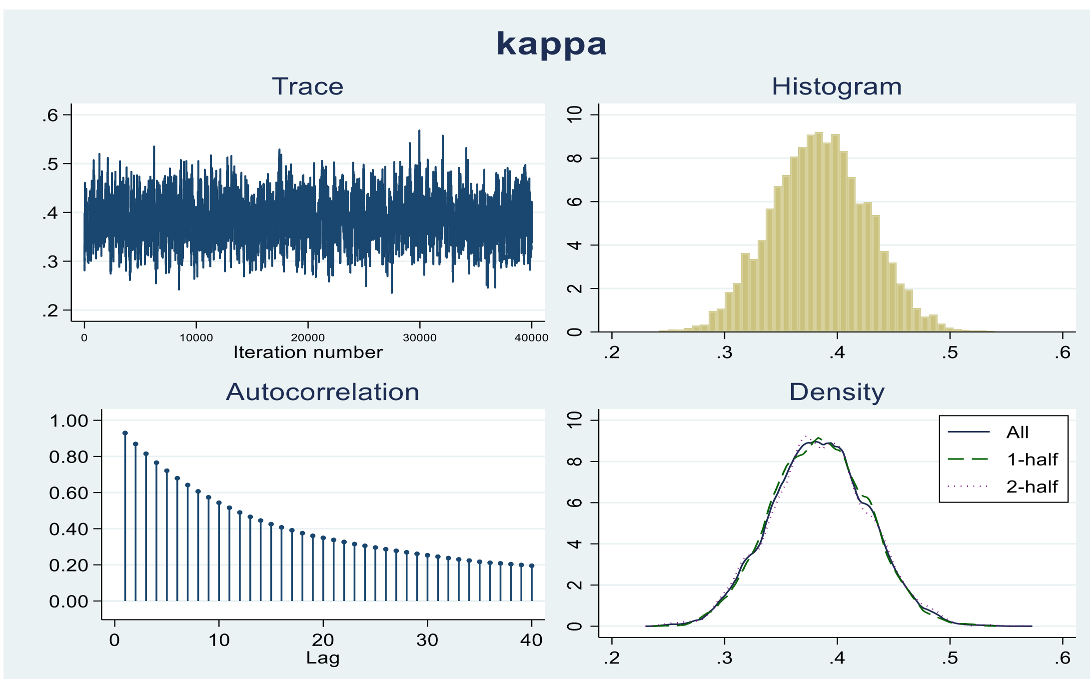
With block option and increase mcmc size and burn in period

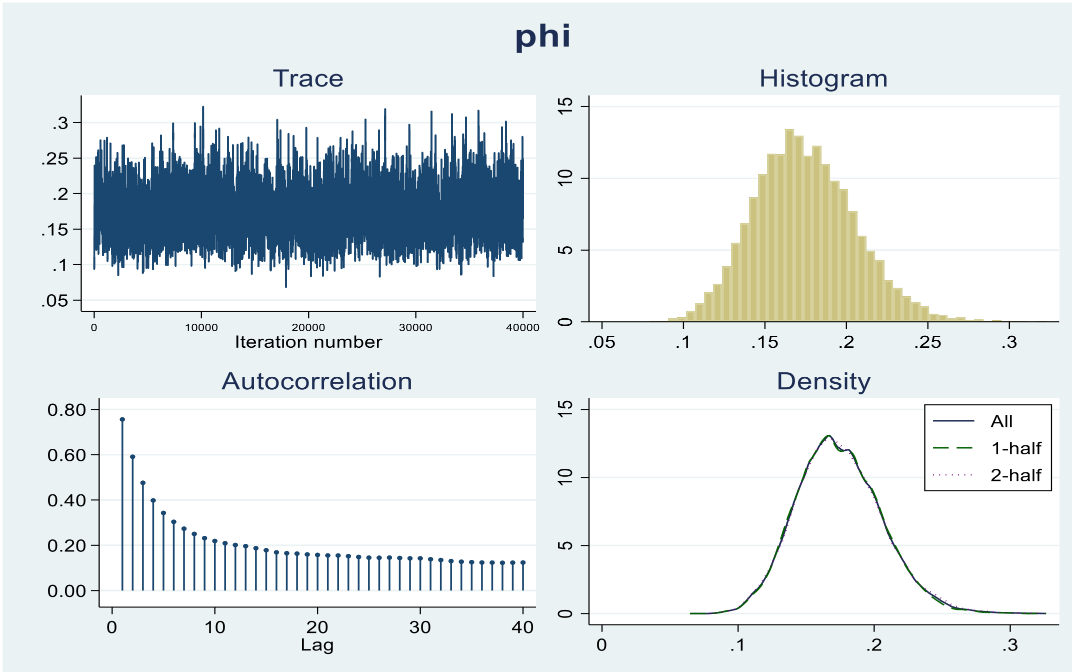
```
Bayesian linear DSGE model                        MCMC iterations  =     46,000
Random-walk Metropolis–Hastings sampling          Burn-in          =      6,000
                                                  MCMC sample size =     40,000
Sample: 1995q3 thru 2019q4                        Number of obs    =         98
                                                  Acceptance rate  =       .421
                                                  Efficiency:  min =     .00686
                                                               avg =     .02871
Log marginal-likelihood = -1073.5852                           max =      .1032
```

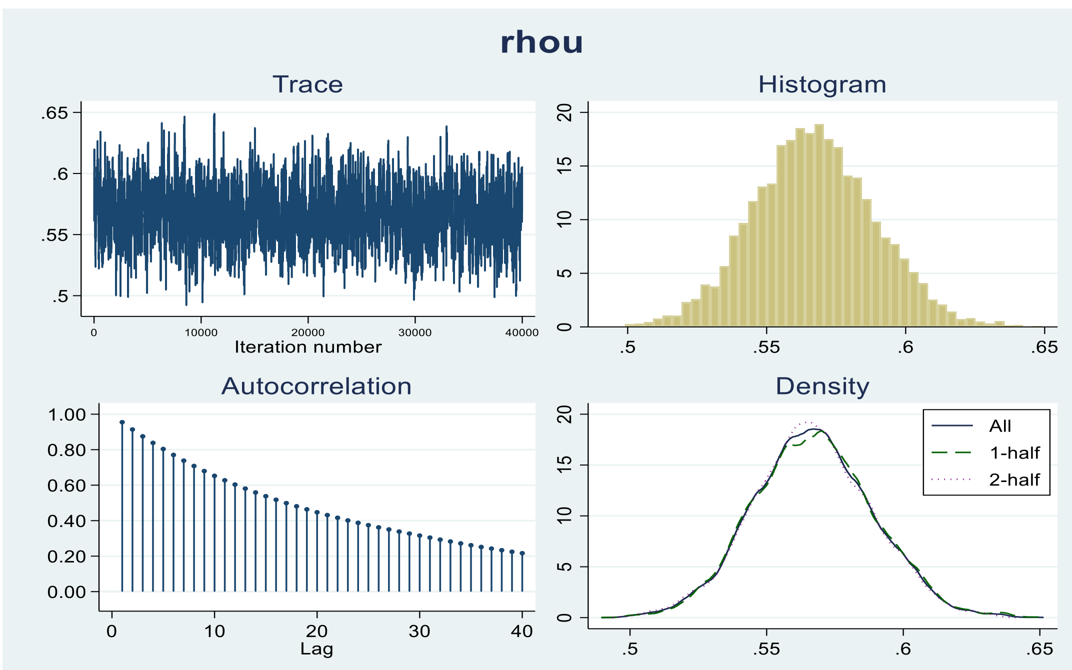
	Mean	Std. dev.	MCSE	Median	Equal-tailed [95% cred.	interval]
rhor	.8740223	.0225435	.001302	.8757501	.8253945	.9126396
psi	.5657535	.0445668	.000889	.5659725	.4774237	.6520251
rhop	.1668446	.0266463	.001072	.1658648	.1180329	.2211582
beta	.9500966	.0214677	.000334	.9529669	.9001818	.9833082
kappa	.3844037	.0429853	.001535	.384292	.3010679	.4678595
phi	.1744916	.031333	.000936	.1725063	.1174675	.2408905
rhou	.5670259	.0219645	.000757	.5666962	.5241811	.6102676
rhog	.6367762	.0504939	.001404	.6364663	.5382521	.7361658
rhoe	.6421196	.0509945	.002061	.6419117	.5449814	.7450071
sd(e.u)	5.093664	.9553258	.057671	4.988506	3.512529	7.228815
sd(e.g)	7.637546	1.766405	.091956	7.441919	4.820099	11.63941
sd(e.es)	16.58788	1.22598	.040255	16.52402	14.3947	19.13601

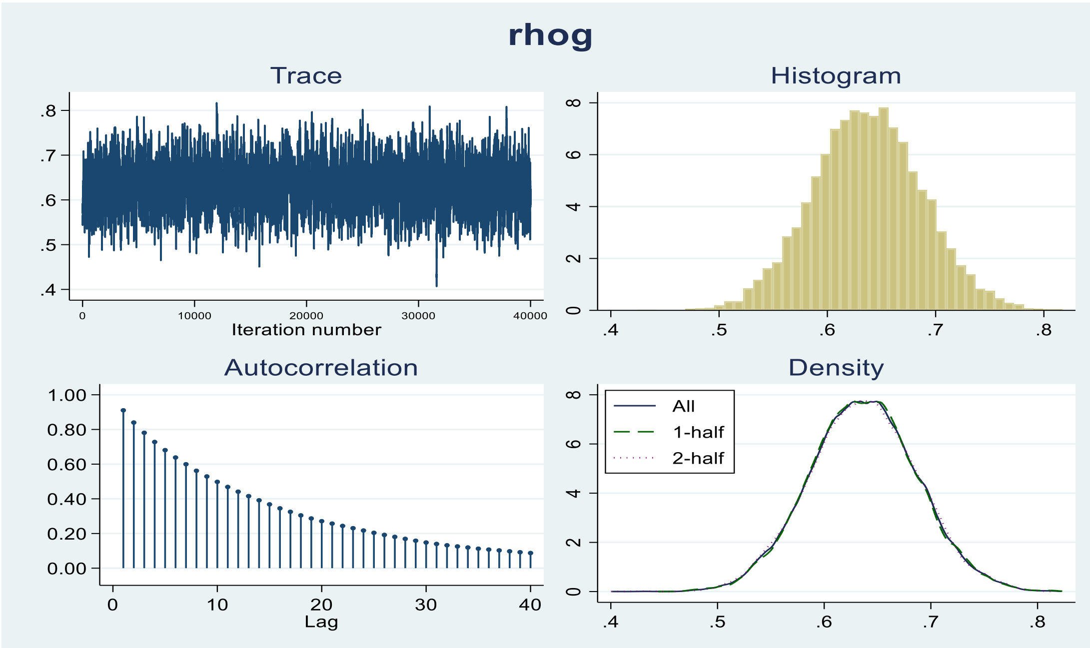


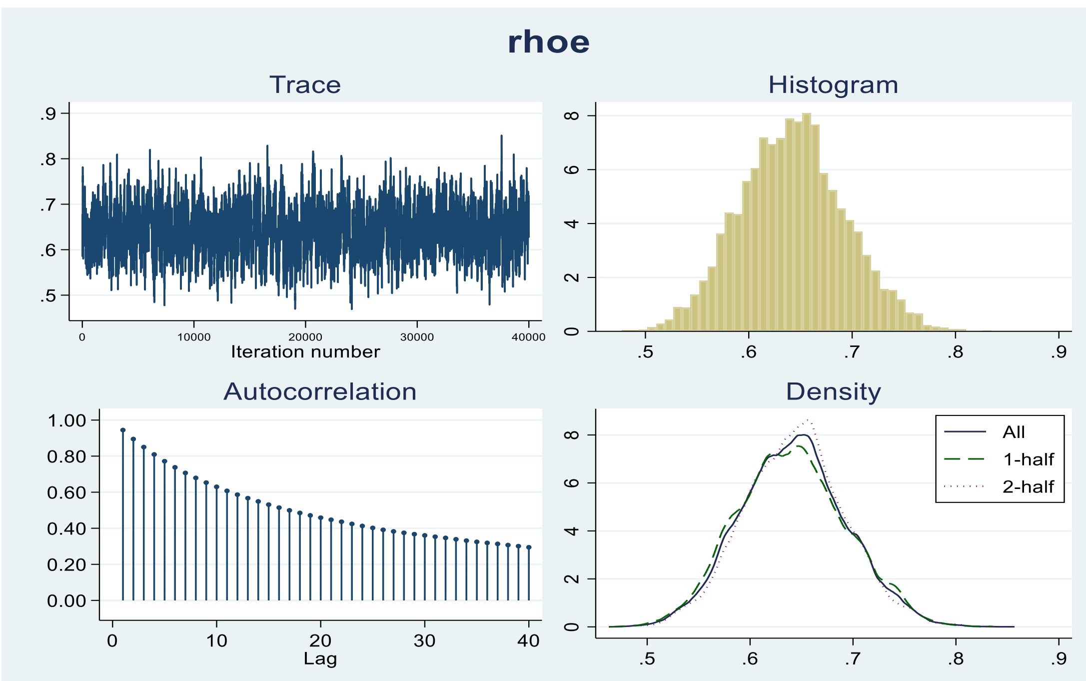

beta
Trace
Iteration number
Histogram
Autocorrelation
Lag
Density
All
1-half
2-half

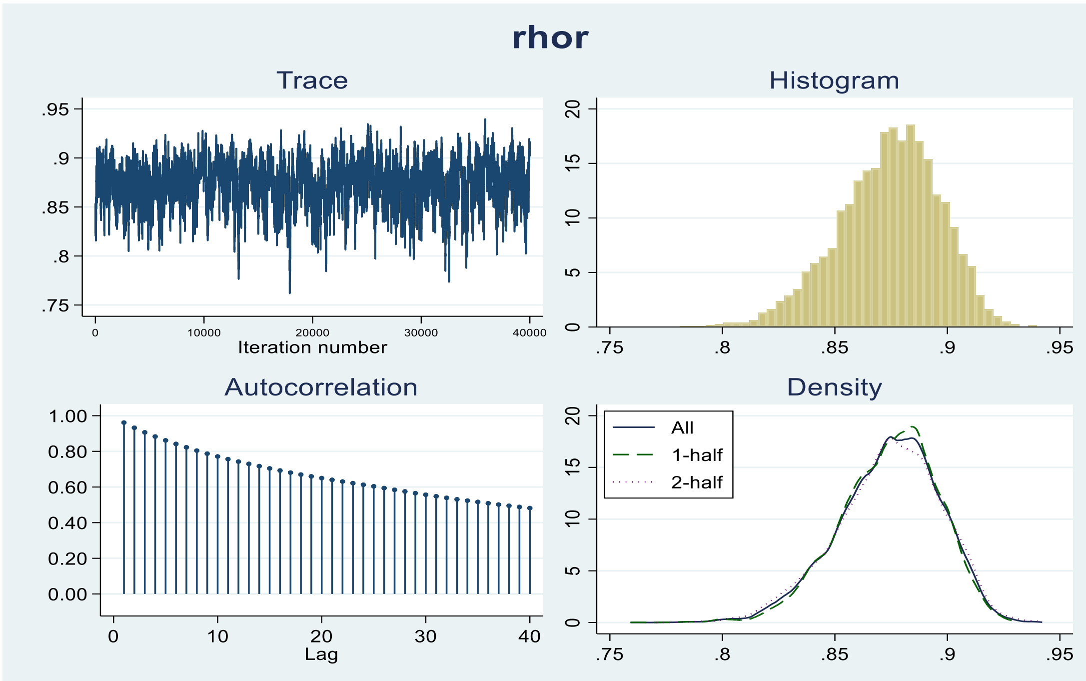

kappa
Trace
Iteration number
Histogram
Autocorrelation
Lag
Density
All
1-half
2-half

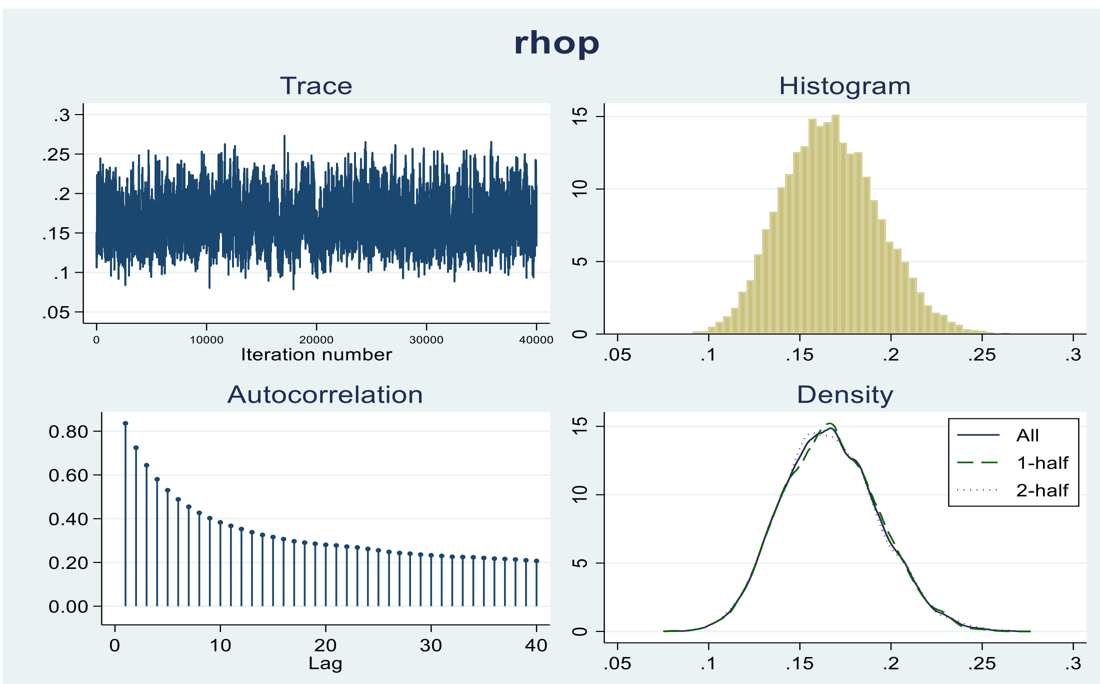

phi
Trace
Iteration number
Histogram
Autocorrelation
Lag
Density
All
1-half
2-half


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
Iteration number
Histogram
Autocorrelation
Lag
Density
All
1-half
2-half

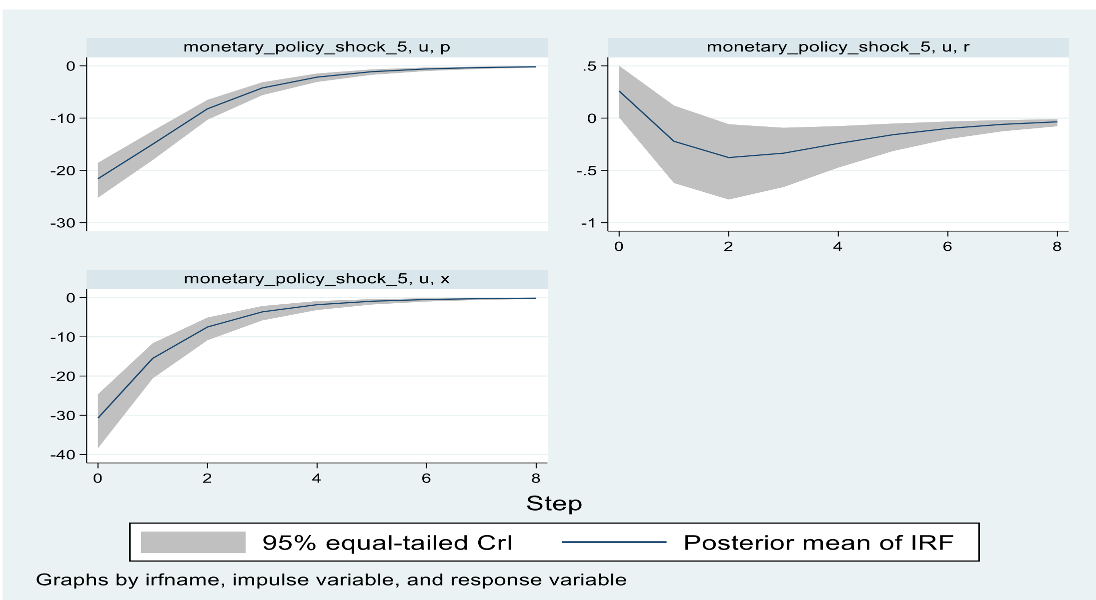

rhor
Trace
Iteration number
Histogram
Autocorrelation
Lag
Density
All
1-half
2-half

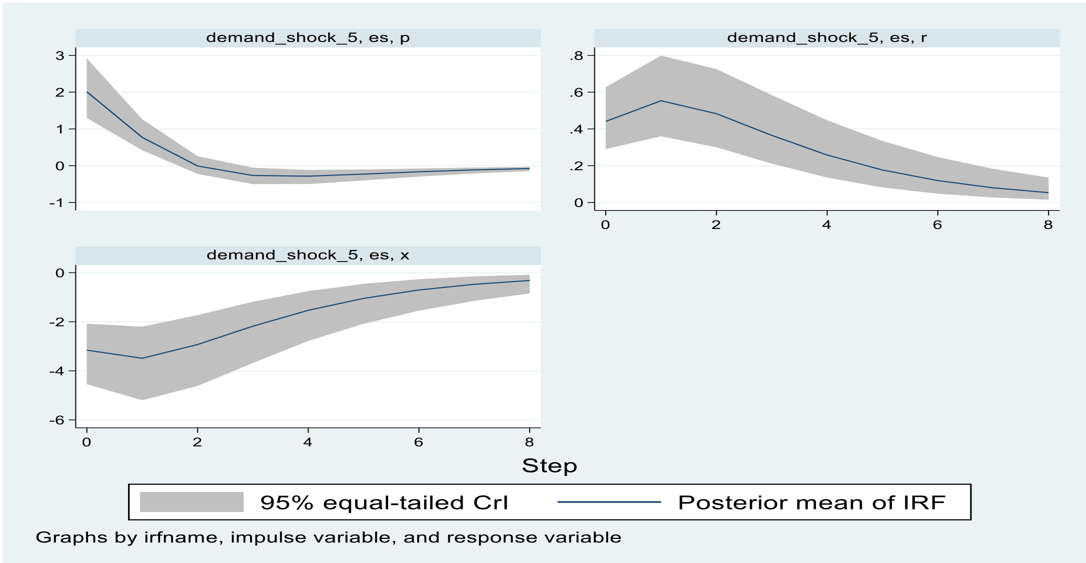

rhop
Trace
Iteration number
Histogram
Autocorrelation
Lag
Density
All
1-half
2-half

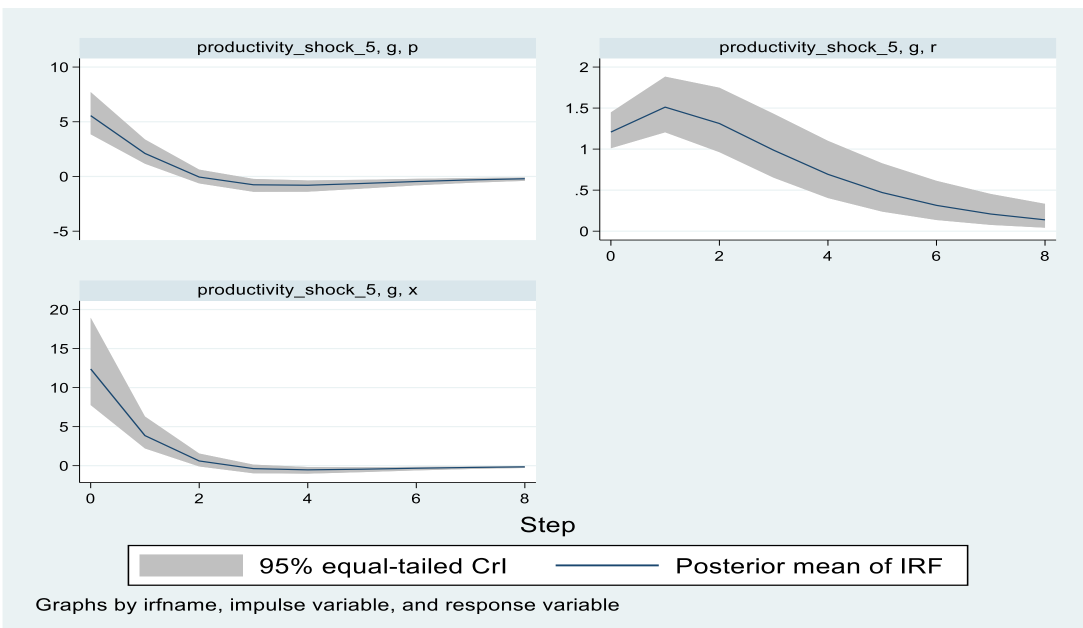
```
Efficiency summaries    MCMC sample size =    40,000
                        Efficiency:  min =    .00686
                                     avg =    .02871
                                     max =     .1032
```

	ESS	Corr. time	Efficiency
rhor	299.77	133.44	0.0075
psi	2511.26	15.93	0.0628
rhop	618.20	64.70	0.0155
beta	4127.39	9.69	0.1032
kappa	784.39	51.00	0.0196
phi	1121.10	35.68	0.0280
rhou	841.74	47.52	0.0210
rhog	1293.91	30.91	0.0323
rhoe	612.22	65.34	0.0153
sd(e.u)	274.40	145.77	0.0069
sd(e.g)	369.00	108.40	0.0092
sd(e.es)	927.51	43.13	0.0232

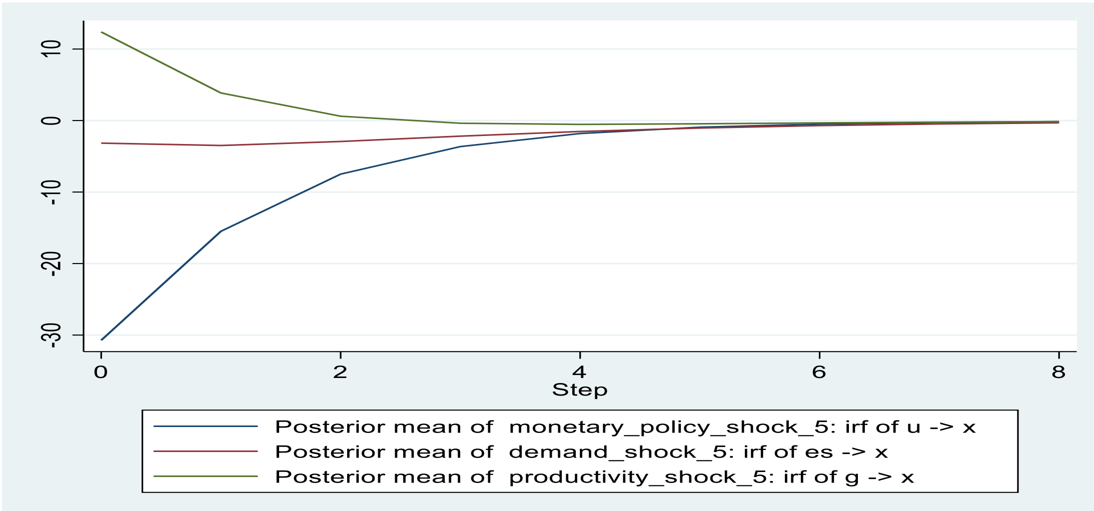
Irf plots

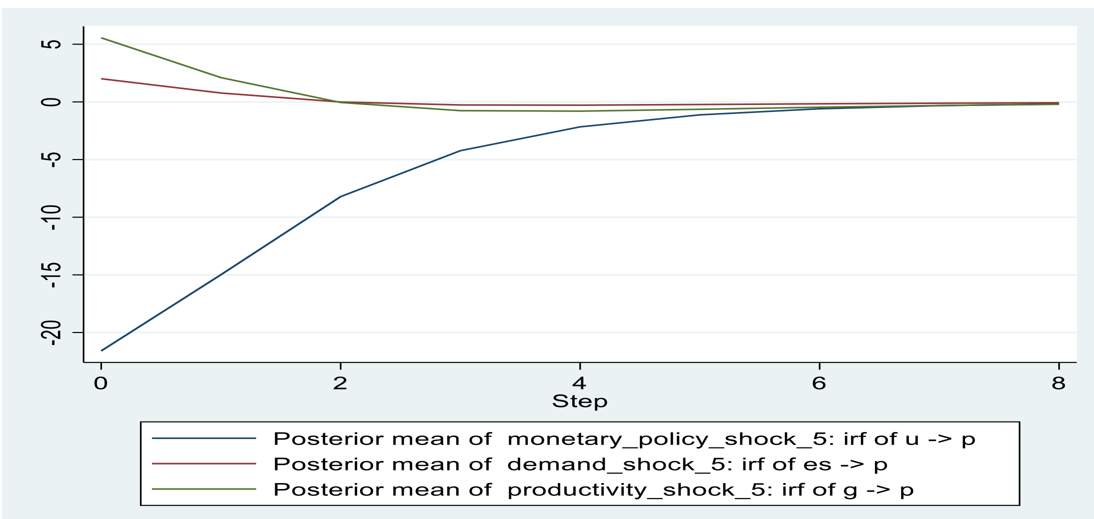


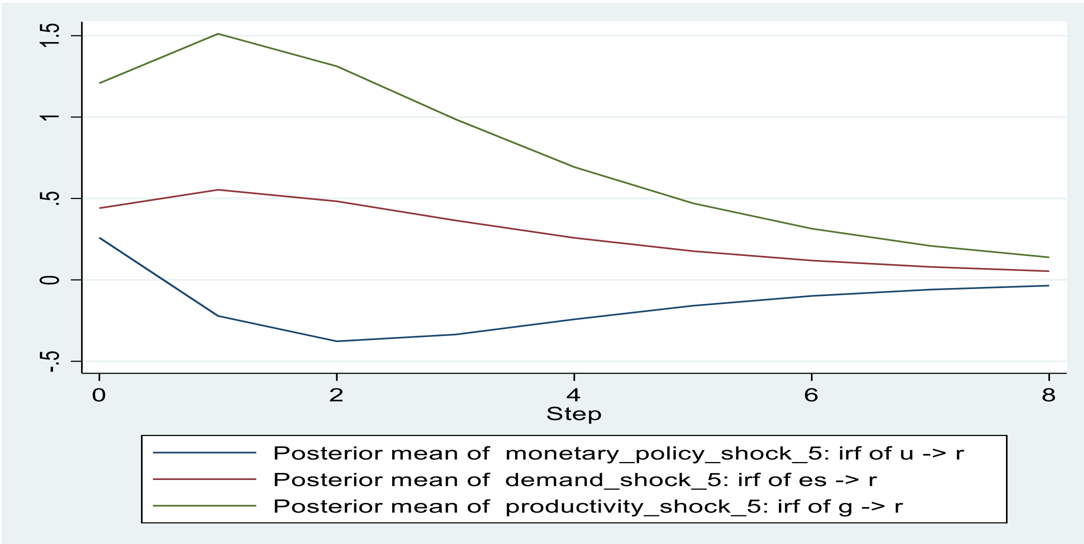




Combined plots of irf


10
0
-10
-20
-30
0
2
4
6
8
Step
Posterior mean of monetary_policy_shock_5: irf of u -> x
Posterior mean of demand_shock_5: irf of es -> x
Posterior mean of productivity_shock_5: irf of g -> x

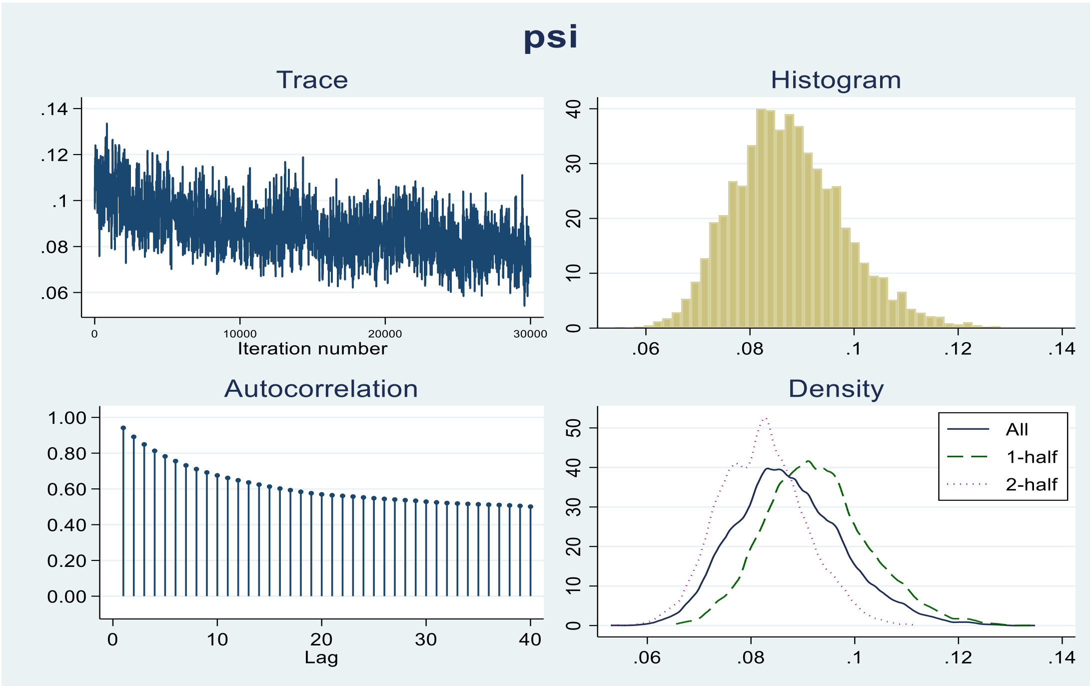

5
0
-5
-10
-15
-20
0
2
4
6
8
Step
Posterior mean of monetary_policy_shock_5: irf of u -> p
Posterior mean of demand_shock_5: irf of es -> p
Posterior mean of productivity_shock_5: irf of g -> p

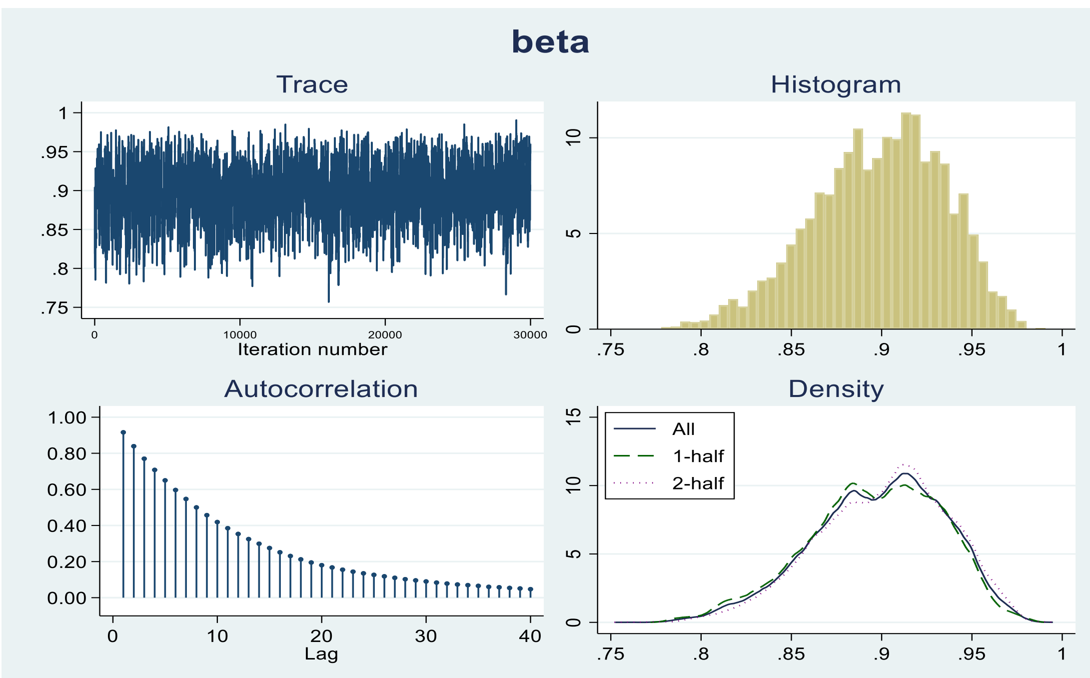


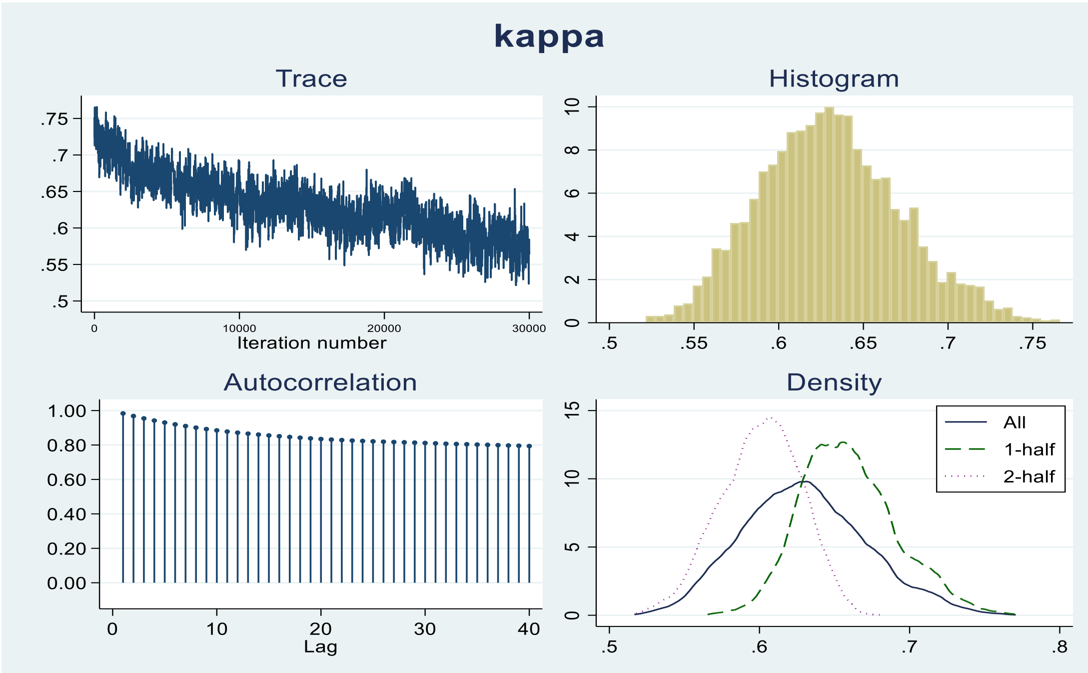
Appendix A.3: Results of Robustness Test (using Consumer Price Index)

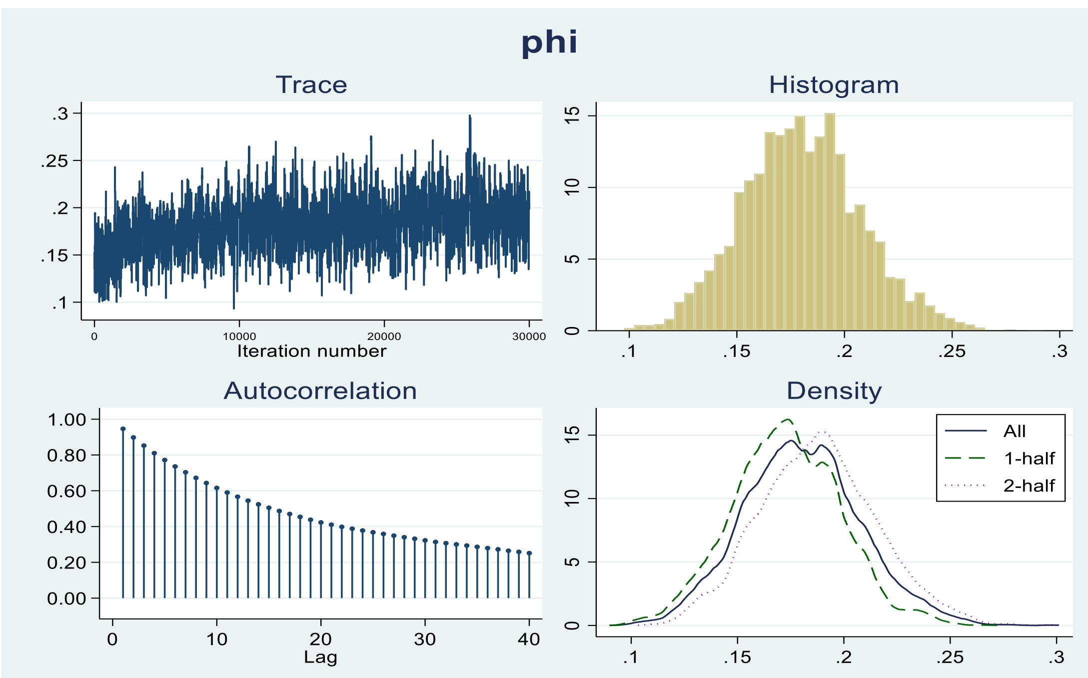
```
Efficiency summaries    MCMC sample size =     40,000
                        Efficiency:  min =     .00686
                                     avg =     .02871
                                     max =      .1032
```

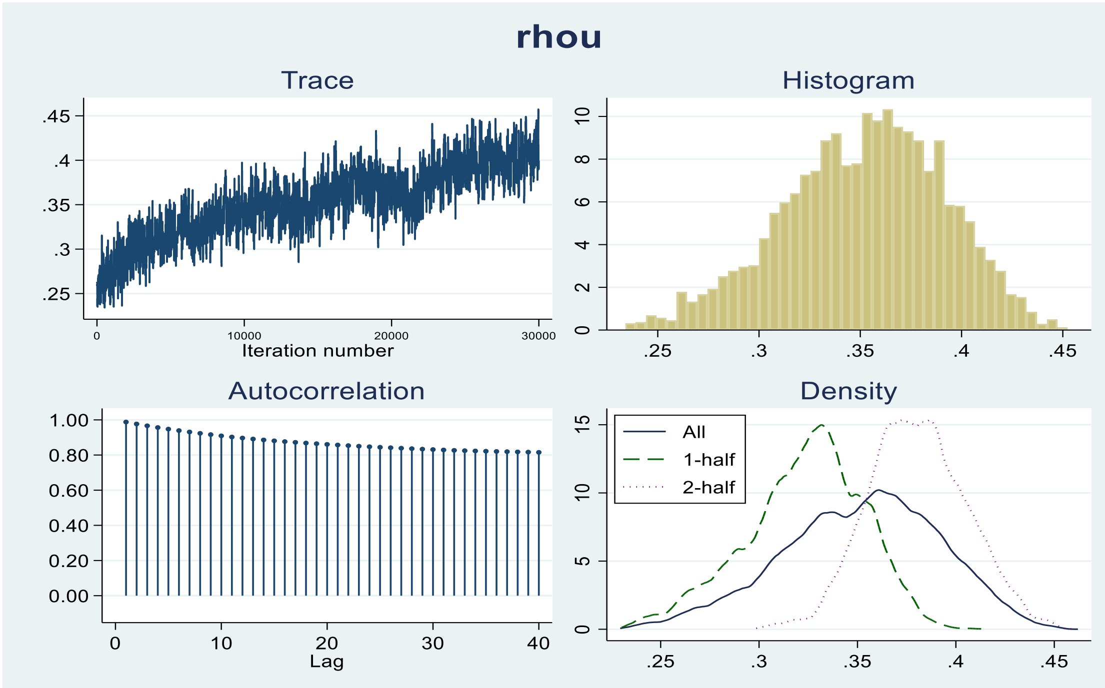
	ESS	Corr. time	Efficiency
rhor	299.77	133.44	0.0075
psi	2511.26	15.93	0.0628
rhop	618.20	64.70	0.0155
beta	4127.39	9.69	0.1032
kappa	784.39	51.00	0.0196
phi	1121.10	35.68	0.0280
rhou	841.74	47.52	0.0210
rhog	1293.91	30.91	0.0323
rhoe	612.22	65.34	0.0153
sd(e.u)	274.40	145.77	0.0069
sd(e.g)	369.00	108.40	0.0092
sd(e.es)	927.51	43.13	0.0232

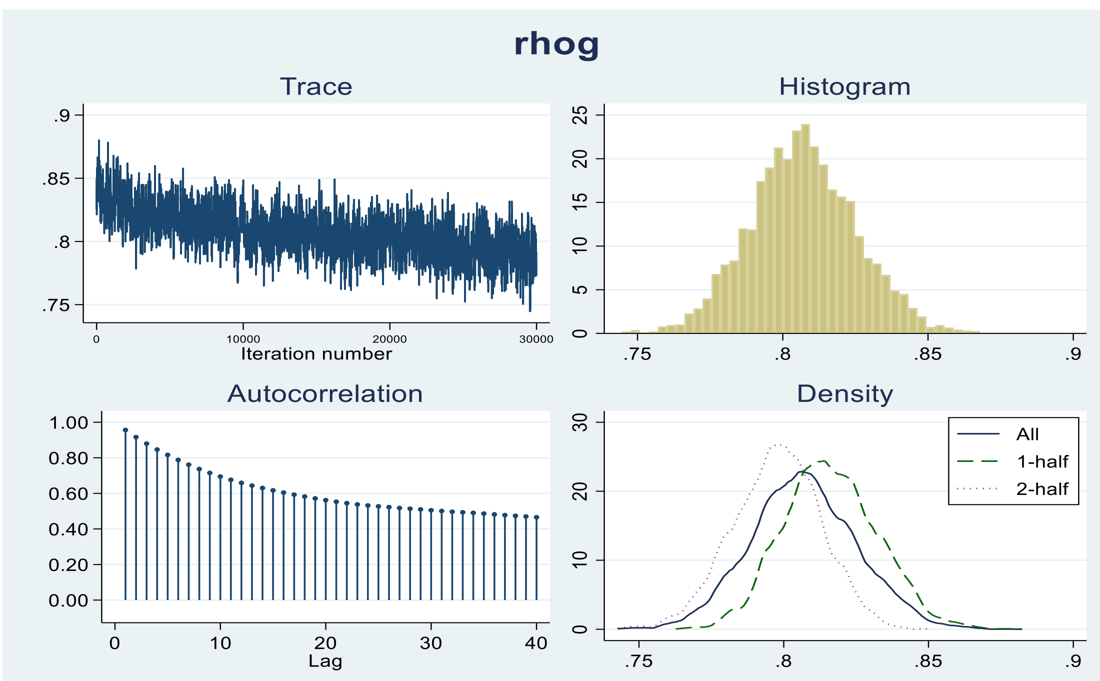

psi
Trace
Iteration number
Histogram
Autocorrelation
Lag
Density
All
1-half
2-half

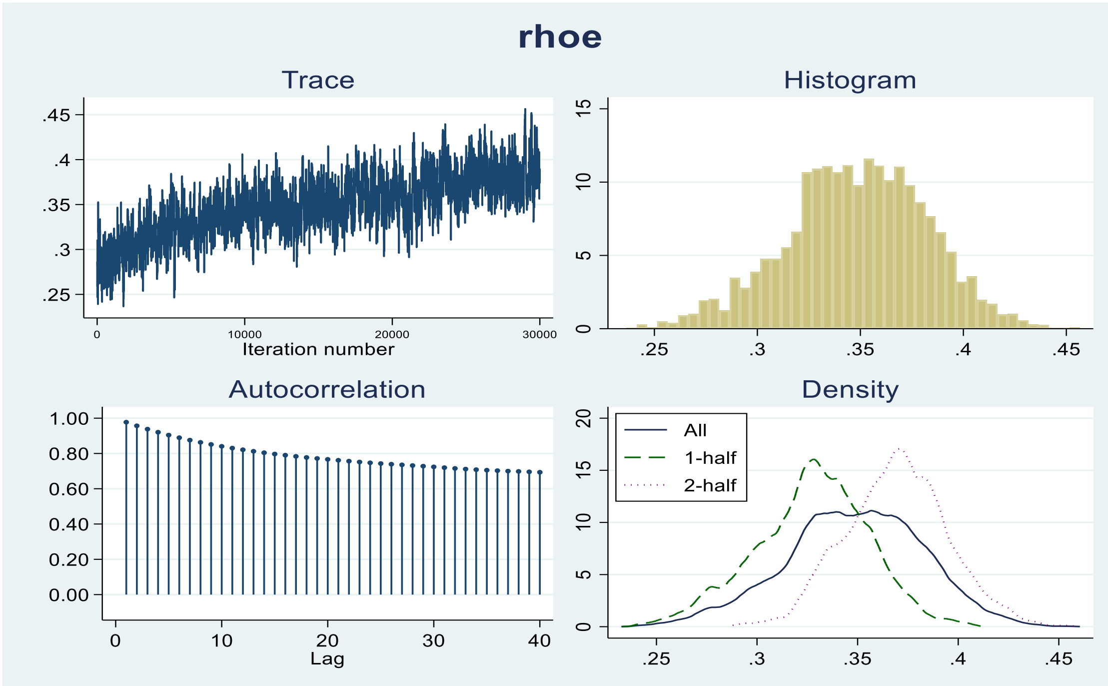

beta
Trace
Iteration number
Histogram
Autocorrelation
Lag
Density
All
1-half
2-half

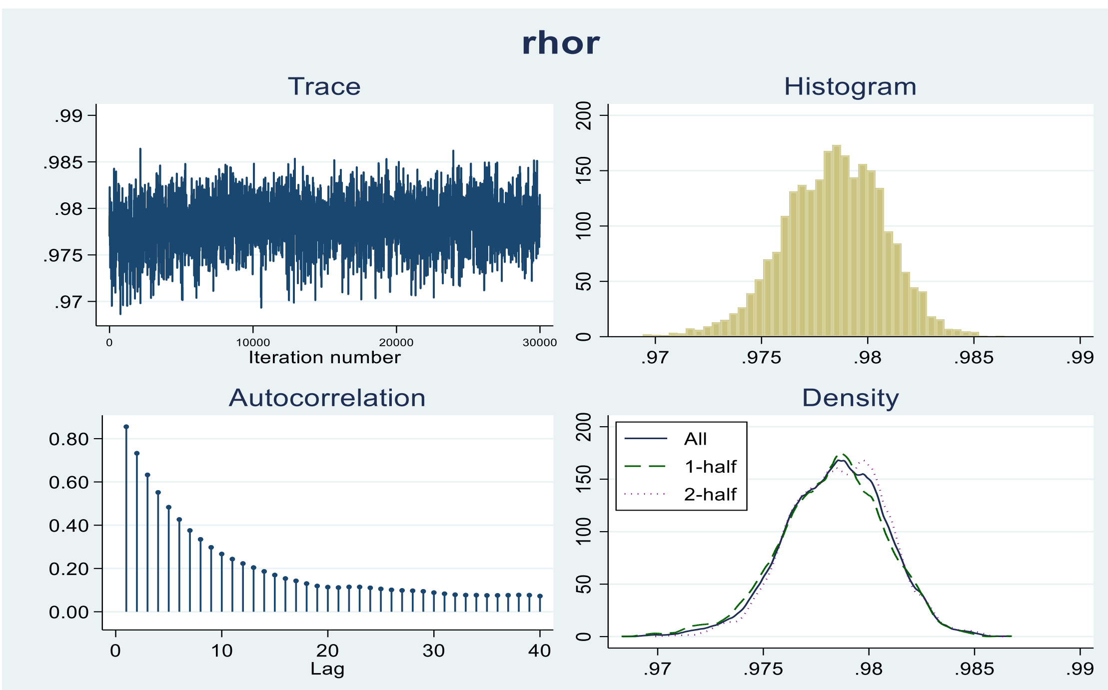

kappa
Trace
Iteration number
Histogram
Autocorrelation
Lag
Density
All
1-half
2-half

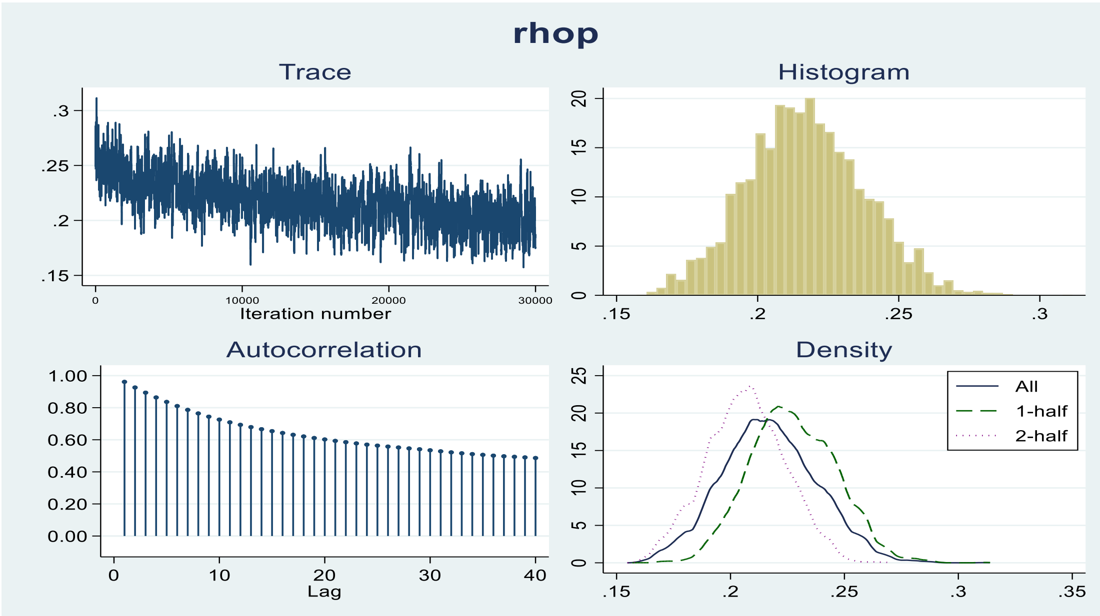

phi
Trace
Iteration number
Histogram
Autocorrelation
Lag
Density
All
1-half
2-half


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
All
1-half
2-half
Lag


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




```
Efficiency summaries    MCMC sample size =    30,000
                        Efficiency:  min =   .001304
                                     avg =   .009105
                                     max =    .04252
```

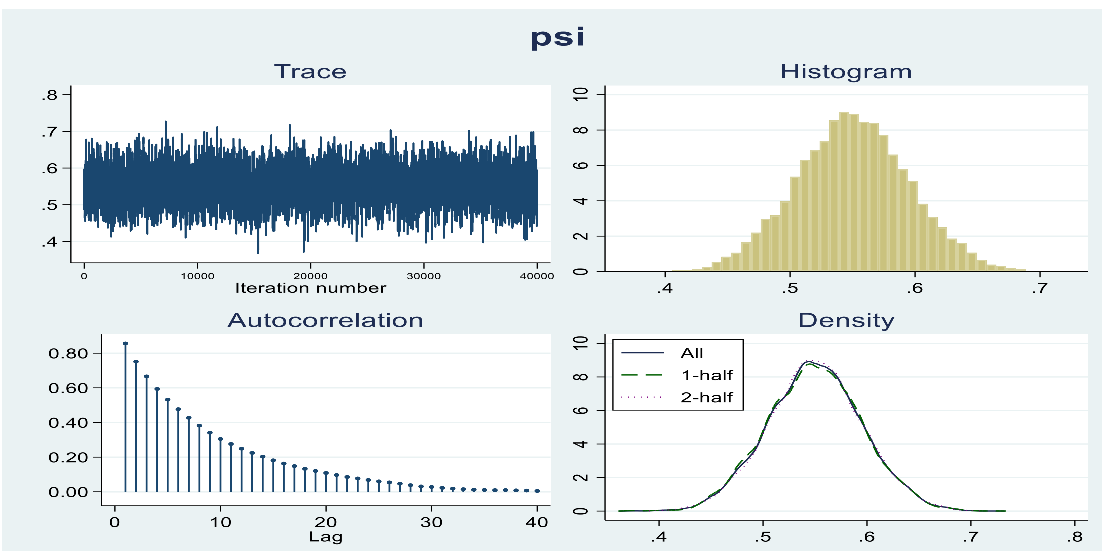
	ESS	Corr. time	Efficiency
rhor	983.49	30.50	0.0328
psi	71.72	418.30	0.0024
rhop	77.33	387.93	0.0026
beta	1275.74	23.52	0.0425
kappa	40.26	745.17	0.0013
phi	171.97	174.45	0.0057
rhou	39.12	766.79	0.0013
rhog	72.45	414.07	0.0024
rhoe	48.98	612.55	0.0016
sd(e.u)	142.77	210.13	0.0048
sd(e.g)	80.05	374.78	0.0027
sd(e.es)	273.81	109.57	0.0091

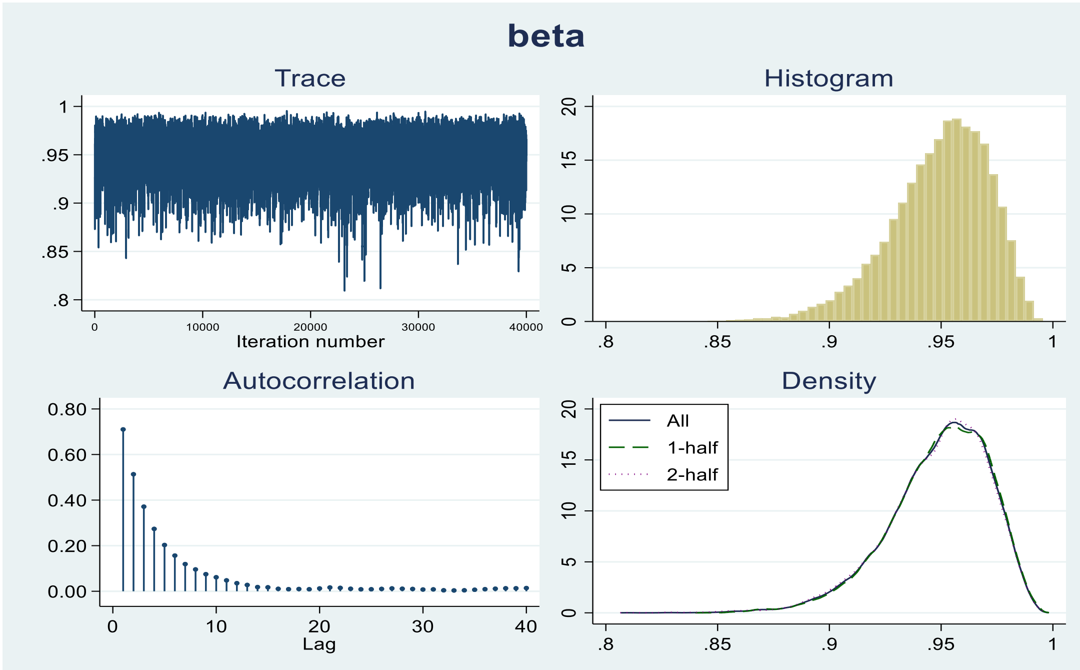
With block option and increase in mcmc size and burn in period

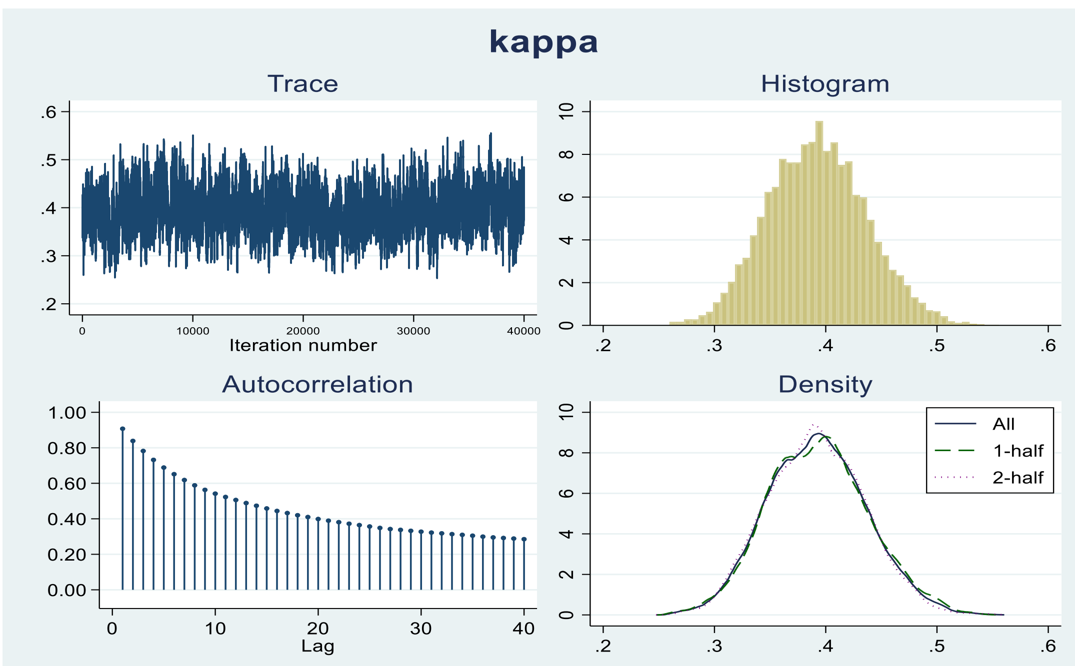
```
Bayesian linear DSGE model                         MCMC iterations  =     46,000
Random-walk Metropolis-Hastings sampling           Burn-in          =      6,000
                                                   MCMC sample size =     40,000
Sample: 1995q3 thru 2021q1                         Number of obs    =        103
                                                   Acceptance rate  =      .4151
                                                   Efficiency:  min =    .005204
                                                                avg =     .03305
Log marginal-likelihood = -1071.4889                            max =      .1544
```

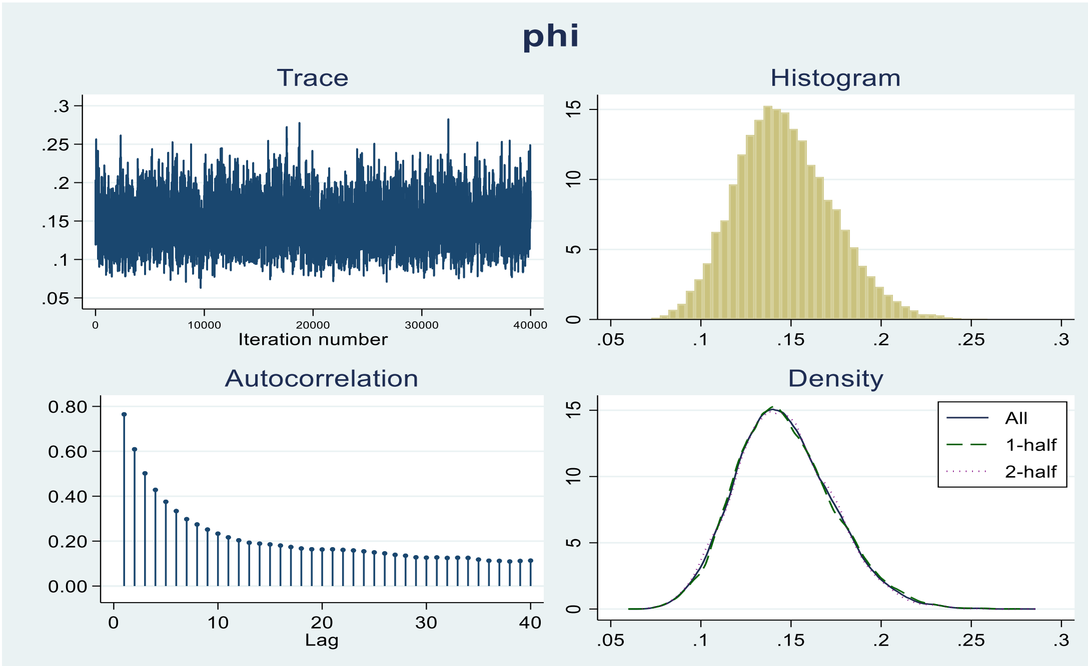
	Mean	Std. dev.	MCSE	Median	Equal-tailed [95% cred. interval]	
rhor	.8364713	.027615	.001459	.838625	.7774476	.8849016
psi	.5499803	.0453931	.000925	.5499094	.4613829	.6399249
rhop	.1877432	.0286782	.000928	.1866768	.1343937	.2486039
beta	.9489642	.0225526	.000287	.9520579	.8968175	.9834467
kappa	.3923292	.0442905	.002214	.3920951	.3092124	.4810758
phi	.1464354	.0269517	.000818	.1445365	.0981097	.2039854
rhou	.573882	.0250543	.001737	.5746234	.5222669	.6189562
rhog	.6312614	.0497496	.001317	.6316609	.53147	.7286628
rhoe	.6429949	.0542111	.001299	.6424922	.5371497	.7499915
sd(e.u)	4.274088	.7495537	.040892	4.184846	3.054912	5.938707
sd(e.g)	6.048532	1.294312	.062803	5.916304	3.93068	8.989874
sd(e.es)	16.21858	1.201295	.065044	16.13278	14.03225	18.73552

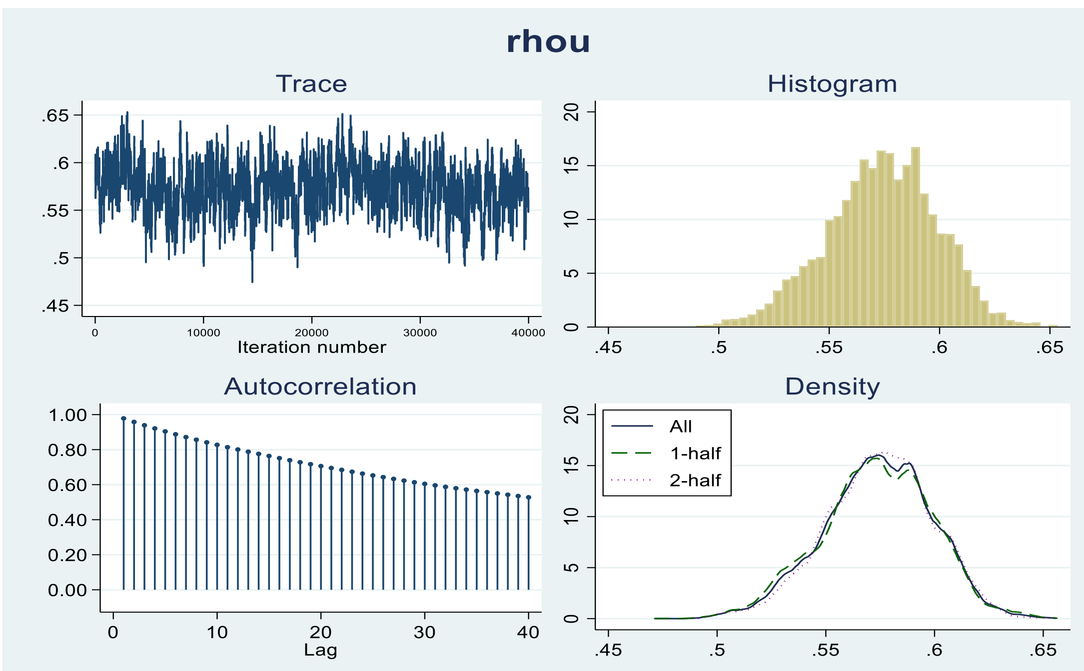
Note: There is a high autocorrelation after 500 lags.

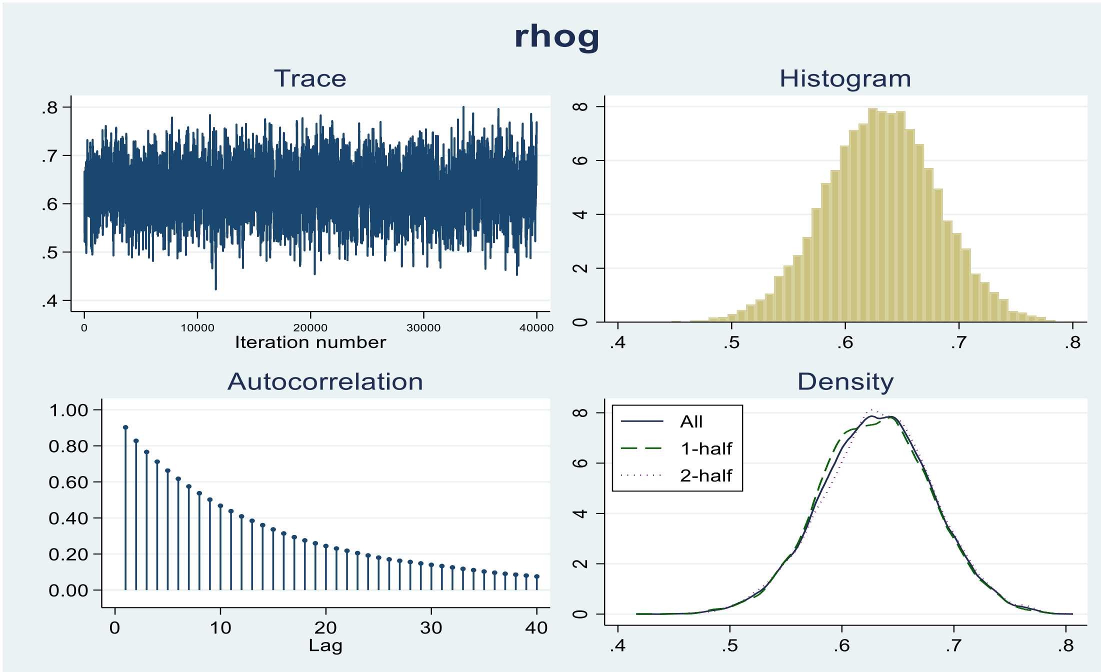


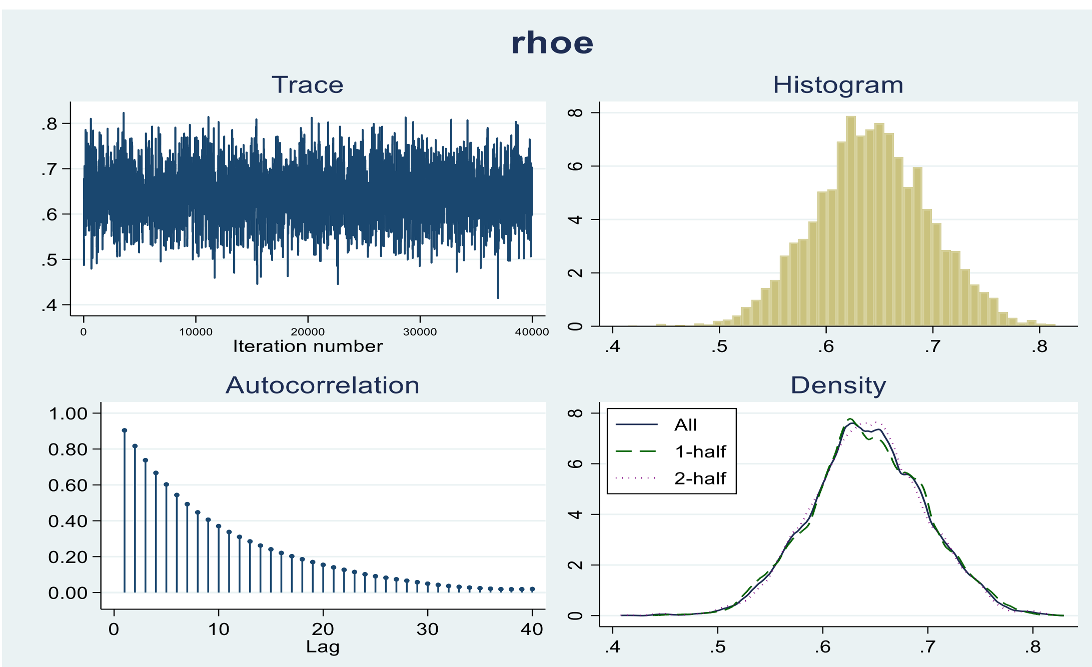

beta
Trace
Iteration number
Histogram
Autocorrelation
Lag
Density
All
1-half
2-half

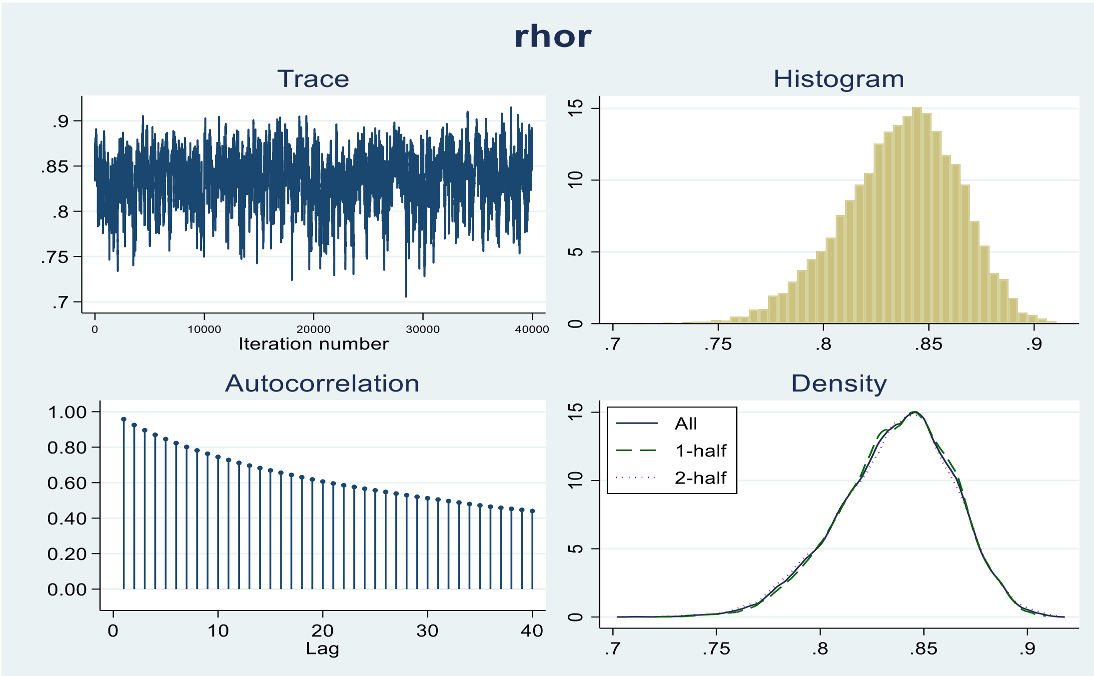

kappa
Trace
Iteration number
Histogram
Autocorrelation
Lag
Density
All
1-half
2-half

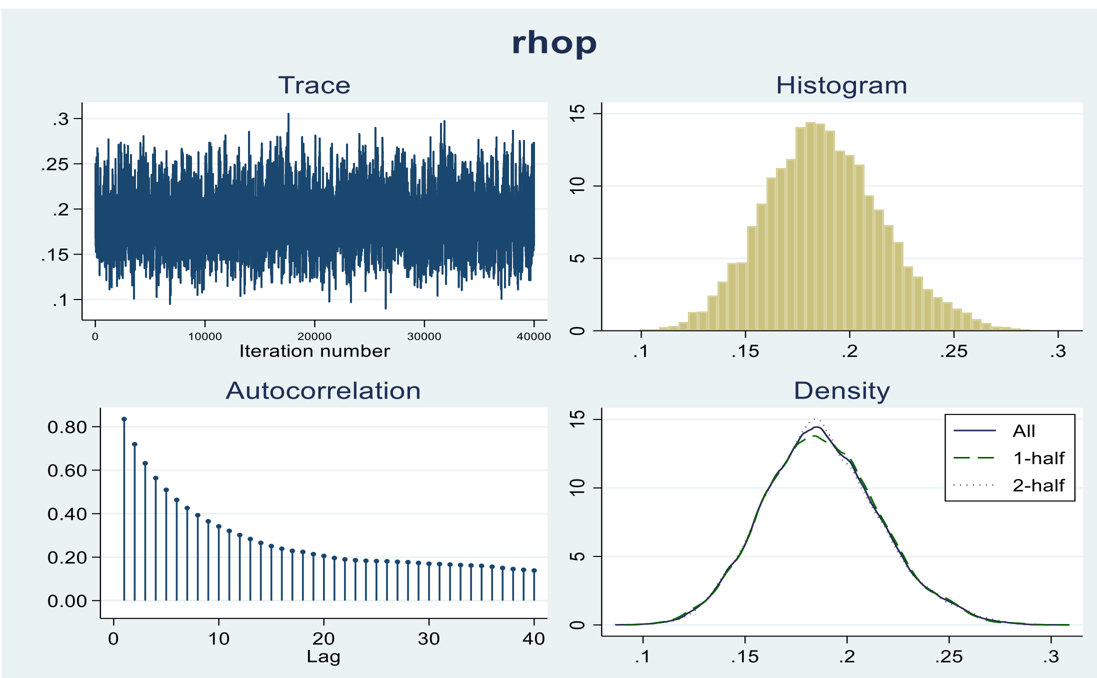

phi
Trace
Iteration number
Histogram
Autocorrelation
Lag
Density
All
1-half
2-half


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

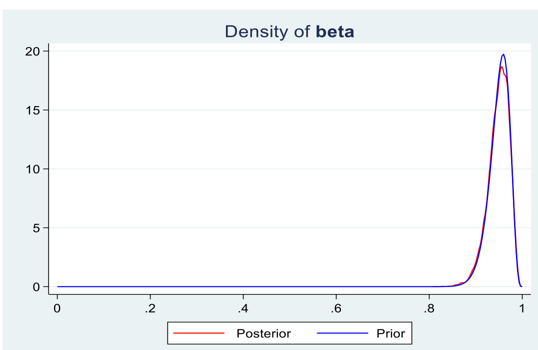

rhoe
Trace
Iteration number
Histogram
Autocorrelation
Lag
Density
All
1-half
2-half

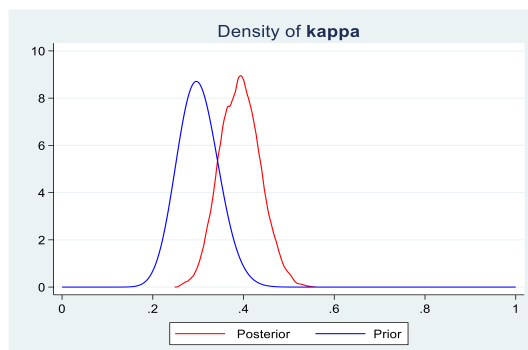

rhor
Trace
Iteration number
Histogram
Autocorrelation
Lag
Density
All
1-half
2-half

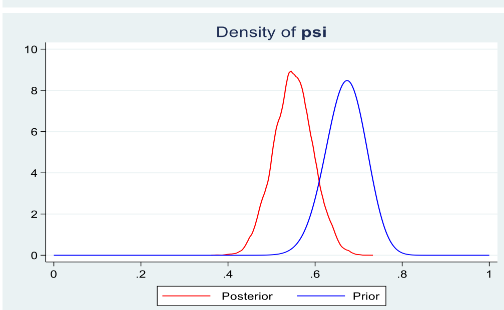

rhop
Trace
Iteration number
Histogram
Autocorrelation
Lag
Density
All
1-half
2-half

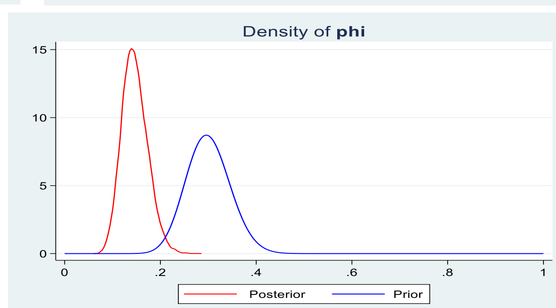
Efficiency summaries   MCMC sample size = 40,000
Efficiency: min = .005204
avg = .03305
max = .1544

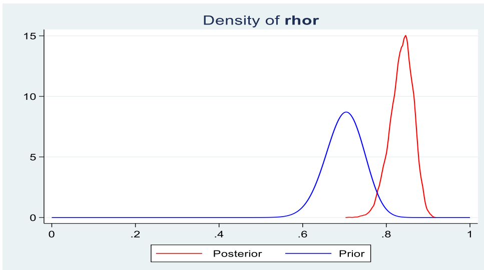
	ESS	Corr. time	Efficiency
rhor	358.35	111.62	0.0090
psi	2408.64	16.61	0.0602
rhop	955.40	41.87	0.0239
beta	6177.73	6.47	0.1544
kappa	400.18	99.95	0.0100
phi	1084.41	36.89	0.0271
rhou	208.15	192.17	0.0052
rhog	1426.67	28.04	0.0357
rhoe	1741.27	22.97	0.0435
sd(e.u)	336.00	119.05	0.0084
sd(e.g)	424.73	94.18	0.0106
sd(e.es)	341.10	117.27	0.0085

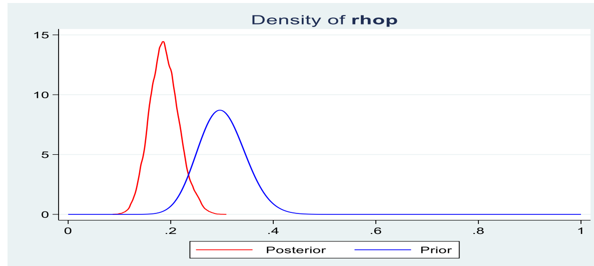


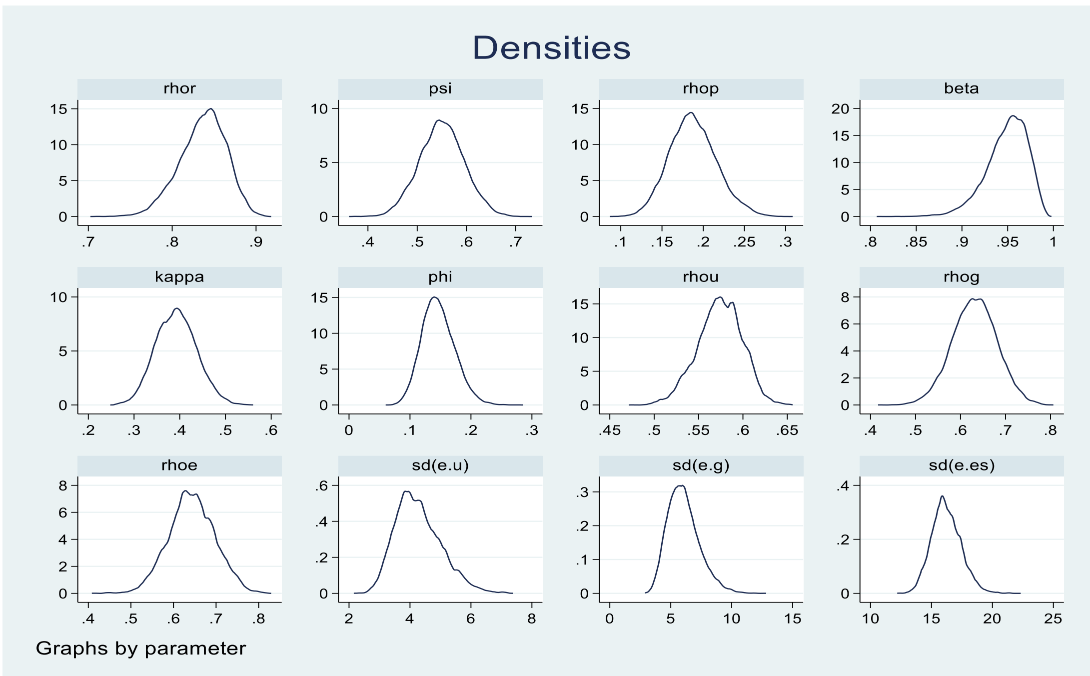


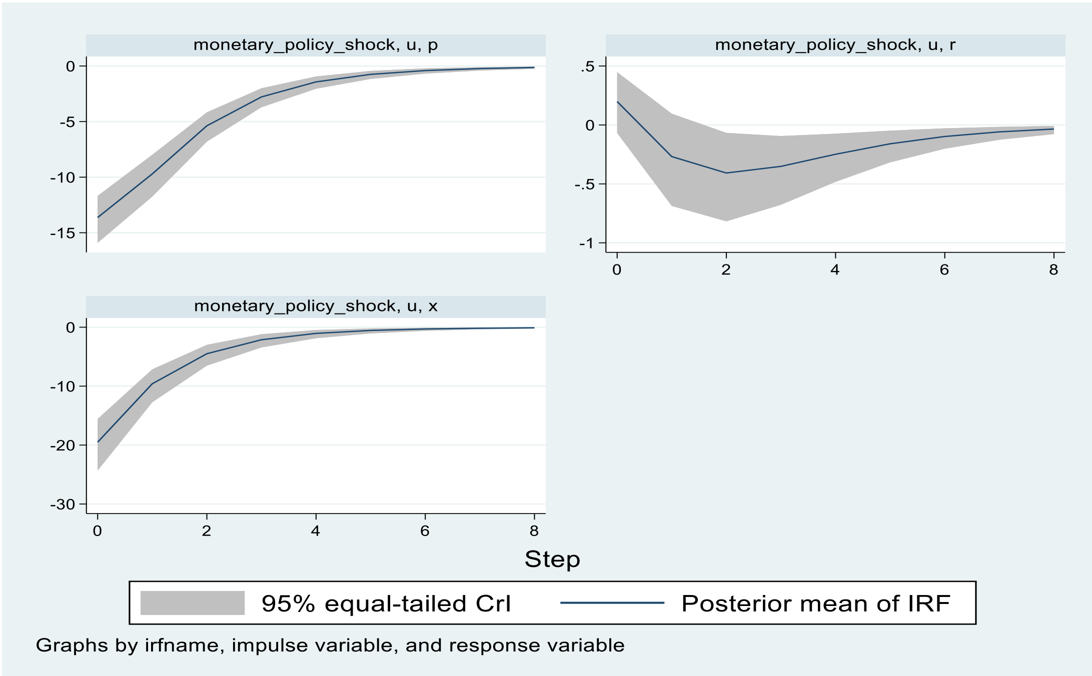


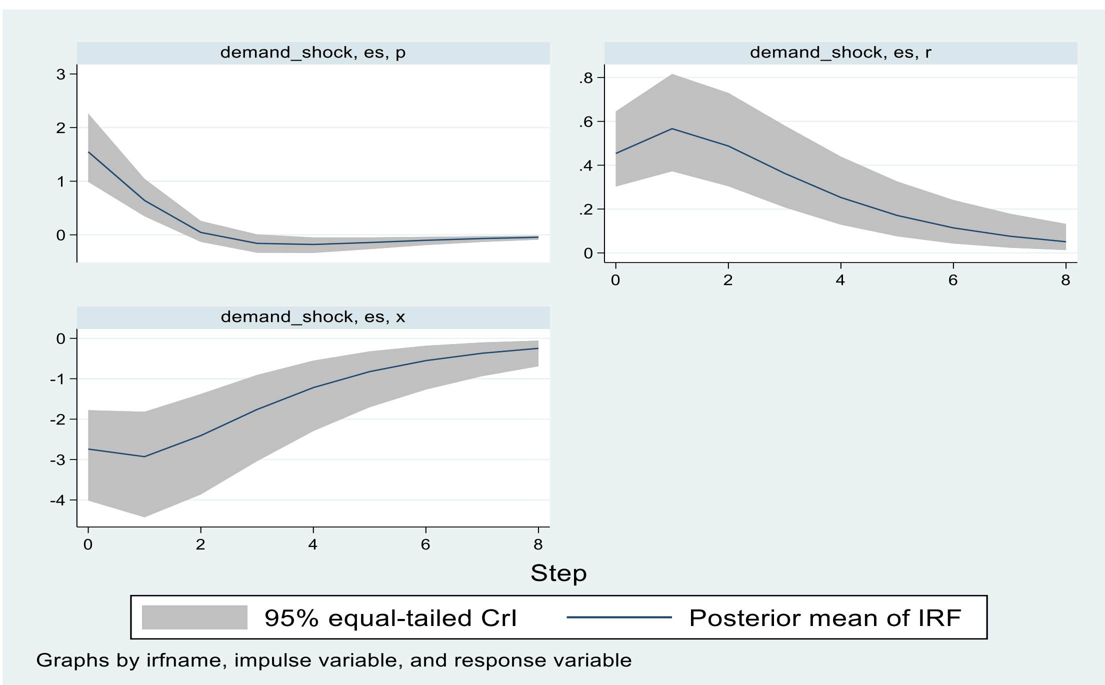


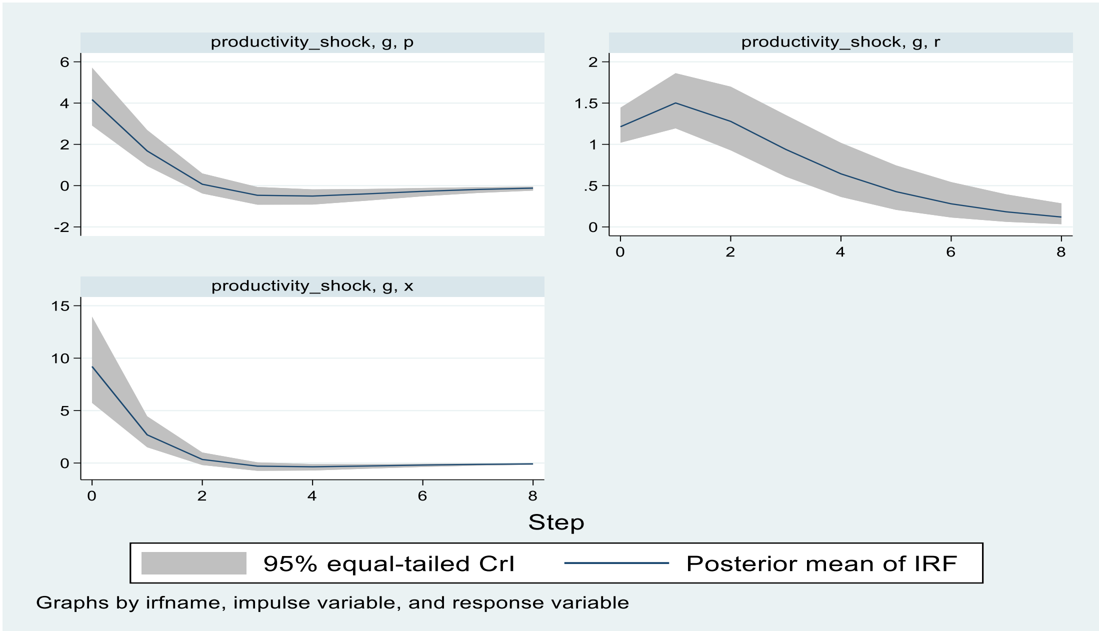

Density of rhor
Posterior
Prior

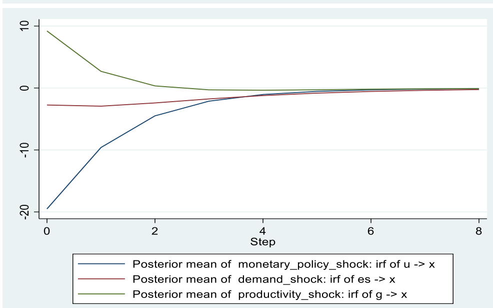

Density of rhop
Posterior
Prior

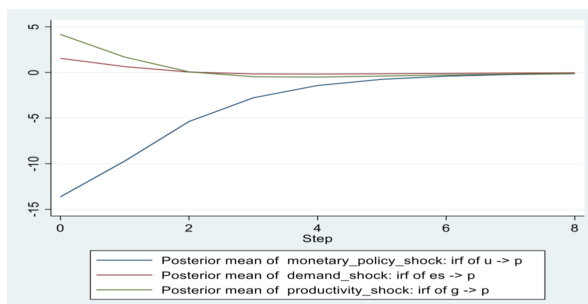

Densities
rhor
psi
rhop
beta
kappa
phi
rhou
rhog
rhoe
sd(e.u)
sd(e.g)
sd(e.es)
Graphs by parameter

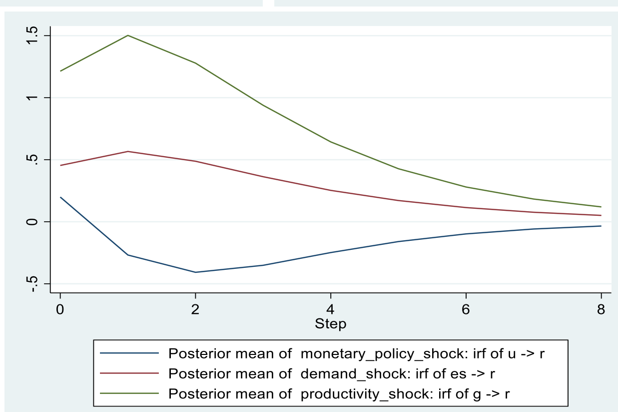

monetary_policy_shock, u, p
monetary_policy_shock, u, r
monetary_policy_shock, u, x
Step
95% equal-tailed CrI
Posterior mean of IRF
Graphs by irfname, impulse variable, and response variable


demand_shock, es, p
demand_shock, es, r
demand_shock, es, x
Step
95% equal-tailed CrI
Posterior mean of IRF
Graphs by irfname, impulse variable, and response variable


productivity_shock, g, p
productivity_shock, g, r
productivity_shock, g, x
Step
95% equal-tailed CrI
Posterior mean of IRF
Graphs by irfname, impulse variable, and response variable


Step
Posterior mean of monetary_policy_shock: irf of u -> x
Posterior mean of demand_shock: irf of es -> x
Posterior mean of productivity_shock: irf of g -> x


Step
Posterior mean of monetary_policy_shock: irf of u -> p
Posterior mean of demand_shock: irf of es -> p
Posterior mean of productivity_shock: irf of g -> p

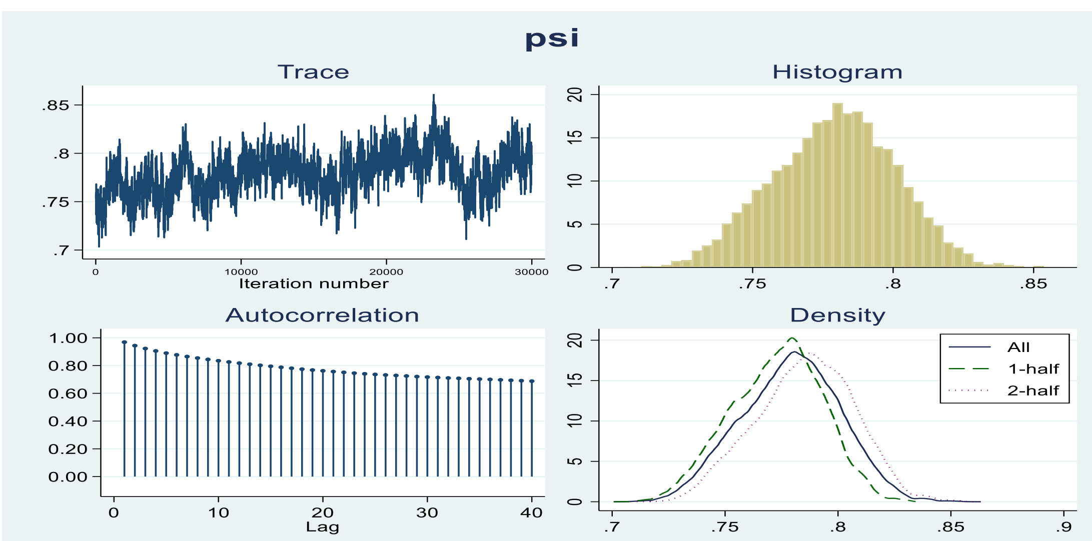

Step
Posterior mean of monetary_policy_shock: irf of u -> r
Posterior mean of demand_shock: irf of es -> r
Posterior mean of productivity_shock: irf of g -> r

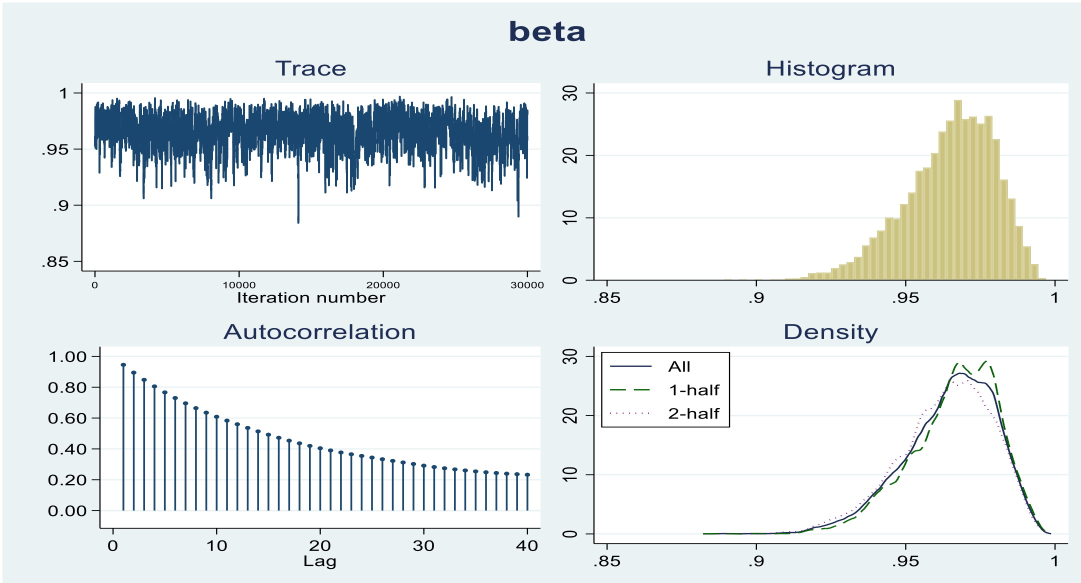
Appendix A.4: Results of Robustness Test (using BDC Exchange Rate)

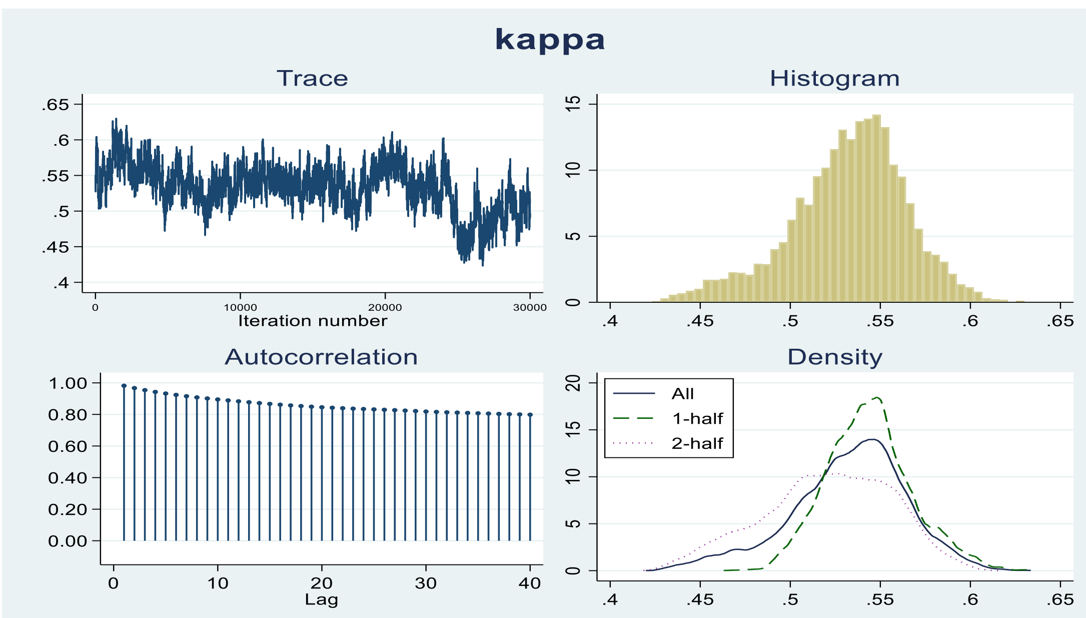
```
Priors:
                      {rhor} ~ beta(70,30)
                       {psi} ~ beta(50,50)
                      {rhop} ~ beta(30,70)
                      {beta} ~ beta(95,5)
                 {kappa phi} ~ beta(30,70)
            {rhou rhog rhoe} ~ beta(75,25)
  {sd(e.u) sd(e.g) sd(e.es)} ~ igamma(.01,.01)

Bayesian linear DSGE model                          MCMC iterations  =     35,000
Random-walk Metropolis-Hastings sampling            Burn-in          =      5,000
                                                    MCMC sample size =     30,000
Sample: 1995q3 thru 2021q1                          Number of obs    =        103
                                                    Acceptance rate  =      .2519
                                                    Efficiency:  min =    .001561
                                                                 avg =    .005355
Log marginal-likelihood = -1138.1966                             max =     .01144
```

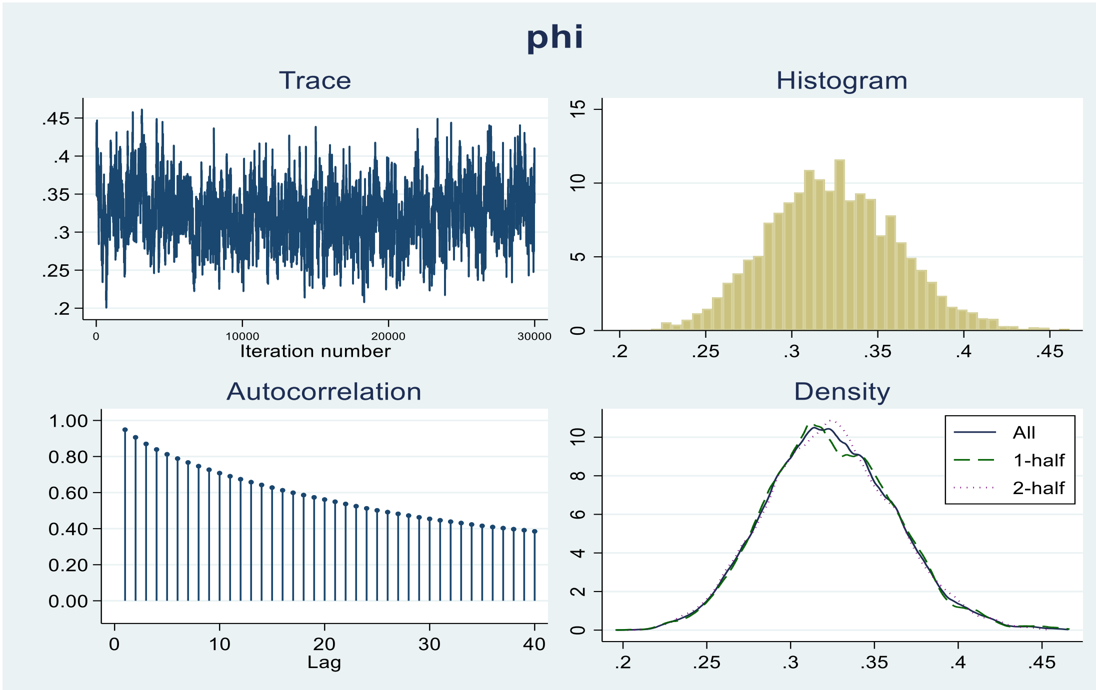
	Mean	Std. dev.	MCSE	Median	Equal-tailed [95% cred.	interval]
rhor	.8564828	.0110239	.00117	.8567871	.8342574	.8773923
psi	.7790136	.0217849	.002819	.779864	.7362499	.8200996
rhop	.0988243	.0154548	.000876	.0980995	.0704665	.1313232
beta	.9647491	.0152435	.000823	.9668164	.930208	.9887383
kappa	.5322168	.0323204	.004723	.5355849	.4561941	.5902208
phi	.3237013	.0379837	.002522	.3222245	.2525996	.4017737
rhou	.4759075	.0160925	.001956	.474943	.4454776	.5105052
rhog	.9523203	.0076113	.000994	.9524709	.9370908	.9663205
rhoe	.344899	.0253533	.001666	.3448413	.2952041	.3945622
sd(e.u)	3.360823	.094102	.006195	3.35932	3.175254	3.548488
sd(e.g)	.846475	.057009	.004983	.8452165	.740025	.9565191
sd(e.es)	3.813641	.0962262	.008374	3.813271	3.631325	4.007791

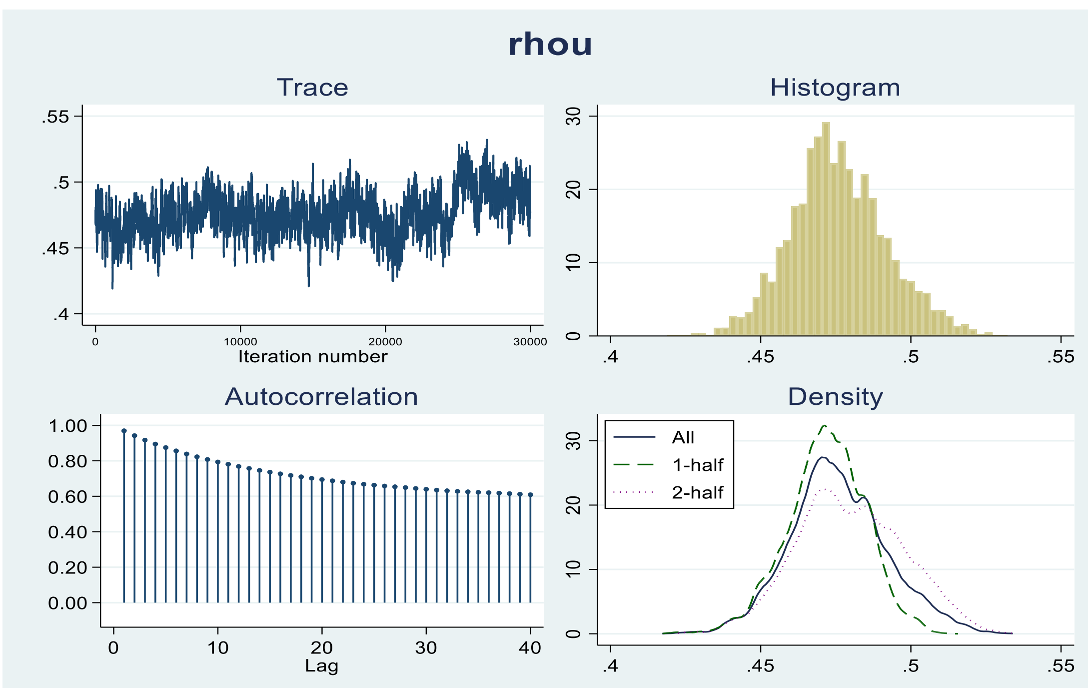
Note: There is a high autocorrelation after 500 lags.

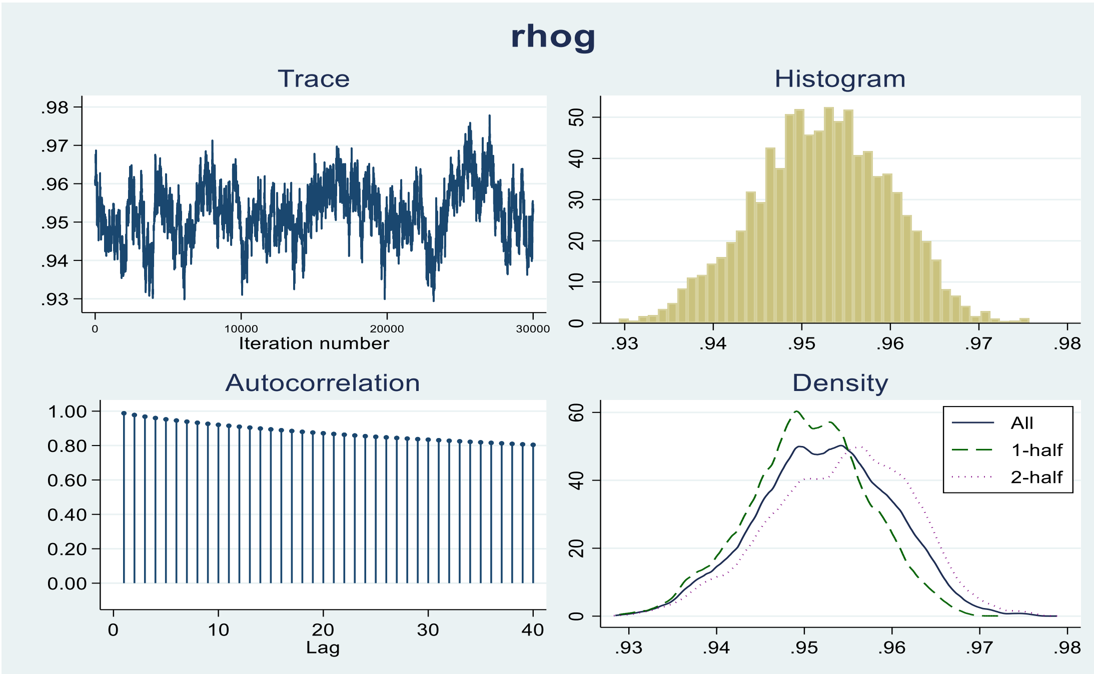


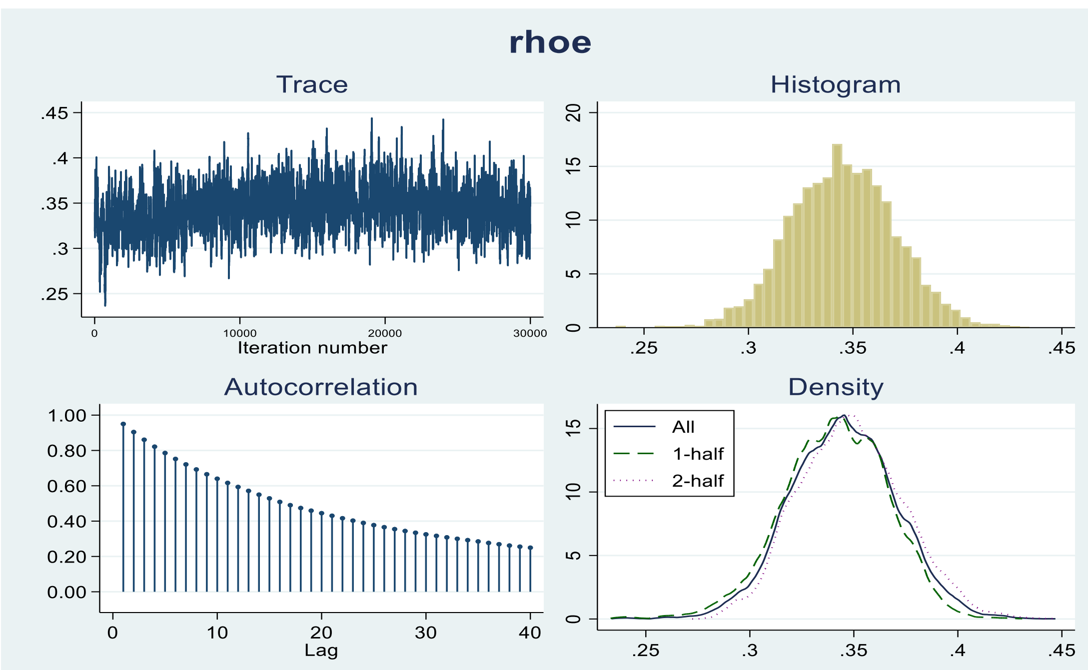

beta
Trace
Histogram
Iteration number
Autocorrelation
Density
All
1-half
2-half
Lag

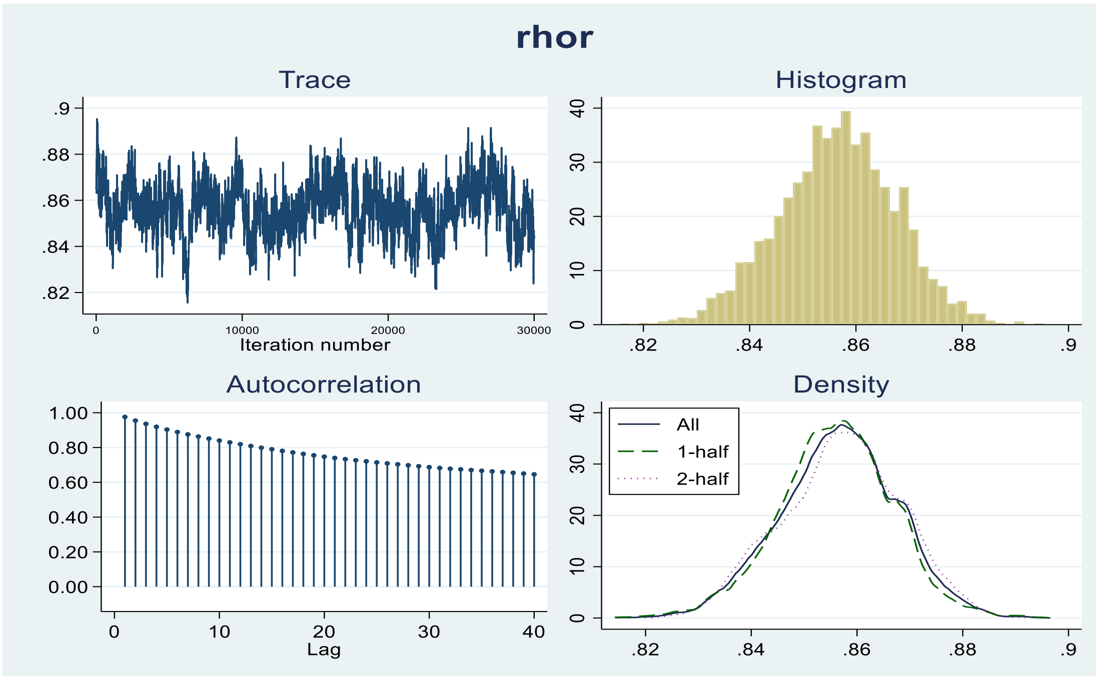

kappa
Trace
Histogram
Iteration number
Autocorrelation
Density
All
1-half
2-half
Lag

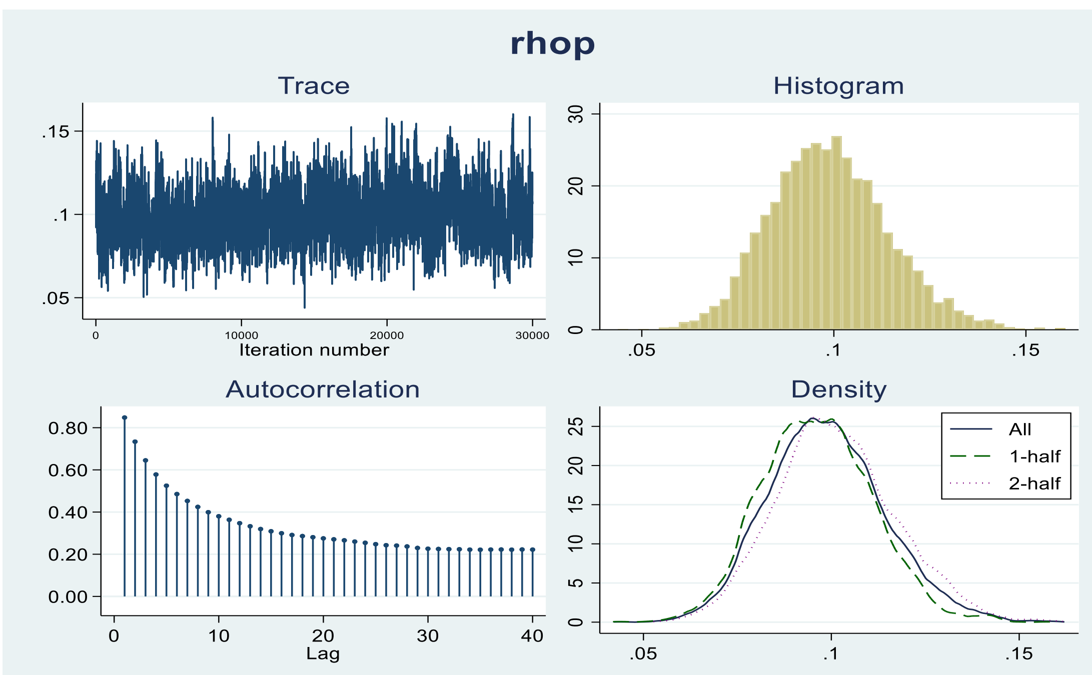

phi
Trace
Histogram
Iteration number
Autocorrelation
Density
Lag
All
1-half
2-half


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


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


rhop
Trace
Histogram
Iteration number
Autocorrelation
Density
All
1-half
2-half
Lag

```
Efficiency summaries     MCMC sample size =     30,000
                         Efficiency:  min =    .001561
                                      avg =    .005355
                                      max =     .01144
```

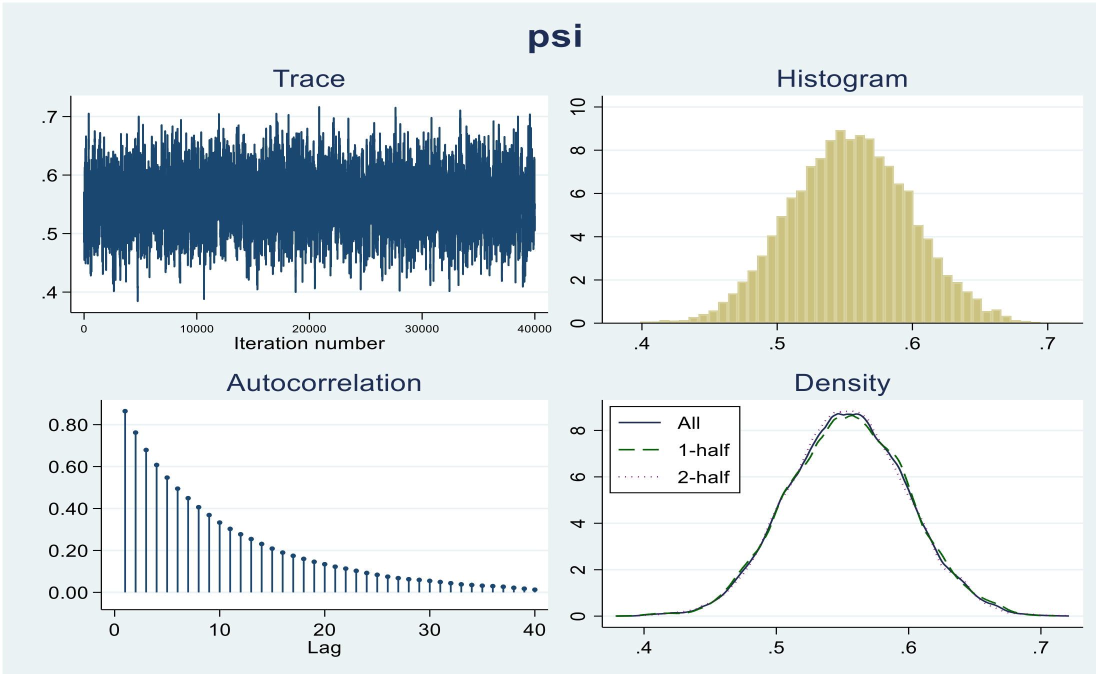
	ESS	Corr. time	Efficiency
rhor	88.72	338.13	0.0030
psi	59.70	502.50	0.0020
rhop	311.02	96.46	0.0104
beta	343.08	87.44	0.0114
kappa	46.82	640.69	0.0016
phi	226.89	132.22	0.0076
rhou	67.70	443.10	0.0023
rhog	58.58	512.12	0.0020
rhoe	231.69	129.48	0.0077
sd(e.u)	230.72	130.03	0.0077
sd(e.g)	130.90	229.19	0.0044
sd(e.es)	132.04	227.20	0.0044

.

With block option and increase mcmc size and burn in period

```
Priors:
                      {rhor} ~ beta(70,30)
                       {psi} ~ beta(50,50)
                      {rhop} ~ beta(30,70)
                      {beta} ~ beta(95,5)
                 {kappa phi} ~ beta(30,70)
            {rhou rhog rhoe} ~ beta(75,25)
  {sd(e.u) sd(e.g) sd(e.es)} ~ igamma(.01,.01)

Bayesian linear DSGE model                         MCMC iterations  =     46,000
Random-walk Metropolis-Hastings sampling           Burn-in          =      6,000
                                                   MCMC sample size =     40,000
Sample: 1995q3 thru 2021q1                         Number of obs    =        103
                                                   Acceptance rate  =      .4122
                                                   Efficiency:  min =    .004803
                                                                avg =     .02744
Log marginal-likelihood = -1002.4905                            max =      .1077
```

	Mean	Std. dev.	MCSE	Median	Equal-tailed [95% cred.	interval]
rhor	.8185269	.0308439	.001692	.8202672	.7542043	.8735525
psi	.5538847	.044804	.000963	.5538883	.4673622	.6420103
rhop	.1186695	.0212075	.00087	.1173118	.0812926	.163652
beta	.9512658	.021259	.000324	.9544082	.9016981	.9837665
kappa	.3680009	.0426051	.002859	.3678587	.2854103	.4517045
phi	.2659898	.0400907	.000793	.2641419	.1921128	.3500711
rhou	.5790121	.0200545	.001447	.5789423	.5406785	.6196419
rhog	.6280352	.0493553	.001503	.6276965	.5319642	.7250179
rhoe	.6693067	.0461262	.002228	.6706053	.5759587	.756525
sd(e.u)	7.206381	1.332547	.074047	7.093302	4.89489	10.05678
sd(e.g)	4.975674	1.112795	.067524	4.842506	3.164756	7.397862
sd(e.es)	6.218888	.4343138	.016467	6.197604	5.431068	7.121121


psi
Trace
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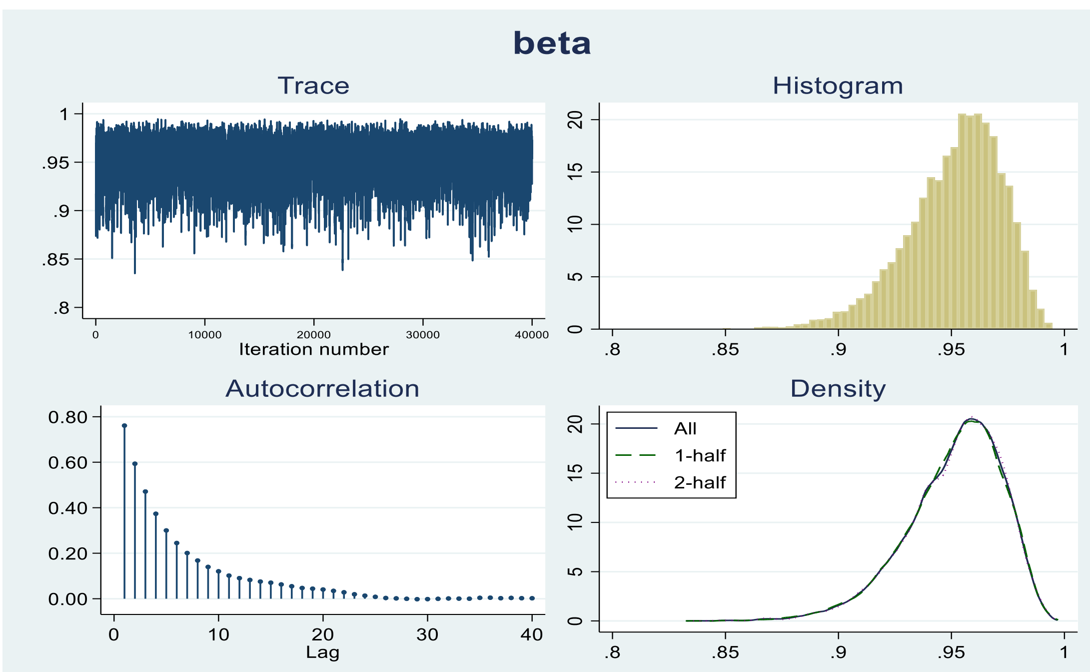
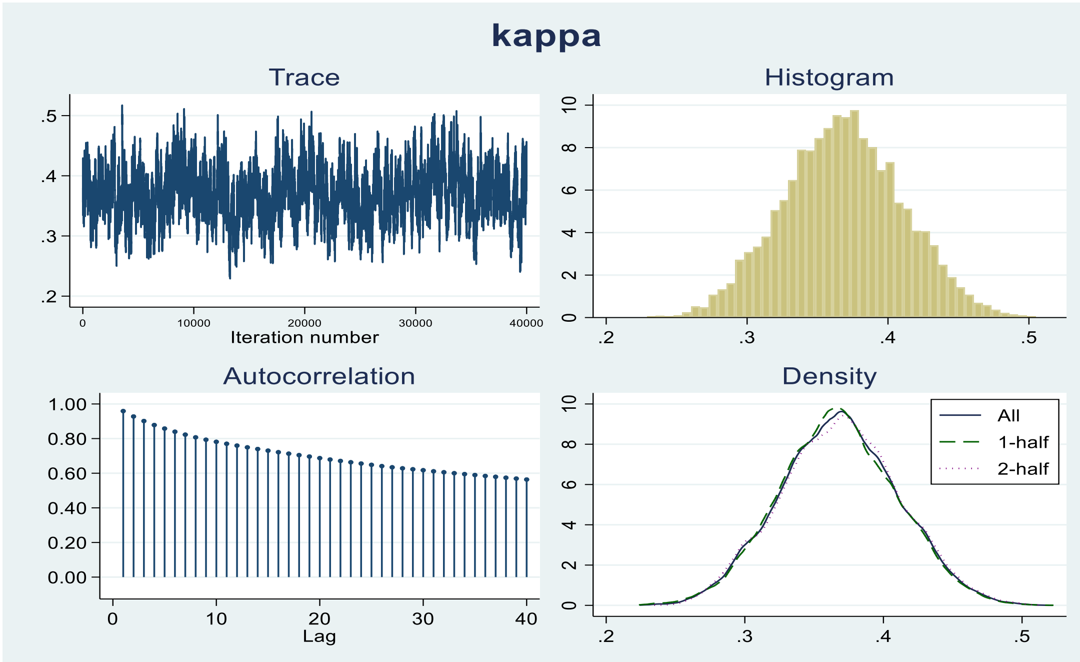
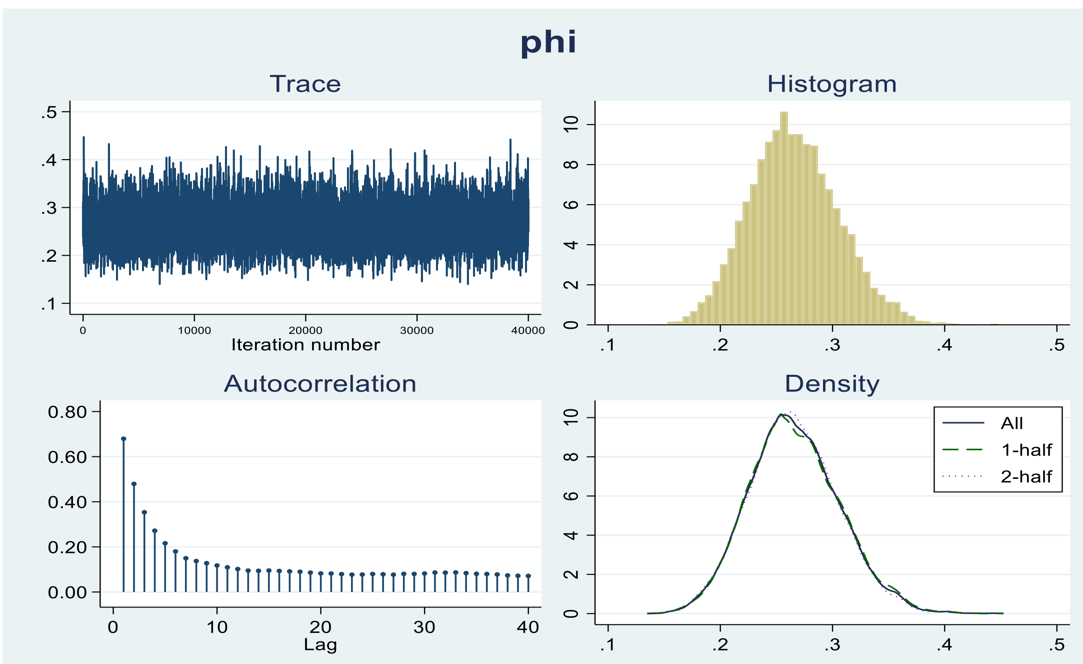
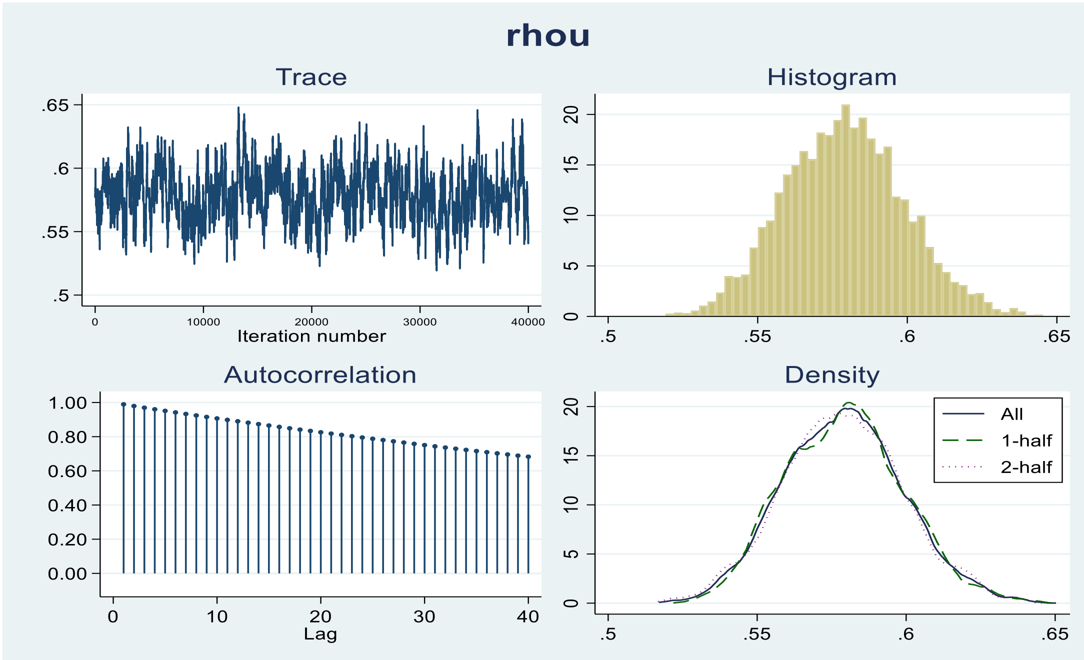
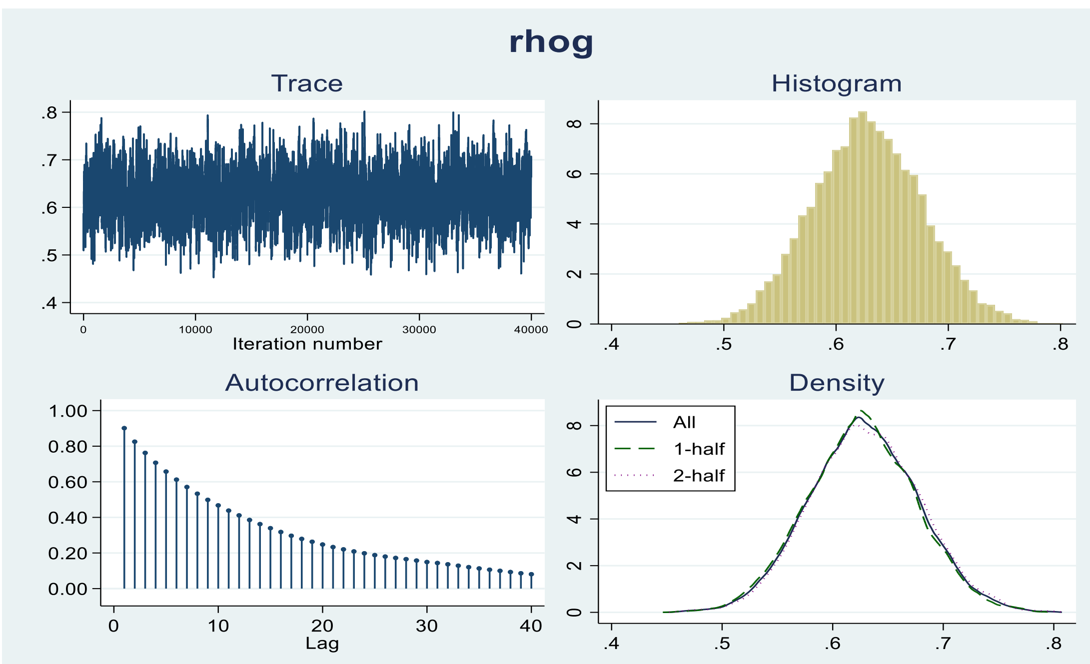
.6
.5
.4
0
10000
20000
30000
40000
Iteration number
Histogram
10
8
6
4
2
0
.4
.5
.6
.7
Autocorrelation
0.80
0.60
0.40
0.20
0.00
0
10
20
30
40
Lag
Density
All
1-half
2-half
8
6
4
2
0
.4
.5
.6
.7

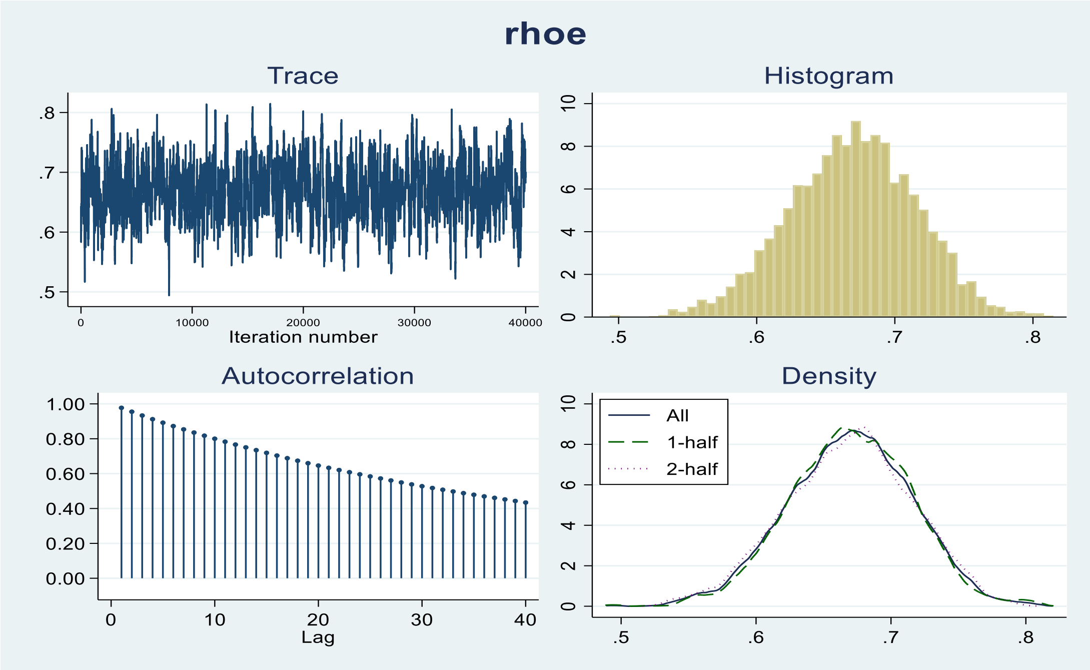

beta
Trace
1
.95
.9
.85
.8
0
10000
20000
30000
40000
Iteration number
Histogram
20
15
10
5
0
.8
.85
.9
.95
1
Autocorrelation
0.80
0.60
0.40
0.20
0.00
0
10
20
30
40
Lag
Density
All
1-half
2-half
20
15
10
5
0
.8
.85
.9
.95
1

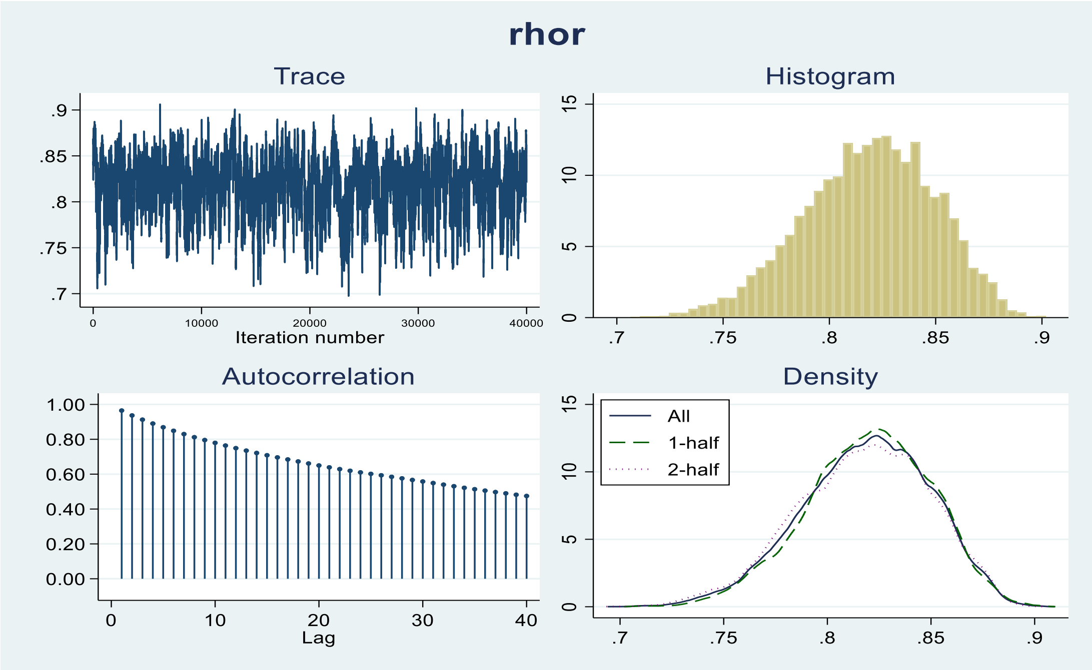

kappa
Trace
Iteration number
Histogram
Autocorrelation
Lag
Density
All
1-half
2-half

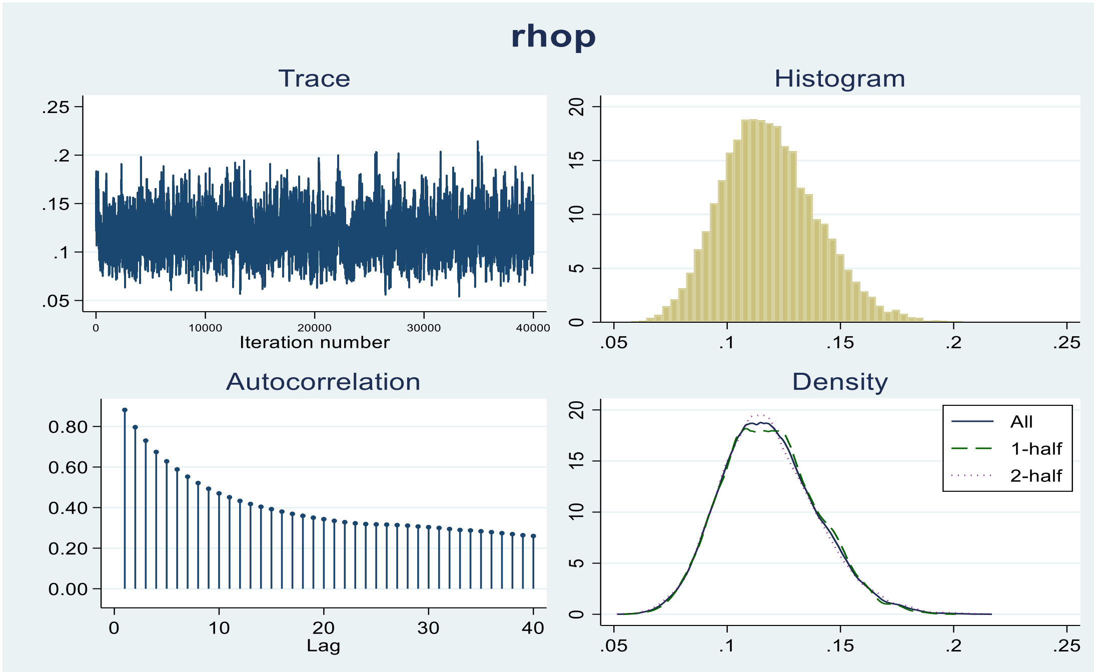

phi
Trace
Iteration number
Histogram
Autocorrelation
Lag
Density
All
1-half
2-half


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

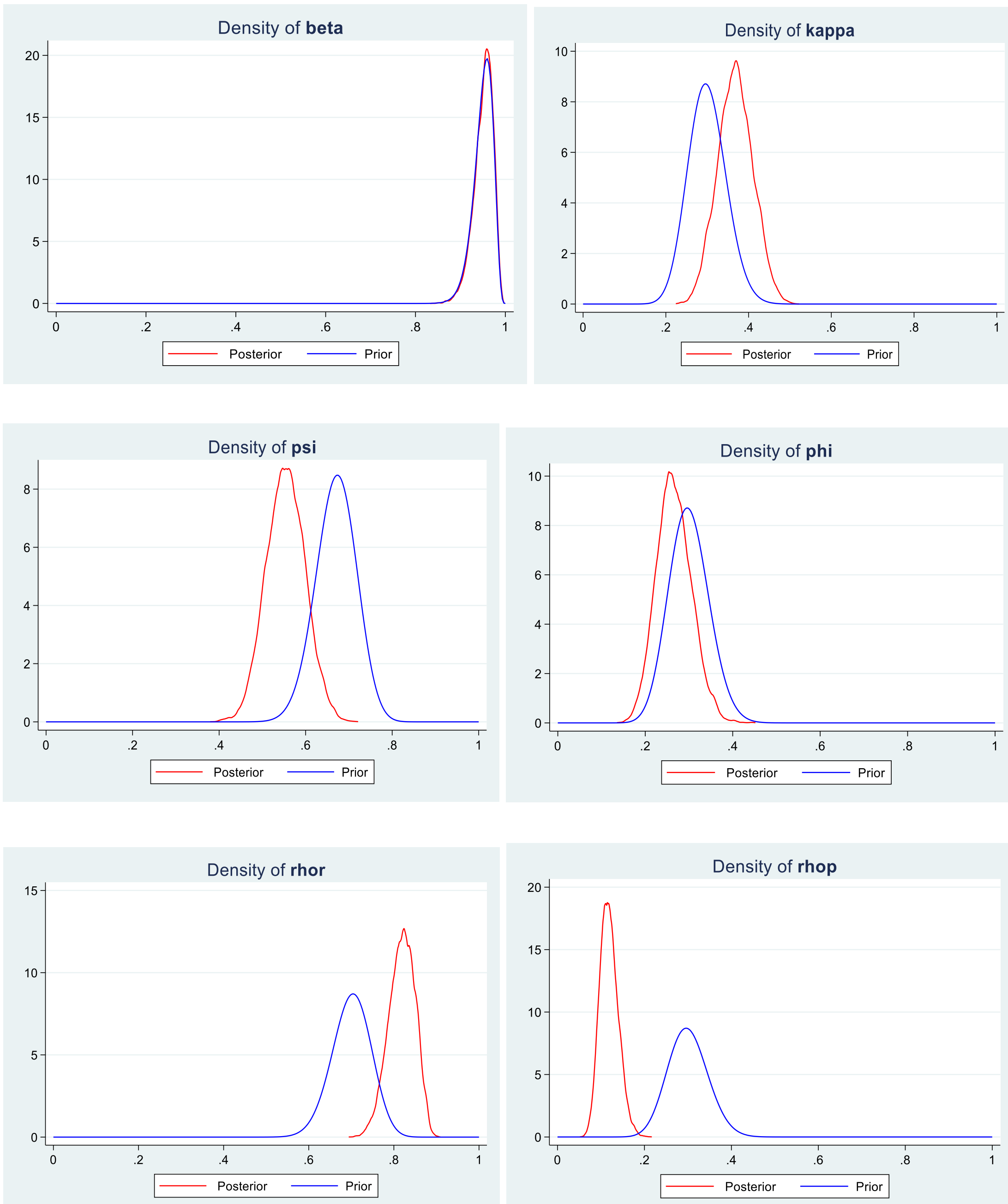

rhoe
Trace
Iteration number
Histogram
Autocorrelation
Lag
Density
All
1-half
2-half

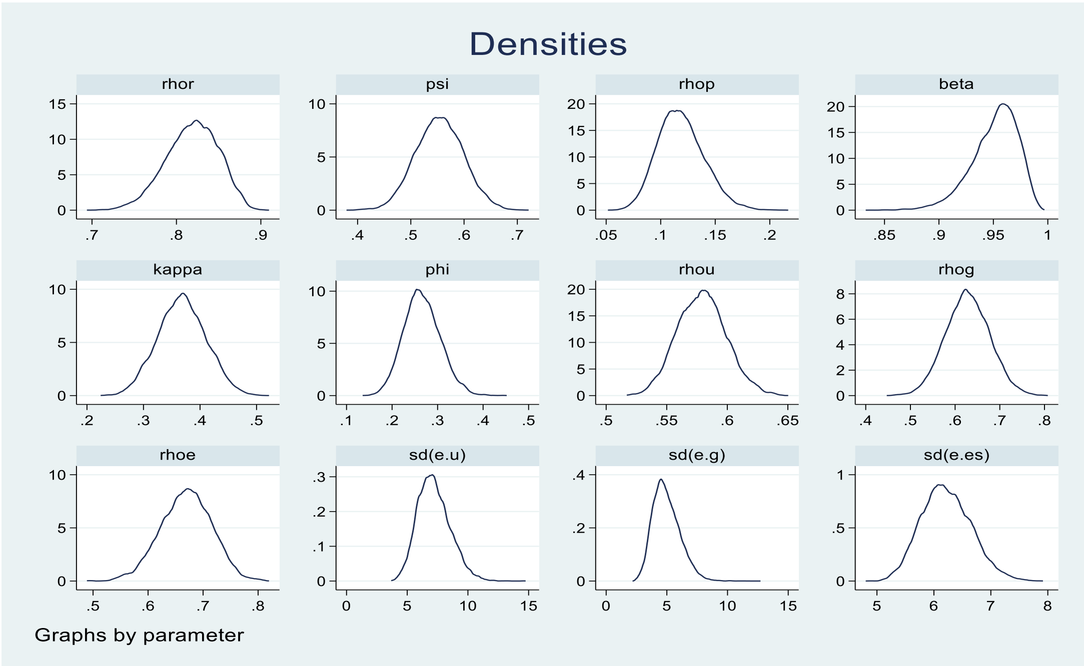

rhor
Trace
Iteration number
Histogram
Autocorrelation
Lag
Density
All
1-half
2-half

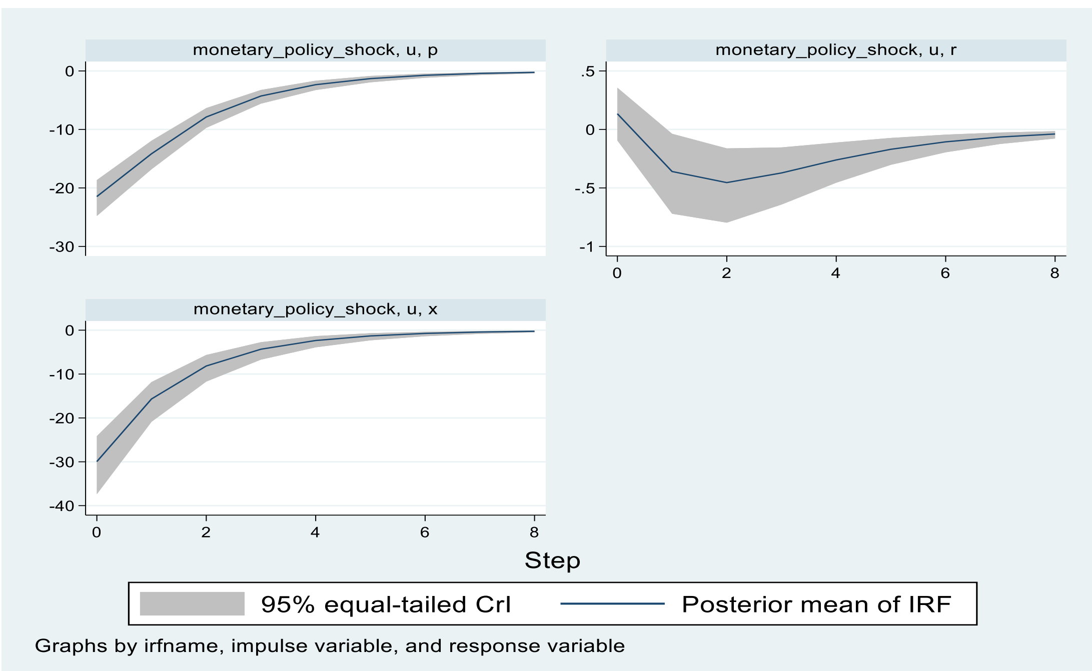


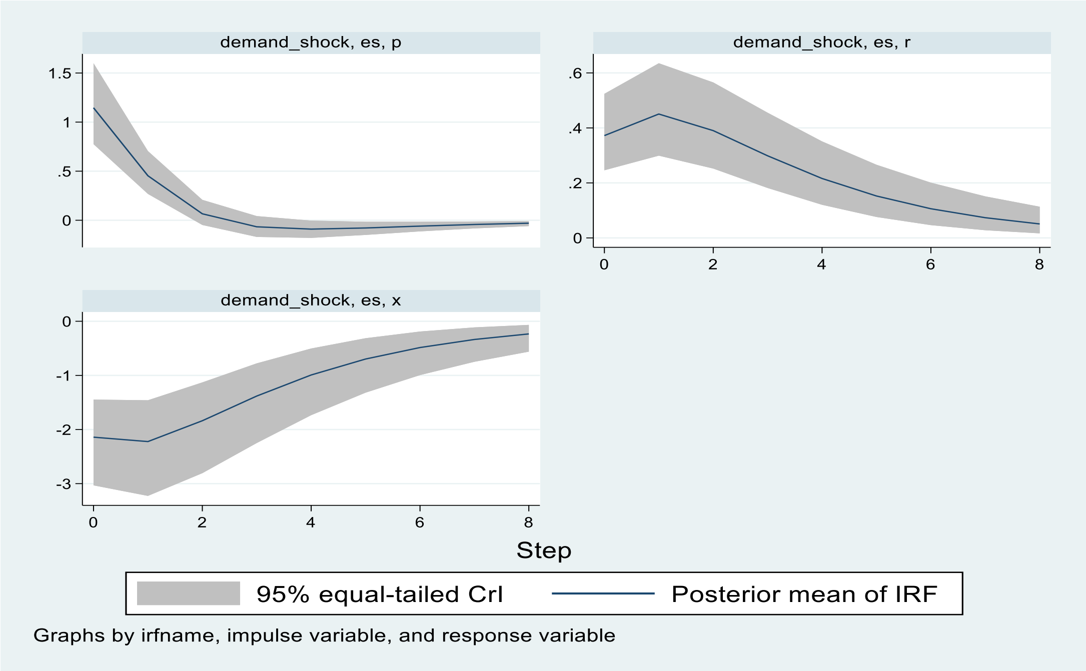

```
Efficiency summaries    MCMC sample size =     40,000
                        Efficiency:  min =    .004803
                                     avg =     .02744
                                     max =      .1077
```

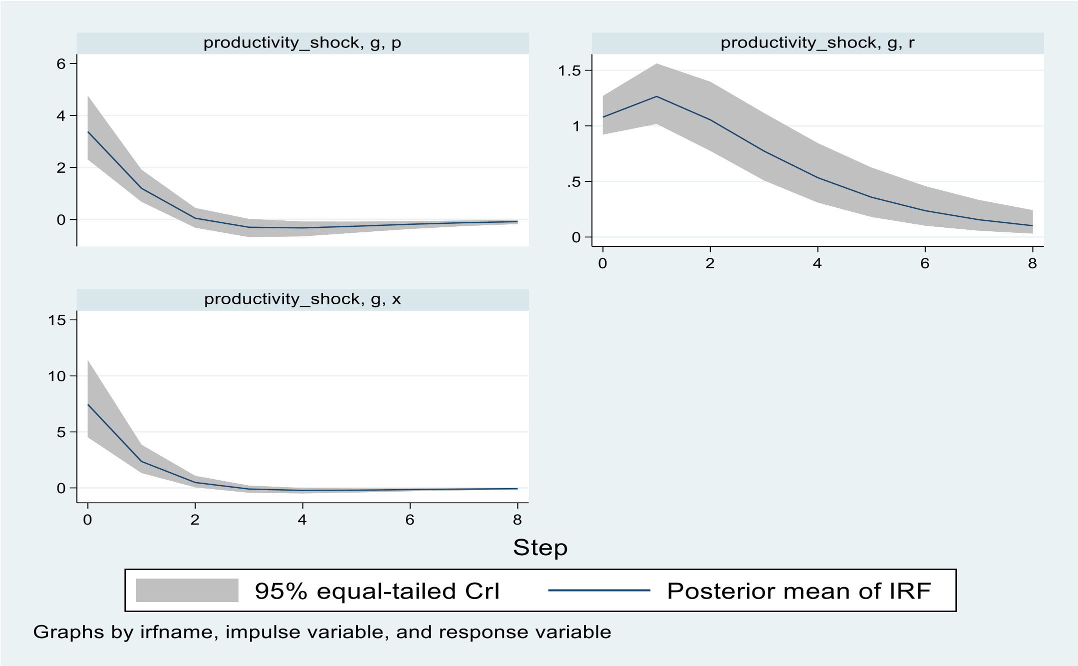
	ESS	Corr. time	Efficiency
rhor	332.23	120.40	0.0083
psi	2165.73	18.47	0.0541
rhop	594.35	67.30	0.0149
beta	4309.30	9.28	0.1077
kappa	222.06	180.13	0.0056
phi	2555.66	15.65	0.0639
rhou	192.12	208.20	0.0048
rhog	1077.84	37.11	0.0269
rhoe	428.61	93.32	0.0107
sd(e.u)	323.85	123.51	0.0081
sd(e.g)	271.59	147.28	0.0068
sd(e.es)	695.67	57.50	0.0174

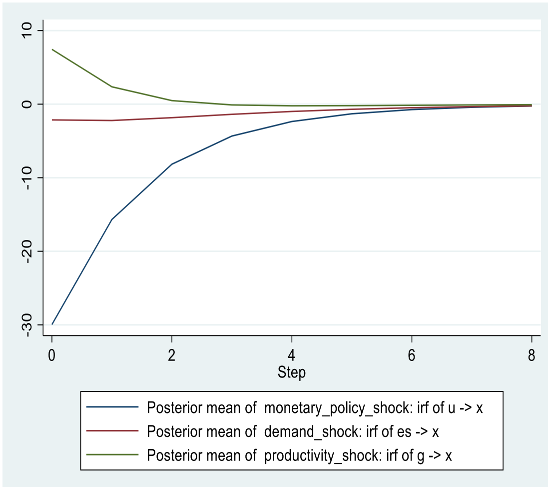

Density of beta
20
15
10
5
0
0 .2 .4 .6 .8 1
Posterior Prior
Density of kappa
10
8
6
4
2
0
0 .2 .4 .6 .8 1
Posterior Prior
Density of psi
8
6
4
2
0
0 .2 .4 .6 .8 1
Posterior Prior
Density of phi
10
8
6
4
2
0
0 .2 .4 .6 .8 1
Posterior Prior
Density of rhor
15
10
5
0
0 .2 .4 .6 .8 1
Posterior Prior
Density of rhop
20
15
10
5
0
0 .2 .4 .6 .8 1
Posterior Prior

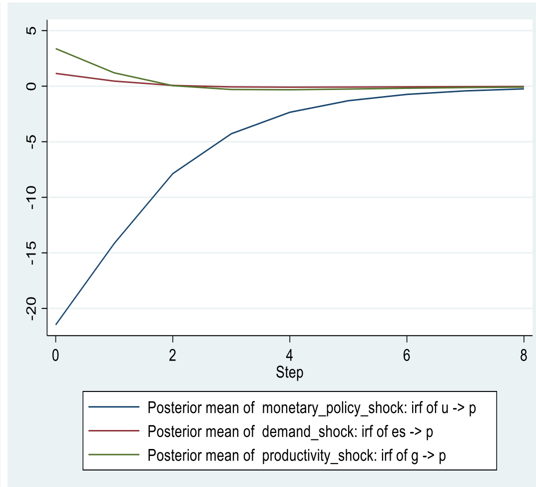

Densities
rhor
psi
rhop
beta
kappa
phi
rhou
rhog
rhoe
sd(e.u)
sd(e.g)
sd(e.es)
Graphs by parameter

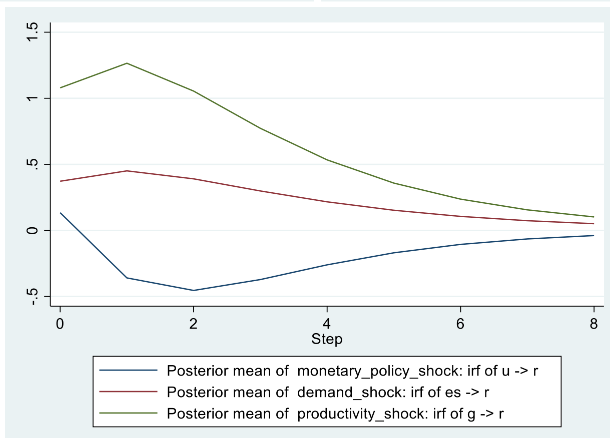

monetary_policy_shock, u, p
monetary_policy_shock, u, r
monetary_policy_shock, u, x
Step
95% equal-tailed CrI
Posterior mean of IRF
Graphs by irfname, impulse variable, and response variable


demand_shock, es, p
demand_shock, es, r
demand_shock, es, x
Step
95% equal-tailed CrI
Posterior mean of IRF
Graphs by irfname, impulse variable, and response variable


productivity_shock, g, p
productivity_shock, g, r
productivity_shock, g, x
Step
95% equal-tailed CrI
Posterior mean of IRF
Graphs by irfname, impulse variable, and response variable


10
0
-10
-20
-30
0
2
4
6
8
Step
Posterior mean of monetary_policy_shock: irf of u -> x
Posterior mean of demand_shock: irf of es -> x
Posterior mean of productivity_shock: irf of g -> x


5
0
-5
-10
-15
-20
0
2
4
6
8
Step
Posterior mean of monetary_policy_shock: irf of u -> p
Posterior mean of demand_shock: irf of es -> p
Posterior mean of productivity_shock: irf of g -> p


1.5
1
.5
0
-.5
0
2
4
6
8
Step
Posterior mean of monetary_policy_shock: irf of u -> r
Posterior mean of demand_shock: irf of es -> r
Posterior mean of productivity_shock: irf of g -> r

ANALYSIS OF MONETARY POLICY RESPONSE TO PRODUCTIVITY AND DEMAND SHOCKS IN GHANA: A BAYESIAN DSGE APPROACH

John Owusu-Afriyie*[1], Emmanuel Owusu-Afriyie[2] and Anderson Farouk Ayambire[3]

Abstract

Exogenous shocks of demand and productivity tend to influence the direction of Monetary Policy. For instance, the global financial crises in 2009 and the COVID-19 pandemic in 2020 negatively impacted the macroeconomic policy objectives of most central banks, including those of the Bank of Ghana. Thus, this paper seeks to analyse the dynamic response of Monetary Policy Rate (MPR) to productivity and demand shocks in Ghana, by employing recent quarterly data to estimate a Bayesian Dynamic Stochastic General Equilibrium (DSGE) Model. The findings indicate that the response of MPR to productivity shock is non-monotonic and somewhat permanent, whilst the response of MPR to demand shock is very transient. Thus, based on the findings, the monetary authority in Ghana has to make a choice between the objectives of maintaining a stable exchange rate and lowering interest rate to raise the level of productivity.

Keywords: Ghana, Monetary Policy, Monetary Policy Rate, Productivity Shocks, Demand Shocks, Bayesian DSGE model.

JEL Classification : C11, C32, C53, D58, E52, E58.

Disclaimer: This research paper does not represent the views of the Bank of Ghana and the West African Institute for Financial and Economic Management (WAIFEM) but those of the authors.

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[3] National Development Planning Commission, Accra, Ghana.

the course for their excellent facilitation. They are Prof. Afees Salisu (University of Ibadan), Prof. Yahya Simons OlaOluwa (University of Ibadan) and Dr. Jamaladeen Abubakar (Central Bank of Nigeria). This research paper is a product of our participation in the above-stated course.

1.0 INTRODUCTION

The overarching objectives of macroeconomic policies are to achieve improved economic growth that is broadly inclusive, stability in both domestic price conditions and the financial system as well as a sound external position. The attainment of these objectives has implications for the general wellbeing of the citizenry by way of increased employment opportunities and reduction in the erosion of their purchasing power. A stable financial system ensures effective financial intermediation and risk sharing to boost investment and consumption, and helps in unblocking the monetary policy transmission mechanism to boost its effectiveness as well as the transmission of monetary policy signals. In addition, a sound and solid external position ensures tranquillity and reduced volatility in the foreign exchange market, which in turn boosts the economy's resilience to external shocks. However, the presence of shocks undermines the potency of policy instruments engaged to achieve these ideals and their outcomes (Amri, Sayadi and Mamipour, 2021). This becomes severe in a situation where the monetary authorities lack knowledge of the nature of the evolution of the shocks, be it temporary or permanent.

Ghana aims at growing her economy at a significant rate and strives to become a developed country in the long run. After achieving the status of a Lower Middle-Income Country (LMIC), Ghana is making strenuous efforts to building on this gain to become a fully-fledged Middle-Income Country (MIC). Besides, the country has also ratified global and international development goals such as the Sustainable Development Goals (SDGs) and the African Union's Agenda 2063 among others, in order to reach her development potentials. Through the coordinated efforts of the fiscal and monetary authorities, varied policy measures and instruments are deployed to ensure the attainment of these broad national aspirations.

For the purpose of implementing monetary policy, central banks typically use a single policy instrument, either a money price (short-term interest rates) or a money quantity (outside money) (Jose and Andrew,1994). The monetary transmission mechanism acts as a conduit to establish an endogenous link between the single policy instrument and the policy objectives. For instance, an adjustment of the policy interest rate by the central bank, through its effects on market rates, asset prices and expectations, tends to affect domestic demand conditions, which ultimately affect price levels in a desired direction. Also, as per the Uncovered Interest Rate Parity (UIP) condition, adjustments in a domestic interest rate influences its differentials with other foreign interest rates, which in turn influences depreciation/appreciation of the domestic currency with either a direct pass-through effect on domestic prices or on demand for imports (Sowa and Kwakye, 1993). This underscores the relevance of any study that attempts to investigate monetary policy transmission channels, particularly the effectiveness of monetary transmission mechanism under conditions of stochastic shocks.

Ghana, being an open-economy like the rest of the world, is susceptible to all the vagaries of the international economic system. Thus, events that happen globally tend to impact the economy either positively or negatively. For instance, when global commodity prices experience fluctuations (whether favourable or unfavourable), they go a long way to impact the economy either positively or negatively. More notably, these exogenous shocks may impede the effectiveness of monetary policy, if appropriate measures are not taken.

Furthermore, in recent times, the geopolitical tensions between USA and China under Donald Trump's administration, interspersed with the COVID-19 global pandemic and the ongoing Ukraine-Russia war are events most likely to impact heavily on the Ghanaian economy (Bank of Ghana, 2022). These may trigger productivity, demand and financial shocks. Thus, in view of this, the key research questions that arise are: how does Monetary Policy Rate (MPR) respond to productivity and demand shocks in Ghana? What is the nature of the effects of these shocks on the MPR (permanent or transient)? What are the policy options to contain these shocks?

This paper therefore seeks to concurrently analyse the dynamic response of Monetary Policy Rate (MPR) to productivity and demand shocks in Ghana, by employing recent data to estimate a Bayesian Dynamic Stochastic General Equilibrium (DSGE) Model.

The rest of the paper is organised as follows: Section 2 presents the stylized facts of monetary policy in Ghana, whilst Section 3 presents the empirical literature review. Framework and methodology are carefully presented in Section 4, whilst Section 5 presents results and discussion. The paper ends with conclusion and policy implication in Section 6.

2.0 STYLISED FACTS OF MONETARY POLICY IN GHANA

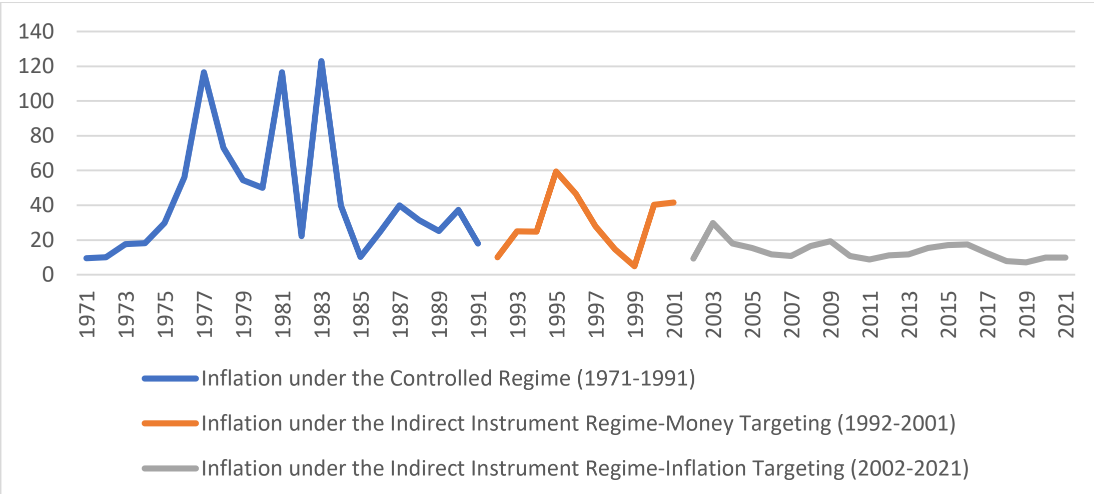
Monetary policy implementation in Ghana has evolved from the application of direct instruments to indirect instruments. Prior to 1992, the Bank of Ghana adopted direct instruments to regulate price and exchange rate. However, due to the mal-performance of the economy (i.e. macroeconomic instability), indirect instruments of monetary policy were adopted from 1992 to 2001 under the Monetary Targeting (MT) regime. The Bank of Ghana eventually switched from MT regime to Inflation Targeting (IT) regime in 2002.

Prior to the introduction of indirect instruments, the Bank of Ghana used direct instruments or the controlled regime, which featured interest rate controls, credit ceilings, and directed lending/ sectoral lending. The objective was to direct credit to the "priority sectors" (i.e. the productive sectors) of the economy, which included agriculture, manufacturing, mining, and export finance. Under the controlled regime, the monetary authority placed a damper both on interest rates and credits that were allocated to the designated priority sectors including the agricultural sector with the view to boosting productivity and hence, reduce unemployment. The controlled regime had benefits as well as costs. Its benefits included the following: relatively easy to implement and explain; quite low direct fiscal costs; attractive to governments that want to channel credit to meet specific objectives; and it is the only option in rudimentary and non-competitive financial systems until the institutional framework for indirect instruments has been developed. On the contrary, the associated costs of the controlled regime included inefficiency of resource allocation and financial repression.

Diverse inflationary outcomes were experienced under the various monetary policy regimes from 1971 to 2021 (Figure 1). For instance, from 1971 to 1991 (the controlled regime), inflation was very high and volatile, whilst from 1992 to 2001 (the indirect instrument era of Money Targeting), inflation was relatively mild but volatile. Inflation was however lower and stable under the indirect instrument era of Inflation Targeting, compared to those of controlled and Monetary Targeting regimes, respectively.

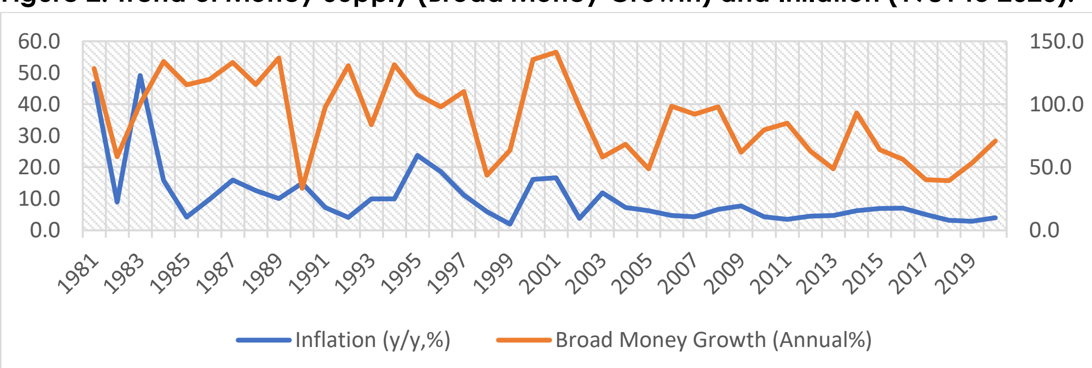
Financial sector reforms were undertaken as part of the broader economic and structural reforms in 1983. Direct control measures were progressively dismantled and replaced with market-based (indirect) instruments in early 1992 under the Monetary Targeting (MT) framework. This framework is based on the Quantity Theory of Money that suggests a stable relationship between the growth of money supply and domestic inflation rate. Hence, curtailing money supply was expected to lead to decreased inflation and hence price stability. However, this regime is hinged on the strong assumption of stable money demand function. The challenge with the Monetary Targeting (MT) regime is the unstable velocity and multiplier due to financial deregulation and innovations, which leads to weak link between money supply and inflation (ineffective nominal anchor). High and volatile inflation also partly reflected monetary accommodation (fiscal dominance).

Figure 1: Trend of Inflation Under Various Regimes of Monetary Policy (1971 to 2021)



Note: This figure is constructed based on inflation data obtained from the Bank of Ghana. The y-axis of the graph represents year-on-year inflation rates (%) whilst the x-axis represents the various years under consideration. The points where there is discontinuity of the line represent a regime switch.

Figure 2: Trend of Money Supply (Broad Money Growth) and Inflation (1981 to 2020).



Note: Date for this Figure are extracted from the World Bank's World Development Indicators (2021). Inflation (y/y, %) is defined as year-on-year inflation rate.

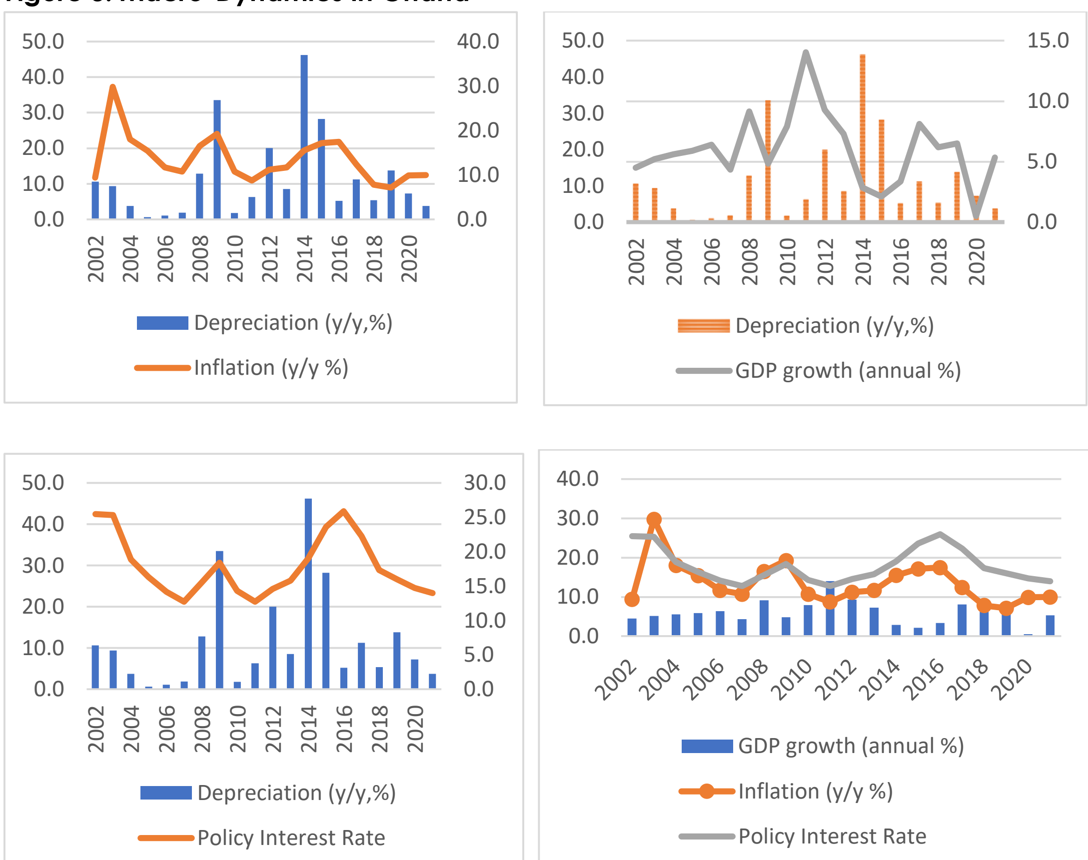
The unstable velocity and money multiplier led to a weaker link between money supply and inflation, especially visible after the year 2000 (see Figure 2). This reduced the relevance of money supply targets in the inflationary process due to many years of financial innovation. In addition, the Monetary Targeting (MT) regime led to high and volatile inflation and exchange rate depreciation as well as strong fiscal dominance (persistent fiscal deficits were financed largely by monetary accommodation). Strong inertial inflation expectations also characterised the regime due to high inflation and exchange rate volatility. Hence, breaking the inflation inertia was a core challenge for monetary policy in the current Inflation Targeting (IT) regime. Consequently, a new BOG Act was enacted, Act 2002 (Act 612), which was passed to enable BOG implement independent policies as well as grant it an operational independence. Specifically, under Section 3 (1) of the Act, the primary objective of the Bank was stated as to maintain stability in the general price level. Furthermore, without prejudice to Section 3 (1) of the Act, Section 3 (2) states that *"the Bank shall support the general economic policy of the Government and promote economic growth, and effective and efficient operation of banking and credit systems in the country, independent of instructions from the Government or any other authority''*.

The BOG Act of 2016 (i.e. Act 918) also resolves the issue of fiscal dominance by placing a limit on government's borrowing in any fiscal year (i.e. Section 30(2)); the limit is 5% of previous fiscal year's total revenue. The Act also provides for the establishment of a Monetary Policy Committee (MPC) [under Section 27] consisting of two external members appointed by the Minister of Finance. These institutional reforms set the tone for the introduction of full Inflation Targeting (IT) regime in 2007. Under the IT framework, the Monetary Policy Rate (MPR) is used as the main policy instrument to signal inflationary pressures.

The IT framework is designed to engineer a switch to low inflation and sound financial system through increased coordination between monetary and fiscal policy, anchored on domestic debt reduction to deal with the problem of fiscal dominance. After the adoption of the IT regime, the rate of inflation has seen a consistent decline (see Figure 2). According to World Bank (2016), inflation rate, which averaged 27.9 per cent between 1992 and 2001 (period of monetary targeting), declined to about 14 per cent between 2002 and 2016 (period of Inflation Targeting).

Similarly, the cedi depreciation was low for the period 2004-2008 with an average rate of depreciation of 4.0%, whilst the period 2012-2016 saw a very high rate of cedi depreciation, with an average rate of depreciation of 21.7% (Figure 3). Periods of high rate of depreciation were accompanied by high rates of inflation, which could be attributed to the pass-through effect (Figure 3). Periods of high rate of depreciation are characterized by low GDP growth rates (Figure 3), which could be attributed to resulting negative effect of high rate of depreciation on demand for imports. The cedi has undoubtedly remained very volatile over the years alongside unstable economic growth momentum. Notwithstanding the continuous decline in the growth of output of Ghana since 2017, the economy has witnessed a tremendous improvement in recent times, especially as she recuperates from the Covid-19 pandemic (see Figure 3).

Figure 3: Macro-Dynamics in Ghana



Note: Authors' construction is based on data from Bank of Ghana and World Development Indicators. Inflation (y/y, %) and Depreciation (y/y, %) are defined as year-on-year inflation and year-on-year cedi depreciation rates respectively.

3.0 LITERATURE REVIEW

The crucial role of money and its related policy in the propagation of shocks across different periods cannot be ignored (Schularick and Taylor, 2012). Monetary policy shocks have long been known to be significant for aggregate output performance (Cochrane, 1994). A contractionary monetary policy, for instance, causes a decline in output, consumption, and employment (see Akosah, 2020; Takyi and Leon-Gonzalez, 2020a). In other words, a procyclical monetary policy to curtail inflationary trend is likely to exacerbate the shock's impact on economic activity (Ocampo and Ojeda-Joya, 2022). Similarly, a shock to income could also be traced to a shock emanating from monetary policy (Takyi and Leon-Gonzalez, 2020b). The foregoing suggests the far-reaching effect of the monetary policy shock (through various channels) on an economy. Similarly, studies on the monetary policy responses to other forms of shocks equally abound in the literature. On account of trade (external) shock, monetary authority could be faced with the options of pursuing a countercyclical policy measure and defending its currency (Vegh et al., 2017), thereby making the response of monetary policy a function of the adopted option.

There is another line of literature that separates the conducts of monetary policy before and after the global financial crisis of 2009. In the former, it was expected that as liquidity dried up during financial panics, the major role of central banks was to inject additional liquidity into the financial system. Thus, the Fed was established primarily to stop financial panics, along with the violent increases in interest rates and their associated bank failures (Cukierman, 2013). Meanwhile, following the global financial crisis, banks have been operating more like a market maker of last resort than like the traditional Thornton-Bagehot lender of last resort (Humphrey, 2010).

Furthermore, the reactions of monetary policy to shocks have been subjected to empirical exercise. Recently, the direction of monetary policy in the face of supply and demand disruptions has been validated (Fornaro and Wolf, 2020). In Ghana, interest rates react to inflation shocks in the manner that is theoretically obtainable, and monetary policy reaction functions are comparable to those of other countries with successful monetary policies (Bleaney et al., 2020). Moreover, the economic performance of Ghana has been attributed to the potency of monetary policy than fiscal’s (Havi and Enu, 2014).

Similarly, responses to monetary policy across countries and regions are evident in the literature. Here, output response to monetary shocks across different groups in Europe appears to follow the same pattern, while the uncertainty bands for price responses show the leeway of stronger effects in some areas (Jarociński, 2010). In the same vein, an upward movement in interest rate depresses commodity prices in no little percentage (Scrimgeour, 2015).

Our interest to this strand of literature is motivated by the recent studies such as Akosah, Alagidede, & Schaling (2020), Peiris & Saxegaard (2007), Lahcen (2014) and Okot (2020). Peiris & Saxegaard (2007), Lahcen (2014) and Okot (2020) who applied Maximum Likelihood DSGE models to low income countries' data, Morrocan and Ugandan data respectively. Generally, these studies find that supply shocks (i.e. productivity shocks) produce short-term effects, whilst demand shock is of long term nature. Also, they find that a positive monetary policy shock reduces interest rate with a positive impact on the output gap. The limitation of these studies is that their model (i.e. Maximum Likelihood DSGE model) does not make use of priors and also, the parameter estimates are point estimates rather than a distribution. Akosah, Alagidede, & Schaling (2020) on the other hand developed a standard representative-agents' New Keynesian model for Ghana and use a Bayesian estimation technique to determine the best suited monetary policy rule for Ghana. Basically, they find that a forward-looking Taylor rule - where authority reacts to one-period ahead of inflation deviation from target alongside current output gap is the most appropriate monetary policy rule for Ghana. In addition, they find that variations in output are mainly driven by price mark-up, labour supply, monetary policy and productivity shocks across the forecast horizons. However, exchange rate innovation representing demand shock was not explicitly captured in their model.

Based on the limitation of the Maximum Likelihood DSGE models and the implicit or inexplicit treatment of exchange rate shock in the recent studies reviewed, we employ the Bayesian DSGE model which gives more efficient parameter estimates. We also explicitly treat exchange rate shock as an exogenous shock unlike Akosah, Alagidede, & Schaling (2020). Overall, our study is a blend of new methodological perspective on DSGE modelling (i.e. Bayesian DSGE model) and the treatment of exchange rate shock as exogenous.

4.0 FRAMEWORK AND METHODOLOGY

4.1 Framework

The macro-econometric model that is adopted in this study, known as the Bayesian Dynamic Stochastic General Equilibrium (DSGE) model, is a small, dynamic and open-economy representation of an economy within the context of a linearized New Keynesian model. The study employs the Bayesian DSGE to analyse the response of monetary policy to productivity and demand shocks as it is built on microeconomic foundation that is good for obtaining reliable results from calibration, has the ability to avoid the Lucas critique and allows priors to be set for various parameters (Hara et al., 2009). Furthermore, in principle, the Bayesian DSGE model can identify sources of fluctuations, provide information about structural changes, forecast and predict the effect of policy changes, and perform counterfactual experiments (Coletti and Murchison, 2002). It is an undeniable fact that DSGE models have come to stay and will remain central to how Macroeconomists think about aggregate phenomenon and policy (Christiano et. al, 2017).

The Bayesian DSGE model takes into account the optimization problems of the three main economic agents namely the household, the firm and the government (herein represented by the Central Bank). Under this model, it is assumed that households maximize utility, taking the paths of real wage and real interest rate as given (Romer, 2012). Firms, which are owned by the households, on the other hand maximizes the present discounted value of their profits subject to constraints on their price-setting (which vary across the different versions of the DSGE model). Finally, as per the model, the central bank (specifically, the Bank of Ghana) determines the path of real interest rate through its conduct of monetary policy (Romer, 2012).

Thus, the optimization problem of the three main economic agents within the context of our Bayesian DSGE model is presented as follows:

4.1.1 The Household

The household's optimization problem leads to an Euler equation specified in linear form as:

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

where x_t is the output gap (modelled as an unobserved control variable), $E_t(x_{t+1})$ is the future expected output gap, r_t is the Monetary Policy Rate (which is modelled as an observed control variable), $E_t(p_{t+1})$ is the future expected inflation and g_t is a first-order autoregressive state variable.

4.1.2 The Firm

Optimization by firms generates the Philips Curve equation that links the current deviation of inflation from its steady state to the expected value of the deviation of inflation from its steady state in future and to the ratio of actual output to the natural level of output. Thus, the Phillips Curve equation is specified linearly as:

$$p_t = \beta E_t(p_{t+1}) + \kappa x_t \quad (2a)$$

where β is the discount factor, which captures households' willingness to delay consumption, p_t is current inflation (which is modelled as an observed control variable and proxied by GDP Deflator), and the parameter, κ , measures the impact of output gap on p_t. Equation (2a) implies that firms' pricing decisions are influence by expected inflation and real marginal costs (herein represented by the output gap).

Ghana being a small open economy and under the assumptions of backward-looking price-setting firms and interest rate smoothing, Equation (2a) is modified as:

$$p_t = \rho_p L p_t + (1 - \rho_p)[\beta E_t(p_{t+1}) + \kappa x_t + \phi es_t] \qquad (2b)$$

where Lp_t is defined as p_{t-1} (which is one period's lag of inflation), and es_t is exchange rate (a measure of economic openness). Exchange rate is defined as cedi per dollar rate using the interbank forex mid-rates. The parameter, ρ_p, measures the effect of one period's lag of inflation on current inflation (i.e. inflation inertia), whilst the parameter, ϕ, captures the effect of exchange rate on current inflation (i.e. the exchange rate pass-through effect).

4.1.3 The Central Bank (i.e. The Bank of Ghana)

The Bank of Ghana's policy response to inflation and exogenous shocks in ensuring price and exchange rate stability is represented by the interest rate equation, also known as the Taylor's rule equation. The central bank adjusts the interest rate (also known as the Monetary Policy Rate or the Prime Rate) in response to inflation deviation from target and other idiosyncratic exogenous shocks. The interest rate equation or the Taylor's rule equation is specified as:

$$r_t = \frac{1}{\beta} p_t + u_t \qquad (3a)$$

where r_t is the short-term nominal Monetary Policy Rate (MPR) and u_t is a state variable that captures all movements in the interest rate that are not driven by inflation. Also, it is worth noting that u_t is the first-order autoregressive state variable and the parameter, $\frac{1}{\beta}$, measures the effect of inflation on MPR.

Building on the work of Woodford (2003) by assuming interest rate smoothing, Equation (3a) is modified as:

$$r_t = \rho_r L r_t + \frac{1-\rho_r}{\beta} p_t + u_t \qquad (3b)$$

where Lr_t is defined as r_{t-1} (which is one period's lag of Monetary Policy Rate), the parameters, ρ_r and $\frac{1-\rho_r}{\beta}$, are the Monetary Policy Rate (MPR) inertia and interest rate smoothing terms respectively. Specifically, the parameter, ρ_r, measures the effect of a period's lag of MPR on the current MPR, whilst the parameter , $\frac{1-\rho_r}{\beta}$, measures the effect of inflation on MPR. u_t in Equation 5 is as previously defined in Equation (3b).

It is worth noting that all the variables of the linearized DSGE equations [i.e. Equations (1), (2a), (2b), (3a) and (3b)] are in logarithms.

4.1.4 Structural Shocks

The last set of equations of the Bayesian DSGE model describes the evolution of the state variables u_t, g_t, and es_t respectively. These equations are relevant because they constitute the stochastic components of the DSGE model. Specifically, they capture the dynamic effects of three shocks namely monetary policy shock (u_t), productivity shock (g_t), and demand shock (es_t). These structural shock equations are specified as first-order autoregressive processes in logarithmic forms as follows:

$$u_{t+1} = \rho_u u_t + \epsilon_{t+1} \quad (4a)$$

$$g_{t+1} = \rho_g g_t + \xi_{t+1} \quad (4b)$$

$$es_{t+1} = \rho_{es} es_t + v_{t+1} \quad (4c)$$

Equations (4a), (4b) and (4c) are the monetary policy shock, productivity shock, and demand shock equations respectively. The stochastic terms of Equations (4a), (4b) and (4c) are ϵ_{t+1}, ξ_{t+1}, and v_{t+1} respectively.

4.2 Estimation Technique

The estimation technique employed by the paper is the Bayesian approach to estimating a DSGE model. The technique uses the Markov Chain Monte Carlo (MCMC) method with the number of iterations measured by an MCMC size of 40, 000 draws. The technique also uses the Metropolis-Hastings sampling algorithm. The length of the burn-in period is set at 6, 000 with a sample size of 80 observations. Furthermore, to analyze convergence diagnostics, the trace, histogram, autocorrelation and density plots are employed. In addition, the block option in the Bayesian DSGE STATA command is employed to circumvent the macro-econometric problem of high autocorrelation and non-stationarity among the respective distributions of the parameters.

4.3 Sources of Data, Description and Summary Statistics

Data for the study spans from 2002 to 2021. The frequency of the data is quarterly series. Data for GDP deflator, interbank forex-mid rates and Monetary Policy Rate (MPR) are obtained from the Bank of Ghana. In the dataset, GDP Deflator is measured as the ratio of nominal GDP to real GDP expressed as a percentage and the interbank forex-mid rate is calculated as the simple average of the interbank selling and buying forex rates (Cedi-Dollar rates). Summary Statistics for the variables employed to estimate our Bayesian DSGE model are reported in Table 1.

Table 1: Summary Statistics of the Variables

Variables	Observations	Mean	Std. Dev.	Coefficient of Variation (%)	Min.	Max.
GDP Deflator (p_t)	76	14.09	5.24	37.2	7.80	32.69
Monetary Policy Rate(r_t)	80	17.90	4.30	24.0	12.50	27.50
Interbank Forex Mid-Rate (es_t)	80	2.52	1.77	70.2	0.63	5.91

Note: Authors' estimates are based on the dataset. Coefficient of Variation (CV) is computed as the ratio of standard deviation to the mean expressed as a percentage (i.e. CV $=\frac{\sigma}{\mu}$ x100, Where σ is the standard deviation and μ is the mean).

Table 1 indicates the following: GDP Deflator (a measure of inflation, p_t) has a mean of 14.09 with a coefficient of variation of 37.2%; Monetary Policy Rate (r_t) has a mean of 17.90 with a coefficient of variation of 24.0% and Interbank Forex Mid-Rate (es_t) has a mean of 2.52 with a coefficient of variation of 70.2%. Thus, among our variables, Interbank Forex Mid-Rate (es_t) has the highest rate of volatility, whilst Monetary Policy Rate (r_t) has the lowest rate of volatility over the sample period (Table 1).

4.4 Prior Distributions of the Estimated Parameter

The priors used in the estimation of our Bayesian DSGE model are presented in Table 2. The distribution of these priors is determined by theory and institutional knowledge. Typically, beta (β) must lie between 0 and 1, with common values ranging between 0.90 and 0.99. The kappa (κ) on the other hand is theoretically assumed to be small and positive. The autocorrelation parameters (i.e. ρ_u, ρ_g, ρ_{es} and ρ_{sp}) must lie between -1 and 1 but are assumed to be positive and closer to 1 than to 0. Furthermore, to maintain stability, the coefficient of inflation to monetary policy rate must be between 0 and 1. The priors for estimating our Bayesian DSGE model are selected to match theoretical expectations. Table 2 therefore highlights the priors for the parameters of our Bayesian DSGE model.

Table 2: Prior Distributions of the Estimated Parameters

Parameter	Interpretation	Range	Nature of Distribution	Para(1)	Para(2)
ρ_r	Interest rate smoothening parameter	(0,1)	Beta	0.70	0.30
ρ_p	Parameter measuring the effect of backward-looking price setting behaviour of firms on inflation	(0,1)	Beta	0.30	0.70
β	Discount factor	(0,1)	Beta	0.95	0.05
κ	Price adjustment parameter	(0,+∞)	Beta	0.30	0.70
ϕ	Pricing decision of the firm	(0,+∞)	Beta	0.30	0.70
ρ_u	AR(1) for monetary policy shock	(-1,1)	Beta	0.50	0.50
ρ_g	AR(1) for productivity shock	(-1,1)	Beta	0.75	0.25
ρ_{es}	AR(1) for demand shock	(-1,1)	Beta	0.50	0.50
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: Prior distributions are the theoretical assumptions of the nature of distributions of the DSGE parameters. They play an important role in the estimation of DSGE models in that they might down-weigh regions of the parameter space that are at odds with observations not contained in the estimation sample. The prior distribution might also add curvature to a likelihood function that is (nearly) flat in some dimensions of the parameter space and therefore strongly influence the shape of the posterior distribution. In principle, priors can be deduced from personal introspection to reflect strongly held beliefs about the validity of economic theories. However, in practice, most priors are chosen based on some observations (See An and Schorfheide, 2007).

5.0 RESULTS AND DISCUSSION

Prior to reporting our estimated Bayesian DSGE parameters (in Table 3), we first carry out some convergence diagnostics to ascertain whether or not our parameters suffer from the macro-econometric problems of non-stationarity and autocorrelation. Thus, we run a convergence test for parameters without block and parameters with block. The results generally indicate that parameters without block have a trace which is not mean-reverting and also have autocorrelations which do not seem to decline over the various time lags (see Appendix A). Also, for parameters without block, the first and second halves of the distribution are non-symmetric with the overall distribution (see Appendix A). However, for parameters with block, our convergence diagnostics results indicate that the trace is mean-reverting, autocorrelations decline as the time lag increases and the first and second halves of the distribution are symmetric with the overall distribution (see Appendix A). This means that our estimated parameters with block (reported in Table 3) do not suffer from the problems of non-stationarity, autocorrelation and non-normality of their respective distributions.

Also, we construct prior and posterior density graphs of the parameters to inquire whether our dataset is informative or not. We find out that the density graphs for the prior and the posterior generally do not overlap each other (see Appendix D). This means that indeed our dataset is informative.

The posterior means of the estimated parameters in Table 3 indicate that the effects of monetary policy shock are 63.5% and 60.7% respectively for the closed and open economy cases respectively. This implies that the degree of persistence of monetary policy shock in the closed economy case is higher than that of the open economy case due possibly to the presence of other external channels to moderate or absolve the effects of policy shocks. Similarly, Table 3 indicates that the degree of persistence of productivity shock in the closed economy case (87.3%) is higher than that of the open economy case (82.5%). This is plausible because in a closed economy, macroeconomic shocks do not defuse to other economies and thus, has a longer lasting effect on the domestic economy compared to the case where the economy is opened to the rest of the world. This finding can be compared to Mickelsson (2009), which finds that shocks in interest rate, inflation, technology and consumption have higher and quicker effects on output and employment in an open economy than in a closed economy.

Table 3: Estimated Parameters of the Closed Economy and Open Economy Models (Both with Block)

	Closed Economy Model		Open Economy Model With an Interest Rate Smoothing Term	
Parameters	***Mean***	***95% Cred. Interval***	***Mean***	***95% Cred. Interval***
Β	0.947	[0.903, 0.980]	0.961	[0.921, 0.987]
1/ β	1.041	[1.013, 1.086]	----	----
Κ	0.232	[0.162, 0.314]	0.369	[0.286, 0.457]
ρ_r	----	----	0.908	[0.872, 0.938]
(1-ρ_r)/β	----	----	0.096	[0.065, 0.133]
ρ_p	----	----	0.162	[0.116, 0.218]
ϕ	----	----	0.253	[0.251, 0.178]
ρ_u	0.635	[0.590, 0.682]	0.607	[0.570, 0.647]
ρ_g	0.873	[0.829,0.913]	0.825	[0.767, 0.878]
ρ_{es}	----	----	0.403	[0.315, 0.497]
$\sigma_{e.u}$	50.816	[43.188, 60.304]	4.388	[2.830, 6.397]
$\sigma_{e.g}$	0.308	[0.180, 0.486]	4.387	[2.404, 7.656]
$\sigma_{e.es}$	----	----	10.732	[9.121, 12.696]

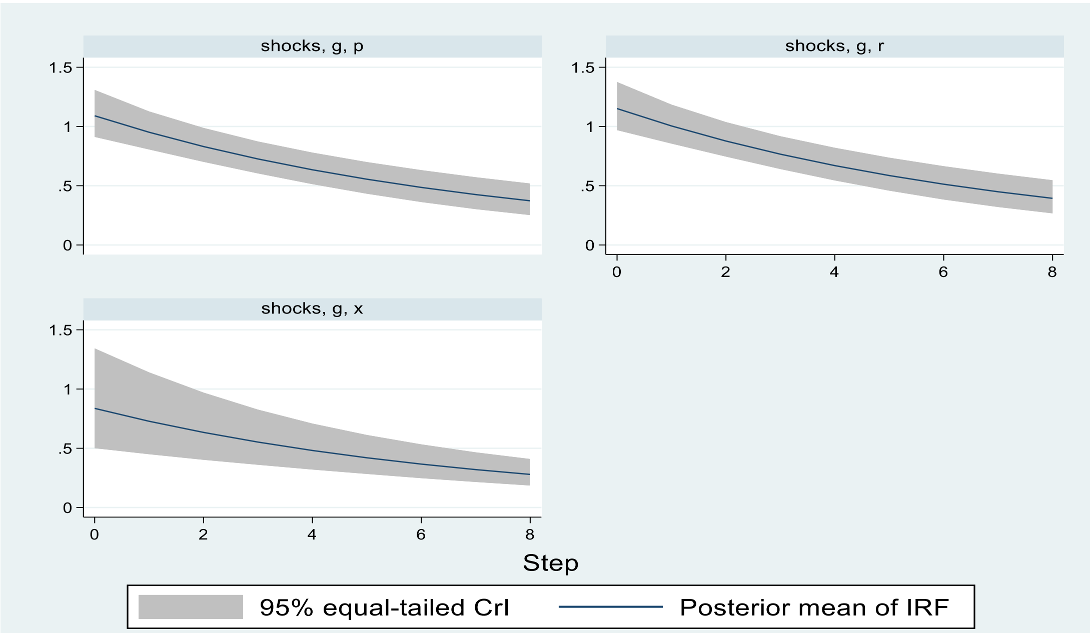
Note: MCMC Size is 40, 000 with a burn-in length of 6000.
---- means parameter is not present in the model.

Furthermore, our results indicate that the degree of persistence of demand or exchange rate shock is 40.3% (Table 3). This implies that for Ghana (a small open economy), the effect of productivity shock is the most persistent, followed by those of monetary policy (60.7%) and demand shocks (40.3%) respectively. The persistence of productivity shock suggest that supply shocks have lasting effects on the economy, which has implication for monetary policy in terms of the relative weights that have to be considered regarding price and output stability in the event of such shocks.

5.1 Response of Monetary Policy Rate (MPR) to Productivity and Demand Shocks Under *a Closed Economy Scenario*

Under the closed economy scenario, the response of MPR to productivity shock is persistent and monotonic in that MPR decreases as the lead lags increase but does not reach its steady state value over the period under consideration (Figure 4). This response is triggered by the permanent and monotonic effects of productivity shock on output gap and prices (Figure 4). MPR responds positively to changes in prices caused by changes in productivity to stabilize inflation. It is worth noting that under the closed economy scenario, a productivity shock to output gap has a direct effect on prices without exchange rate-pass through effect.

Figure 4: Response of MPR to Productivity Shock (Closed Economy Case)

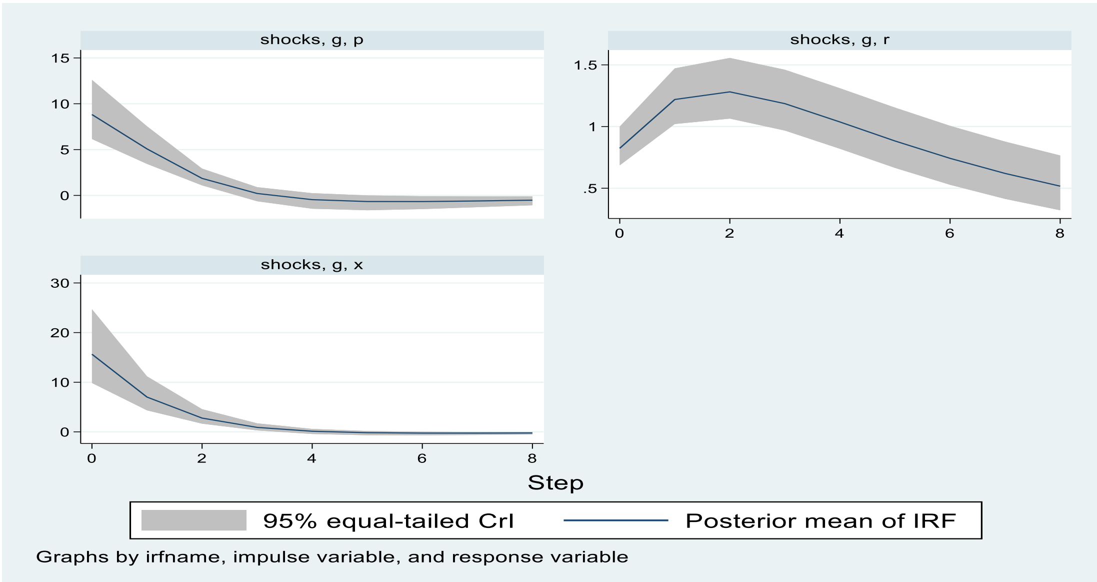


Note: Authors' construct is based on the dataset. The Impulse Response Graph (IRG) in the upper-right quadrant represents percentage deviations in Monetary Policy Rate (MPR) due to Cholesky one standard deviation shock to productivity, whilst the IRG in the upper-left quadrant represents percentage deviations in inflation (i.e. the general price level) due to Cholesky one standard deviation shock to productivity. The IRG in the lower-left quadrant represents percentage deviations in output gap due to Cholesky one standard deviation shock to productivity.

5.2 Response of Monetary Policy Rate (MPR) to Productivity and Demand Shocks Under an Open Economy Scenario

On the contrary, under the open economy scenario (which depicts Ghana's reality), the response of MPR to productivity shock is somewhat persistent but non-monotonic (Figure 5). Specifically, MPR increases in the first two quarters in response to productivity shock (i.e. 1st and 2nd quarters) but starts declining after the 2nd quarter. However, MPR does not decline to its steady state (Figure 5). In terms of shock transmission, productivity shock causes dynamic changes in output gap (x), which dynamically impacts on prices (p). Thus, in response to this shock, it may be desirable to raise MPR in the first two quarters and thereafter, reduce MPR to stabilize prices (Figure 5).

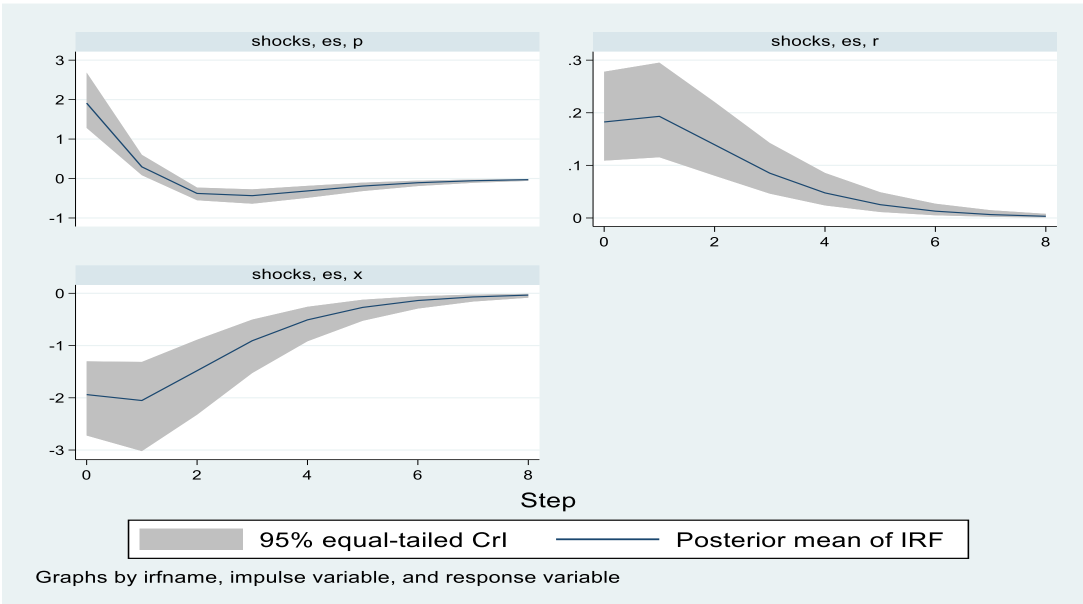
Figure 5: Response of MPR to Productivity Shock (Open Economy Scenario)



Note: Authors' construct is based on dataset. The Impulse Response Graph (IRG) in the upper-right quadrant represents percentage deviations in Monetary Policy Rate (MPR) due to Cholesky one standard deviation shock to productivity, whilst the IRG in the upper-left quadrant represents percentage deviations in inflation (i.e. the general price level) due to Cholesky one standard deviation shock to productivity. The IRG in the lower-left quadrant represents percentage deviations in output gap due to Cholesky one standard deviation shock to productivity.

The response of MPR to demand shock is that it is non-monotonic and transient (see Figure 6). Specifically, MPR increases a quarter after a demand shock but begins to decline thereafter. The decline in MPR continues to the 8th quarter, where the shock roughly dies out (see Table 5C in Appendix C). This is intuitively valid because whenever a demand shock (a positive shock as depicted by Figure 6) leads to rising prices, MPR must rise initially to rein in inflationary pressures. This may equally keep real interest rate positive to avert a decline in savings to support investment. In effect, aggregate demand is stabilized and hence, prices.

Figure 6: Response of MPR to demand Shock (Open Economy Case)

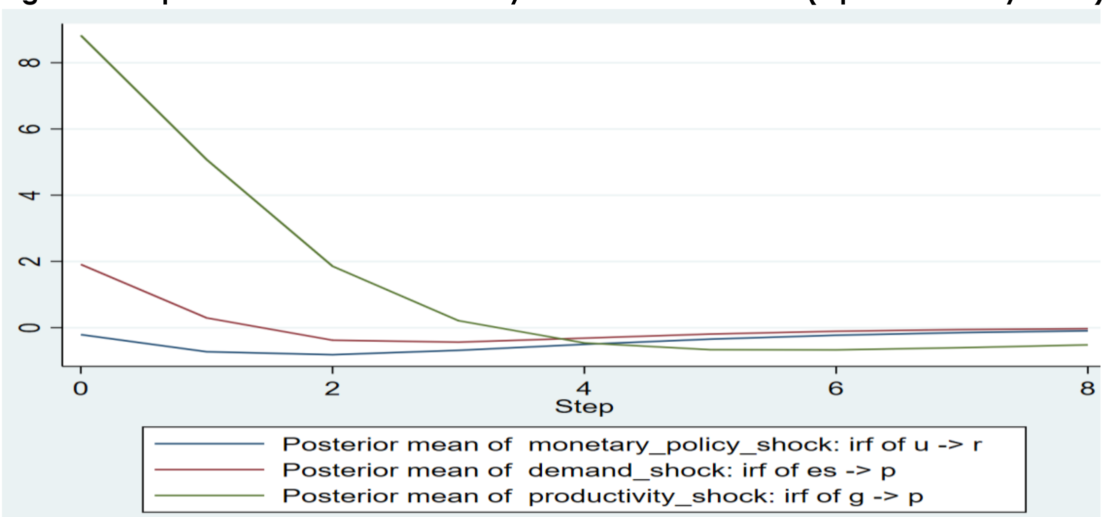


Note: Authors' construct is based on the dataset. The Impulse Response Graph (IRG) in the upper-right quadrant represents percentage deviations in Monetary Policy Rate (MPR) due to Cholesky one standard deviation shock to exchange rate, whilst the IRG in the upper-left quadrant represents percentage deviations in inflation (i.e. the general price level) due to Cholesky one standard deviation shock to exchange rate. The IRG in the lower-left quadrant represents percentage deviations in output gap due to Cholesky one standard deviation shock to exchange rate.

Comparing the two scenarios, we find that the response of MPR to productivity shock is more persistent under the open economy scenario than under the closed economy scenario (see Tables 2C and 4C in Appendix C). This finding is plausible because unlike a closed economy, productivity shock in an open economy does not only affect consumption and investment components of aggregate demand but net export as well. The effect on net export also has a second-round effect on exchange rate and subsequent effects on interest rate and capital flows, which make the shock more persistent under the open economy scenario than under the closed economy scenario.

Finally, in Figure 7, we compare MPR's response to demand and productivity shocks by using the posterior means of demand and productivity shocks (under the open economy scenario). It is evident that the response of MPR to demand shock dies out in the 8th quarter, whilst the response of MPR to productivity shock lingers actively to the 8th quarter and perhaps afterwards (see Figure 7). This implies that MPR's response to demand shock is transient, whilst its response to productivity shock is of a long term nature. This could be explained by the reason that productivity shock (triggered mainly by technological changes) may take a longer time to work itself out through the economy due possibly to the structural nature of the dynamic process. This study compares with the finding by Bondzie, Fosu and Obu-Cann (2013) that productivity shock results in a temporary shrinkage in the final goods sectors due to the reallocation of labour from the final and intermediate goods sectors. The implication of the transient nature of the response of MPR to demand shock could be attributed to the fact that the dynamic process in the financial market, through which monetary impulses are transmitted, appear to be relatively faster than that of the goods market.

Figure 7: Response of MPR to Productivity and Demand Shocks (Open Economy Case)



Note: Authors' construct is based on the dataset. The green Impulse Response Graph (IRG) represents percentage deviations in Monetary Policy Rate (MPR) due to Cholesky one standard deviation shock to productivity, whilst the red IRG represents percentage deviations in MPR due to Cholesky one standard deviation shock to exchange rate. The blue IRG represents percentage deviations in MPR due to Cholesky one standard deviation shock to MPR.

6.0 CONCLUSION AND POLICY IMPLICATIONS

We analyse the response of Monetary Policy Rate (MPR) to productivity and demand shocks in Ghana using a Bayesian Dynamic Stochastic General Equilibrium (DSGE) model. Specifically, we examine the response of MPR to productivity and demand shocks under two scenarios. The first scenario is when Ghana is a closed economy, whilst the second scenario is when Ghana is an open economy, which depicts the reality.

Data for the analysis are obtained from the Bank of Ghana. The frequency of the data is quarterly, which spans from 2002 to 2021.Our findings indicate that in a small open economy known as Ghana, demand and productivity impulses have monetary policy implications. Specifically, we find that the response of MPR to productivity shock is more persistent in the open economy case than in the closed economy case. This finding is consistent with Mickelsson (2009). We also find the response of Monetary Policy Rate (MPR) to productivity shock in the open economy case to be non-monotonic and somewhat permanent, whilst the response of MPR to demand shock is very transient. This finding implies that the response of MPR to productivity shock in this COVID-19 era will be long lasting.

Overall, a suggestion is made to Bank of Ghana based on our findings that in terms of policy options, a trade-off exists between maintaining a stable exchange rate and lowering MPR to raise the level of productivity.

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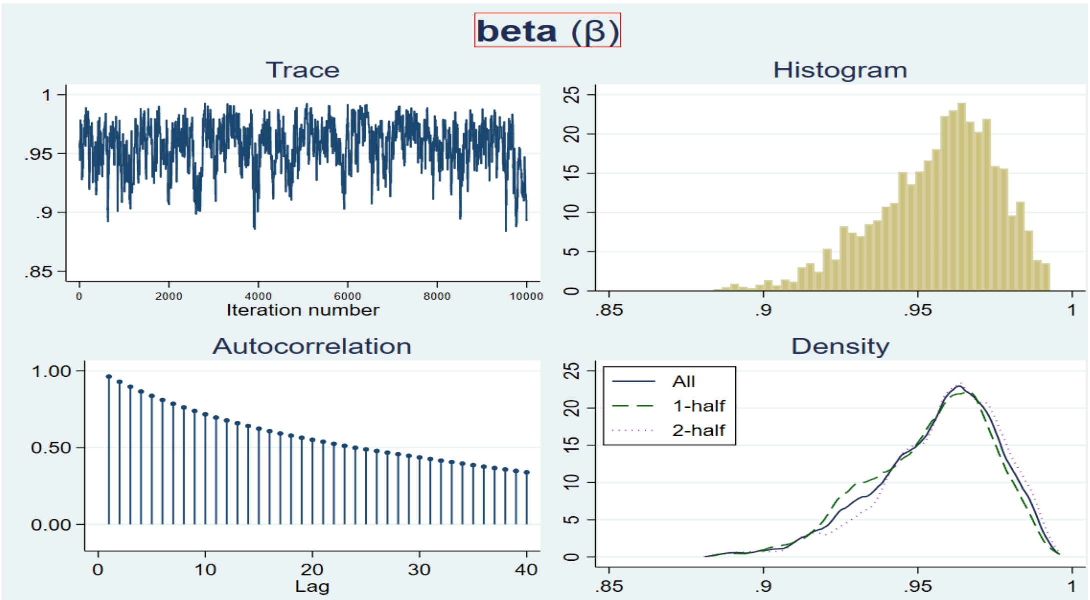
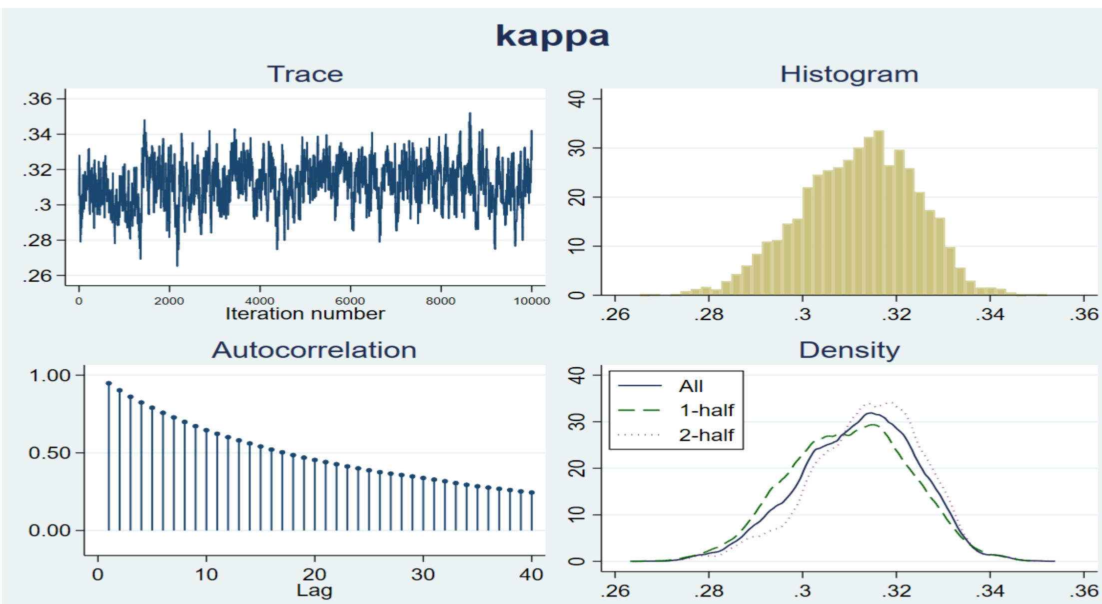
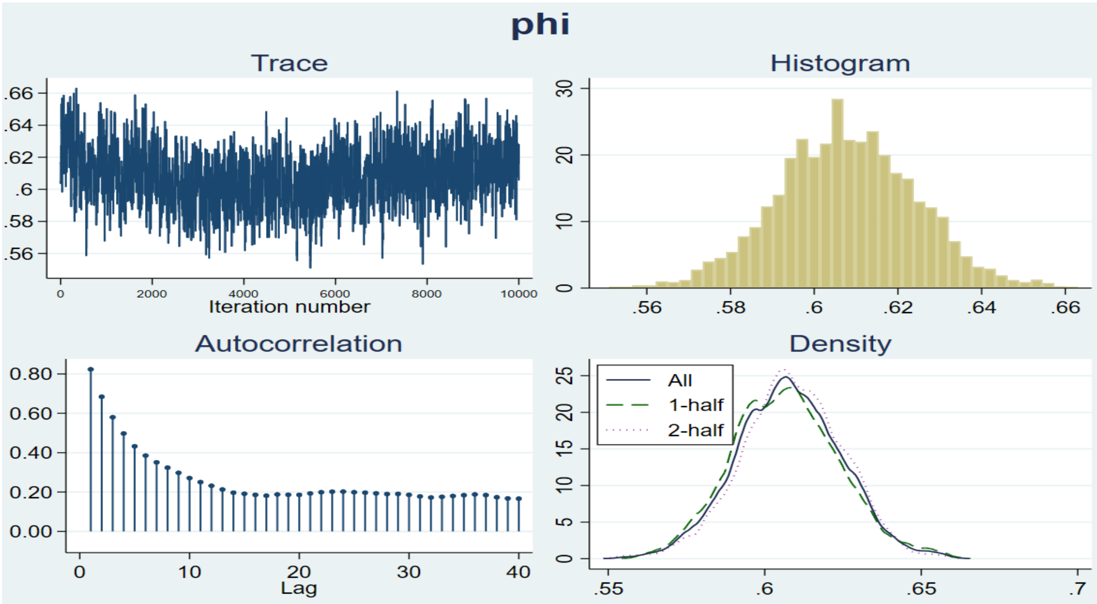
APPENDIX A
(CONVERGENCE DIAGNOSTICS)

1. Open Economy with Interest Rate Smoothing Model

A. Convergence Diagnostics for Parameters without Block



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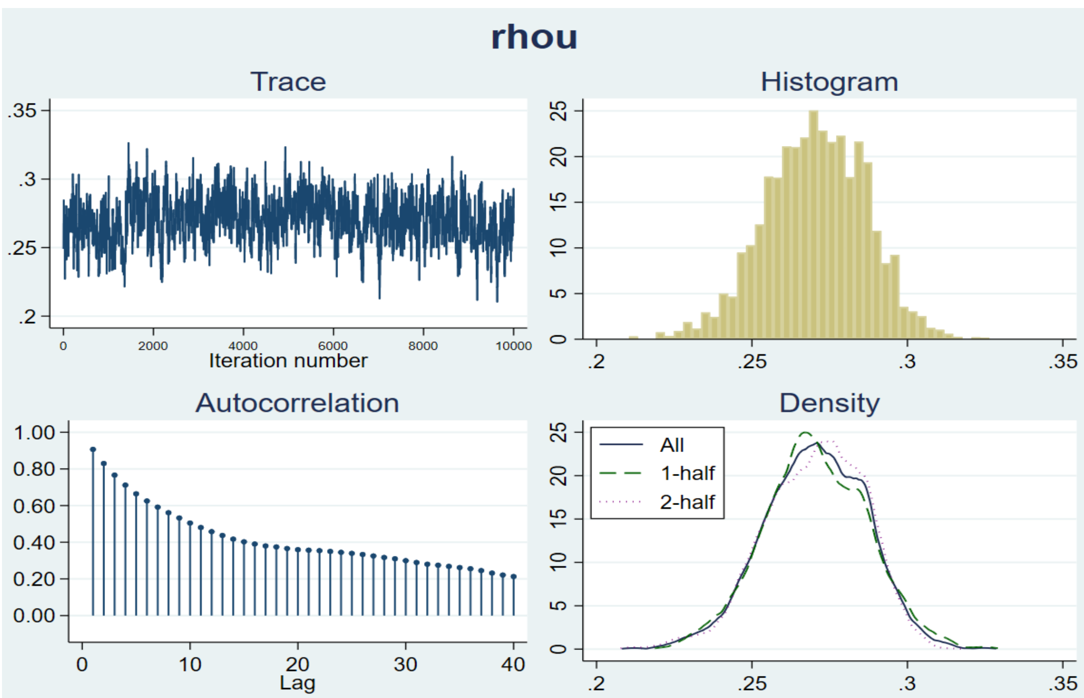
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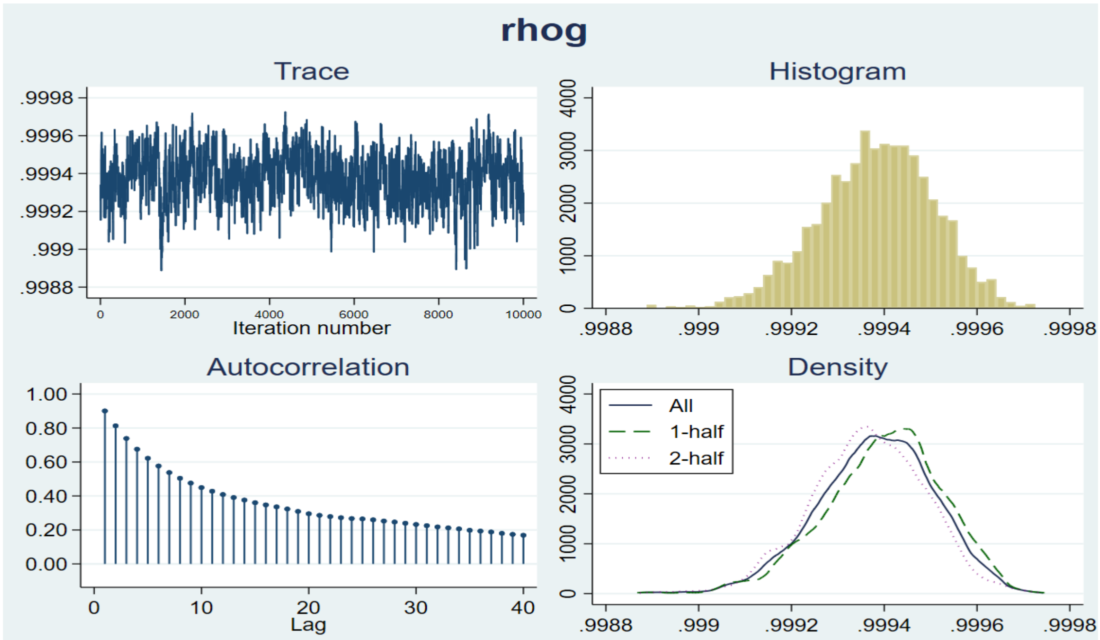
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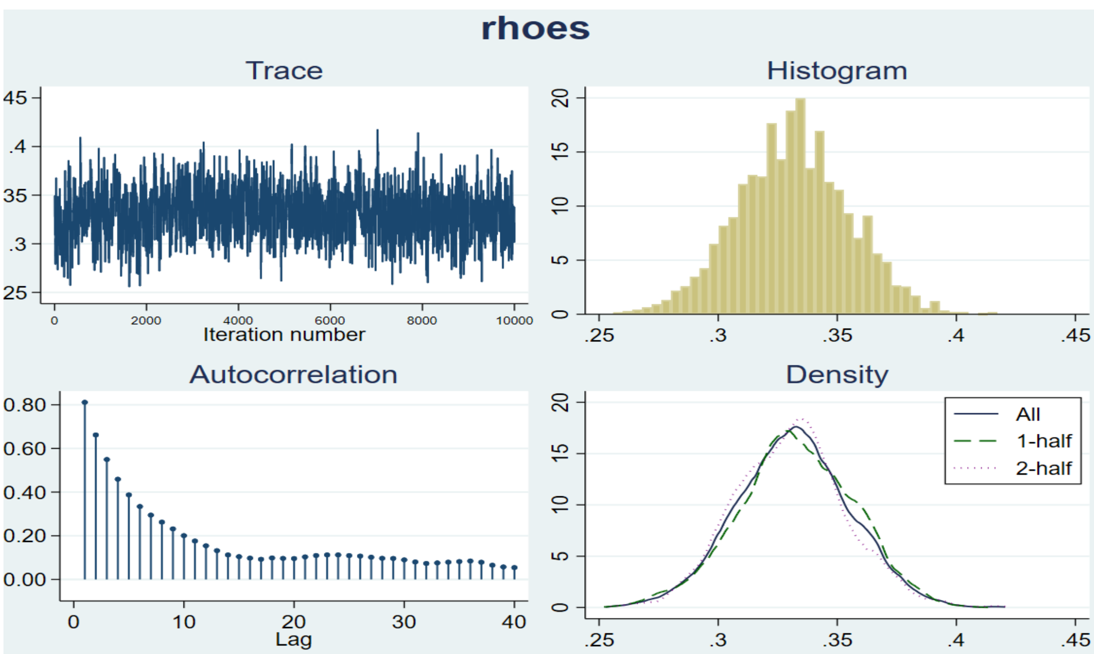
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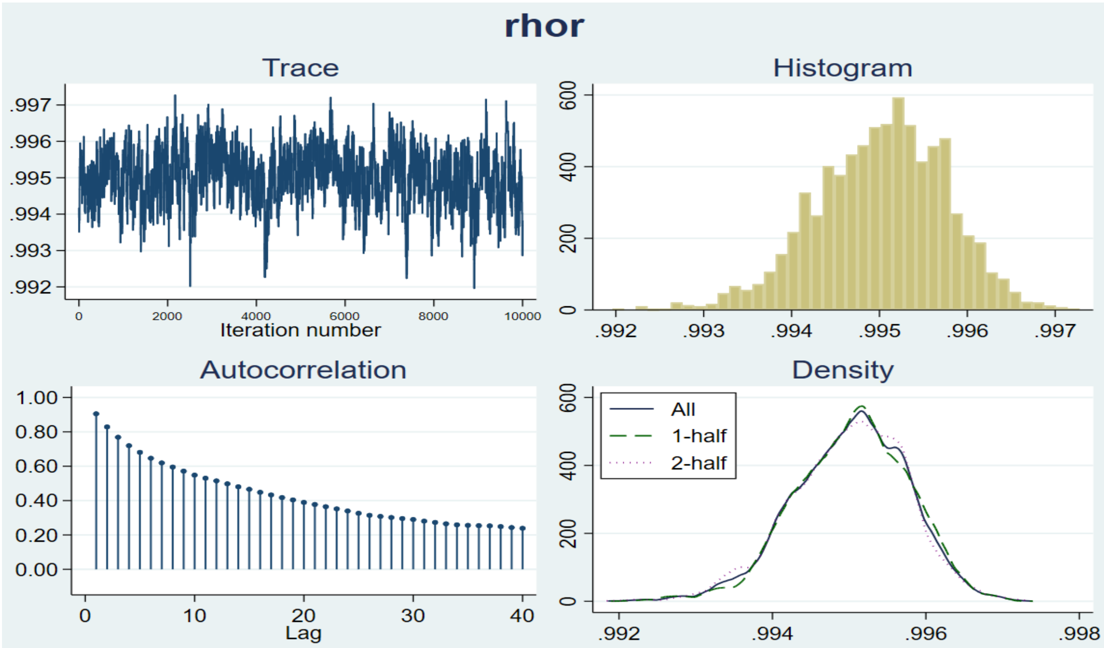
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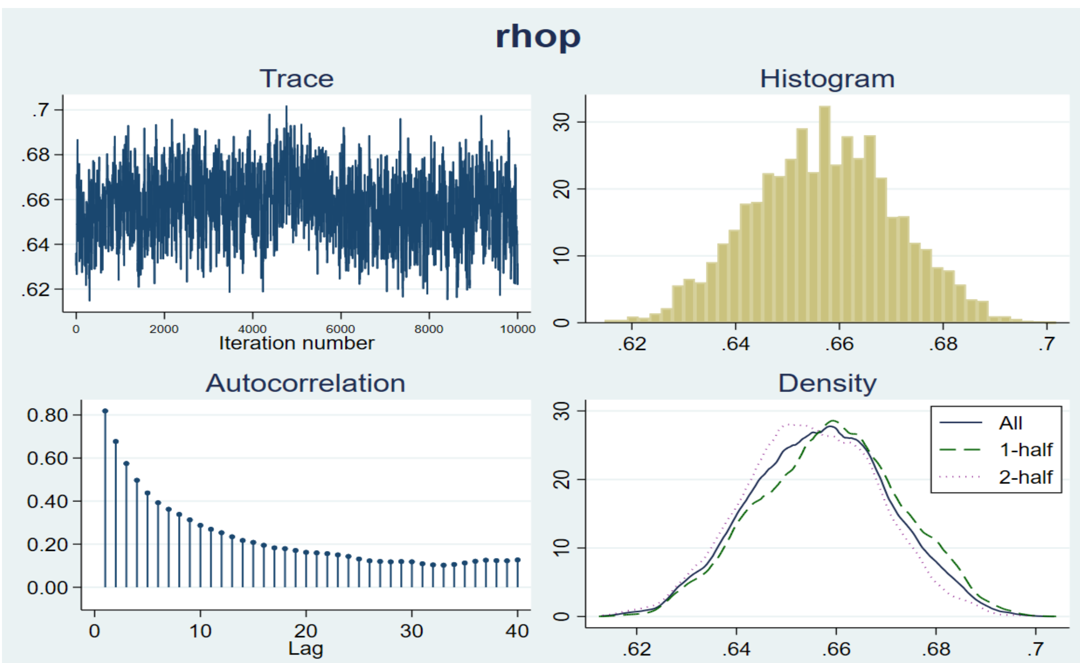
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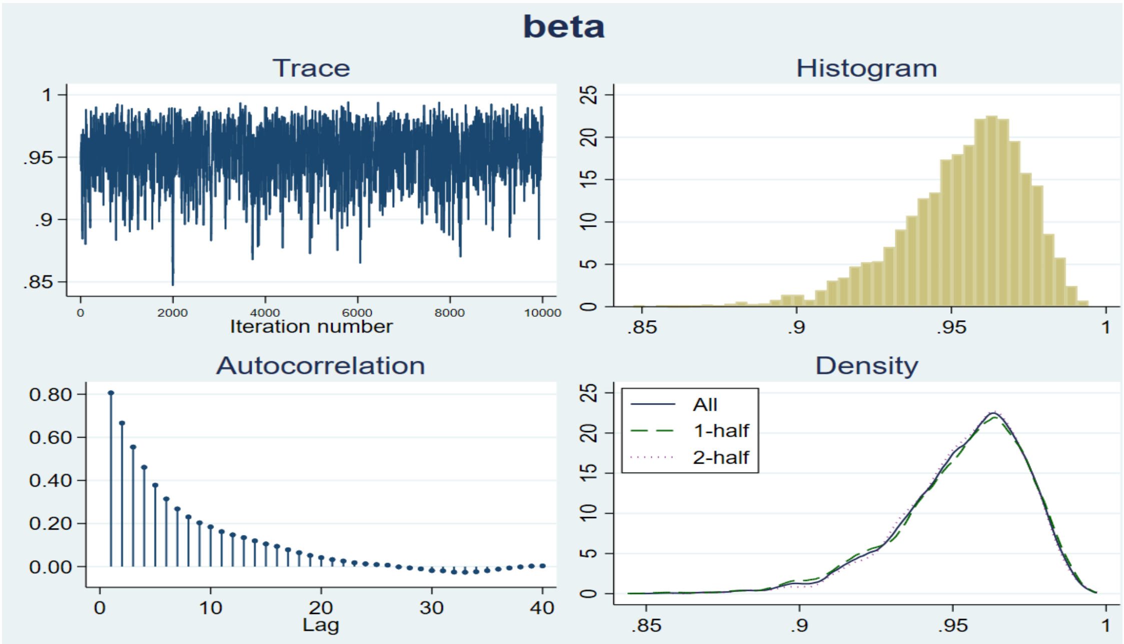

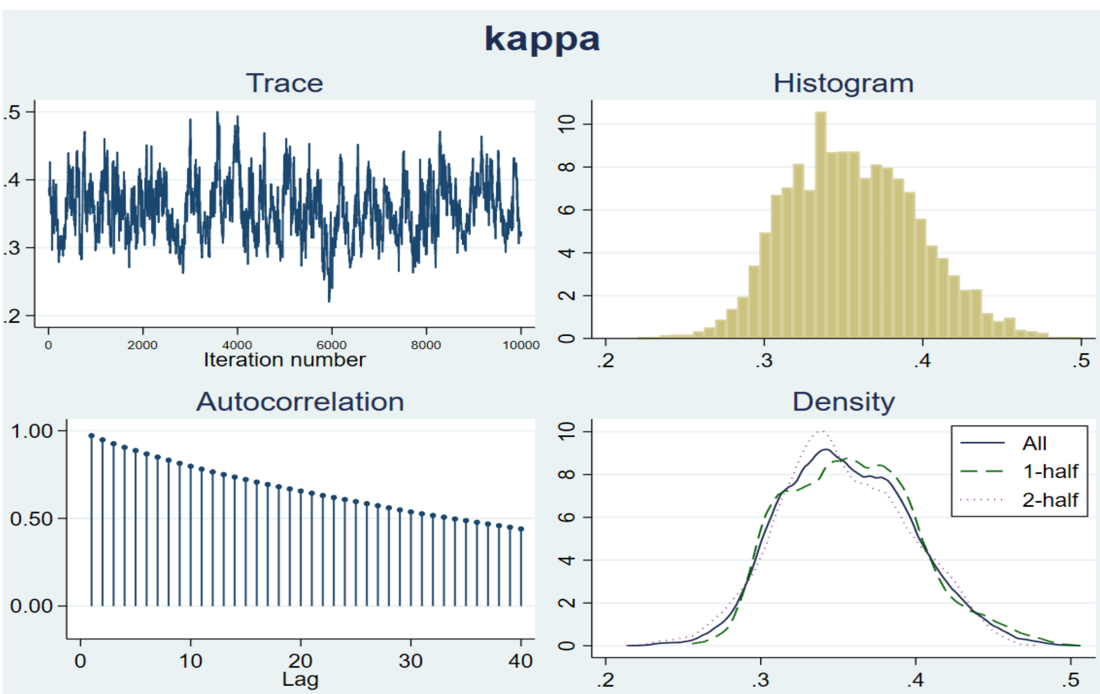

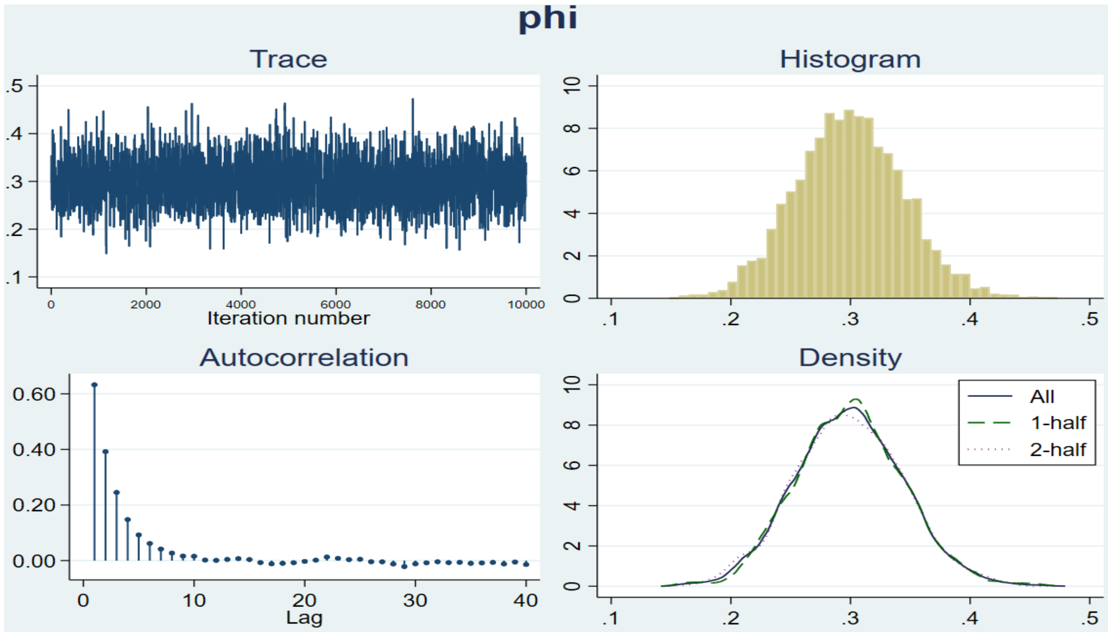
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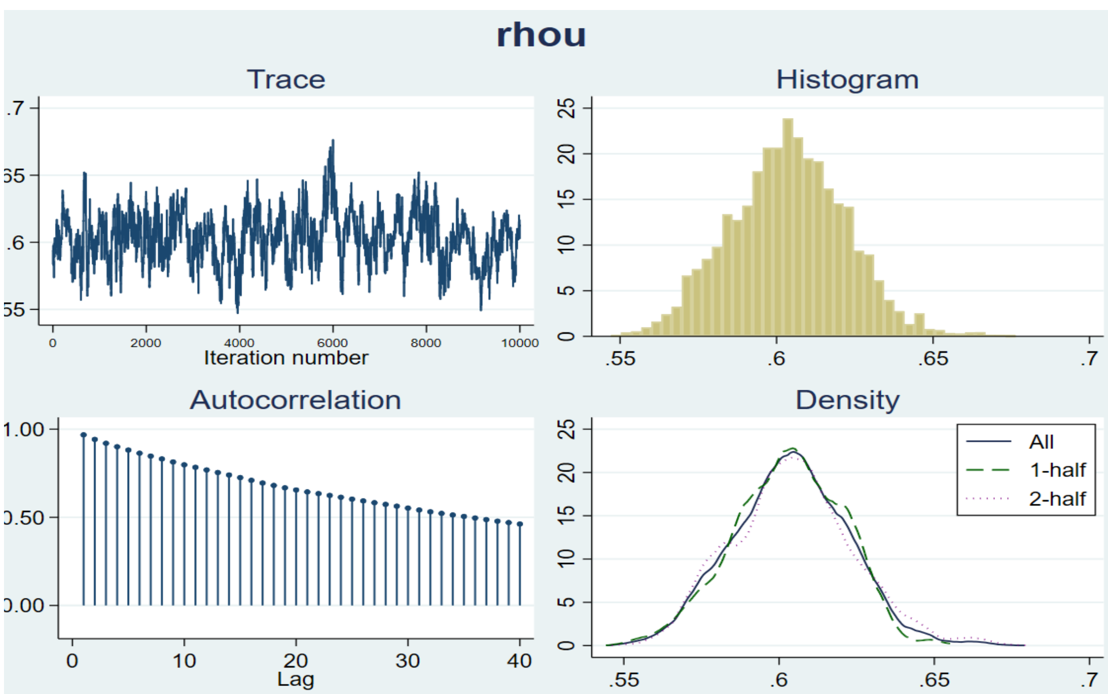
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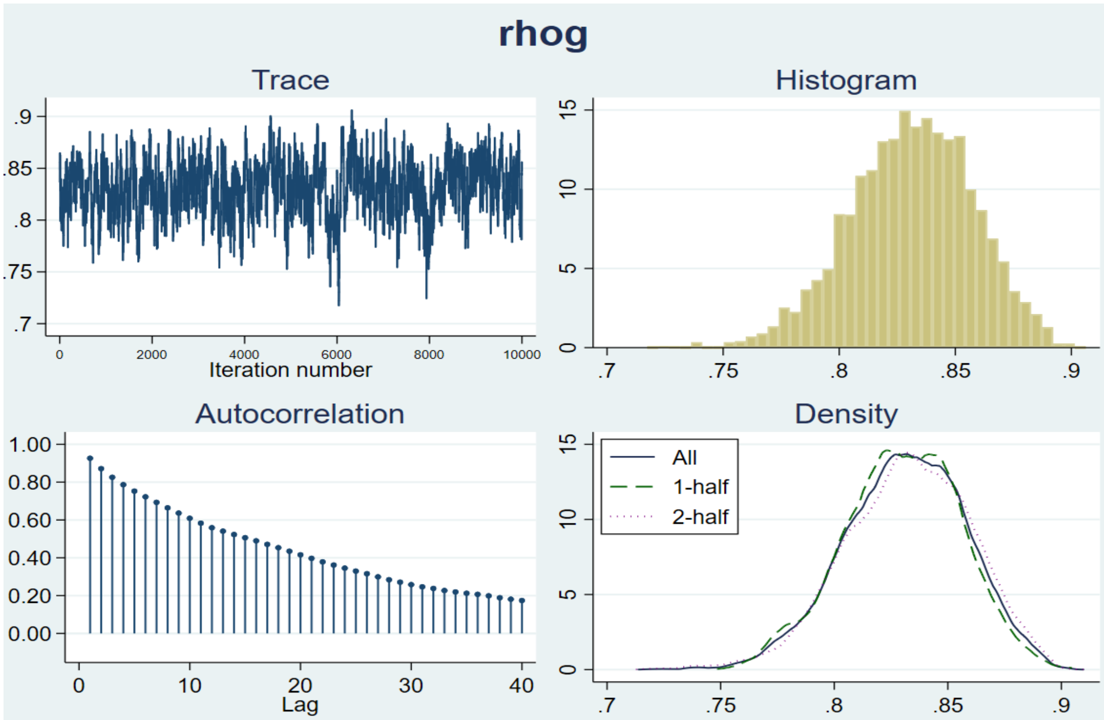
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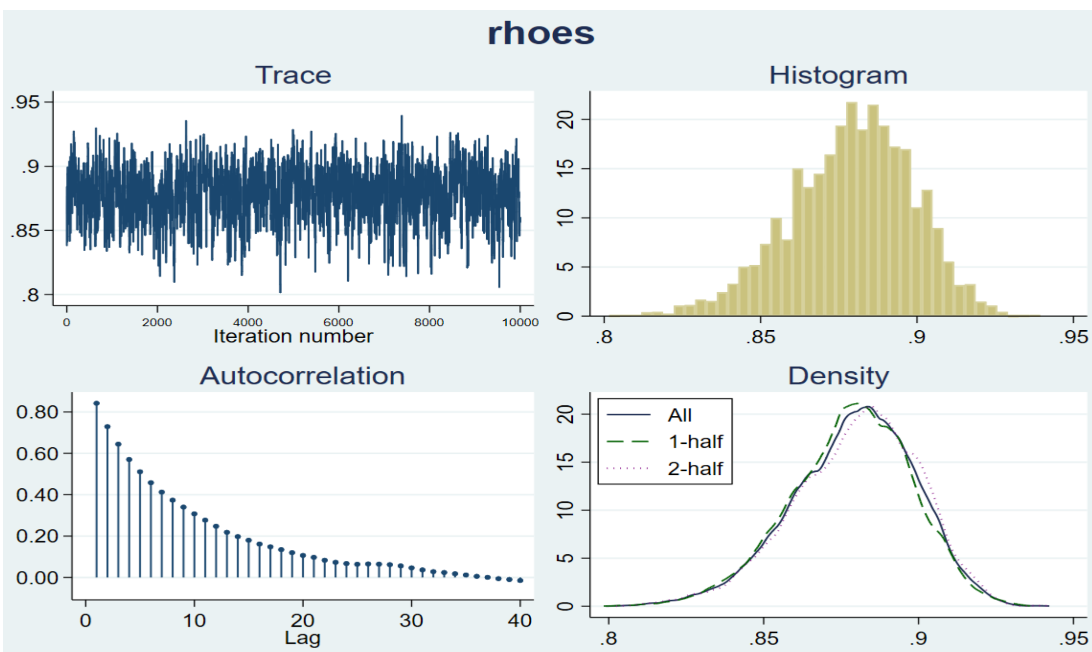
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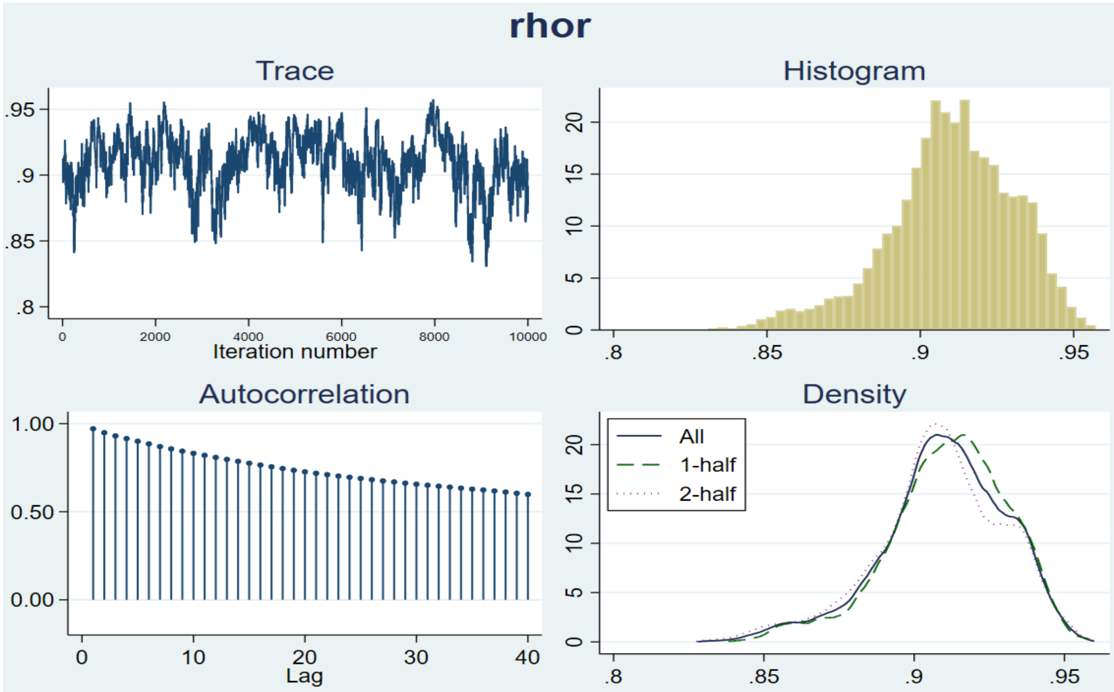
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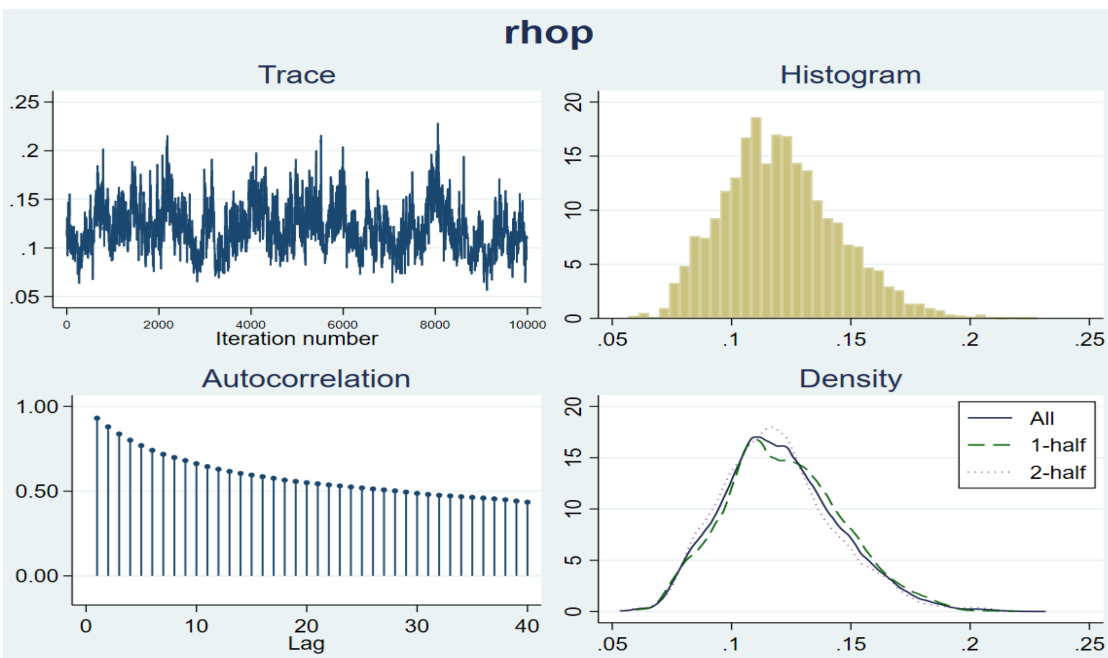
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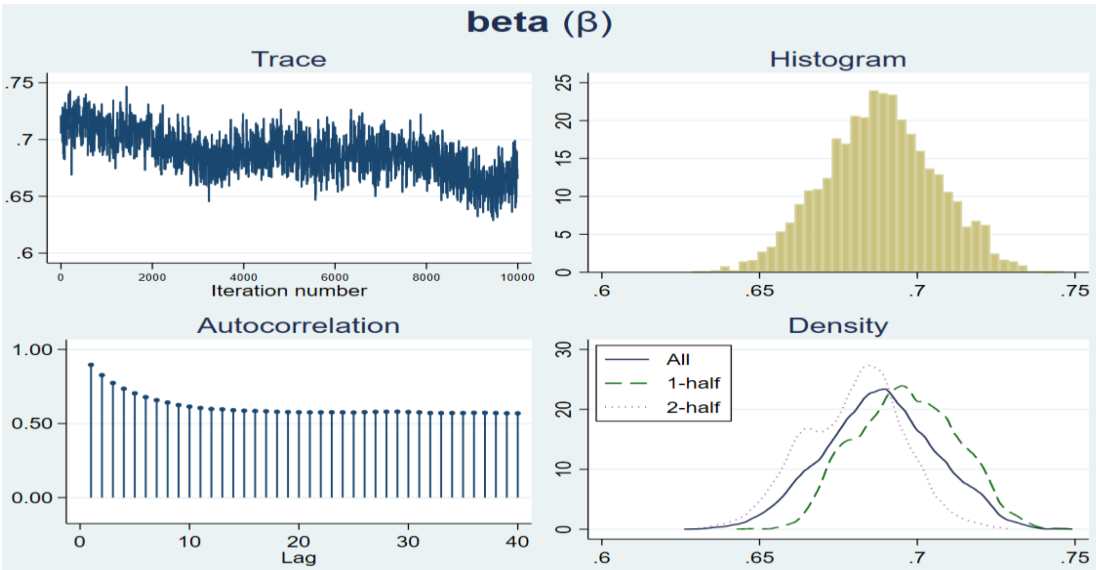
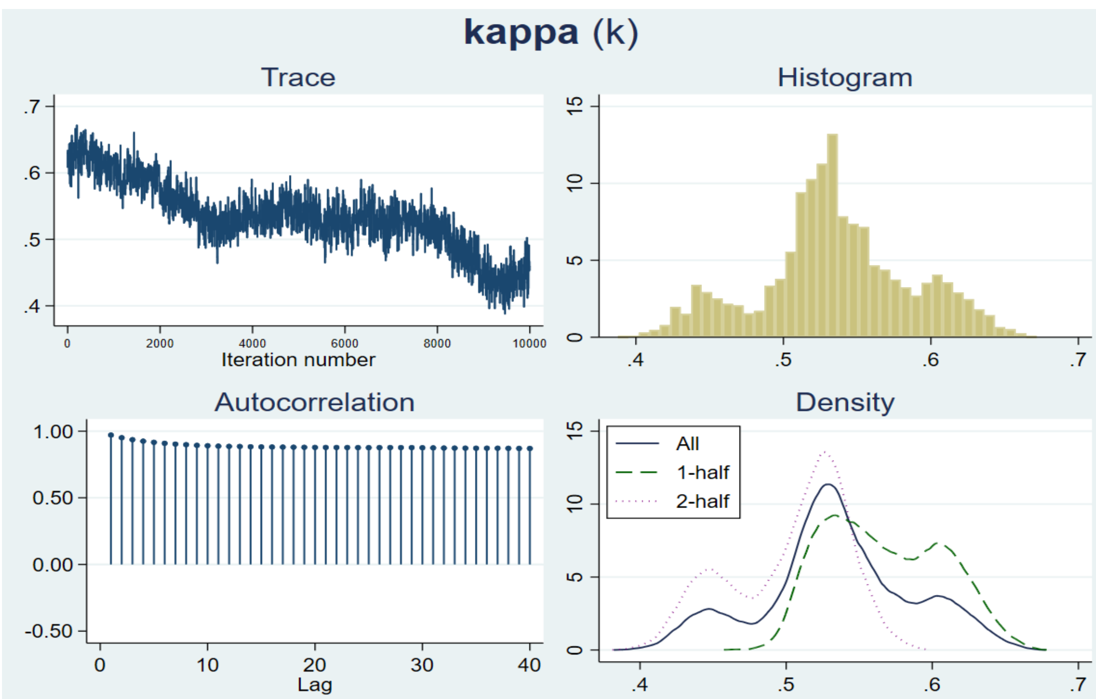
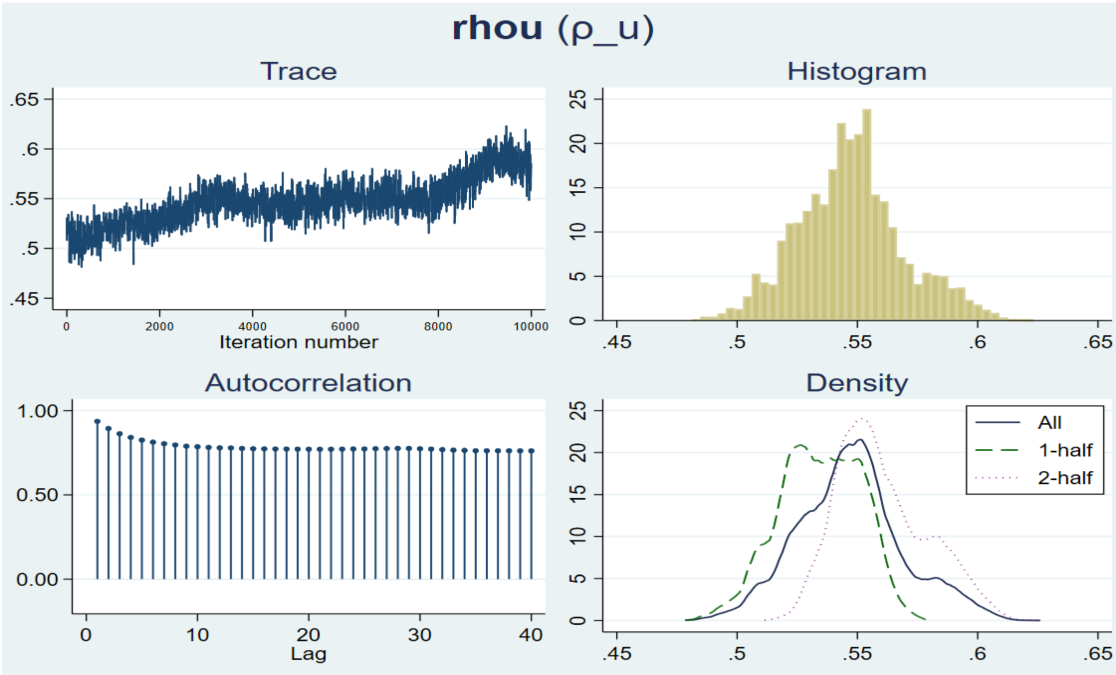
2. Closed Economy Model Without Interest Rate Smoothing

A. Convergence Diagnostics for Parameters without Block



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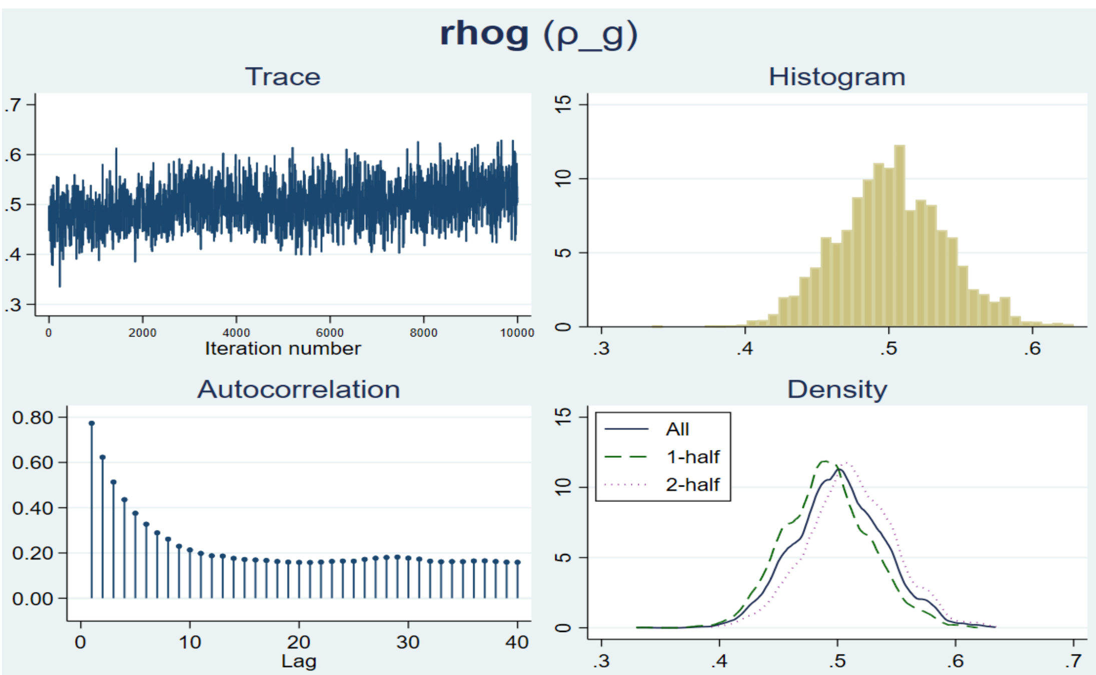
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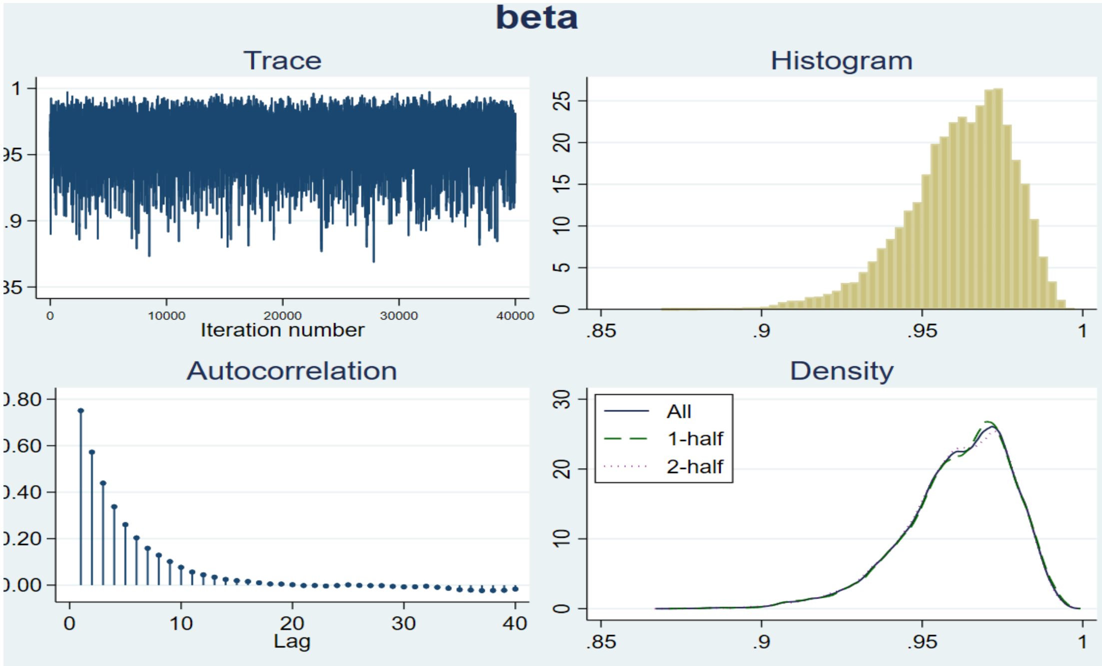

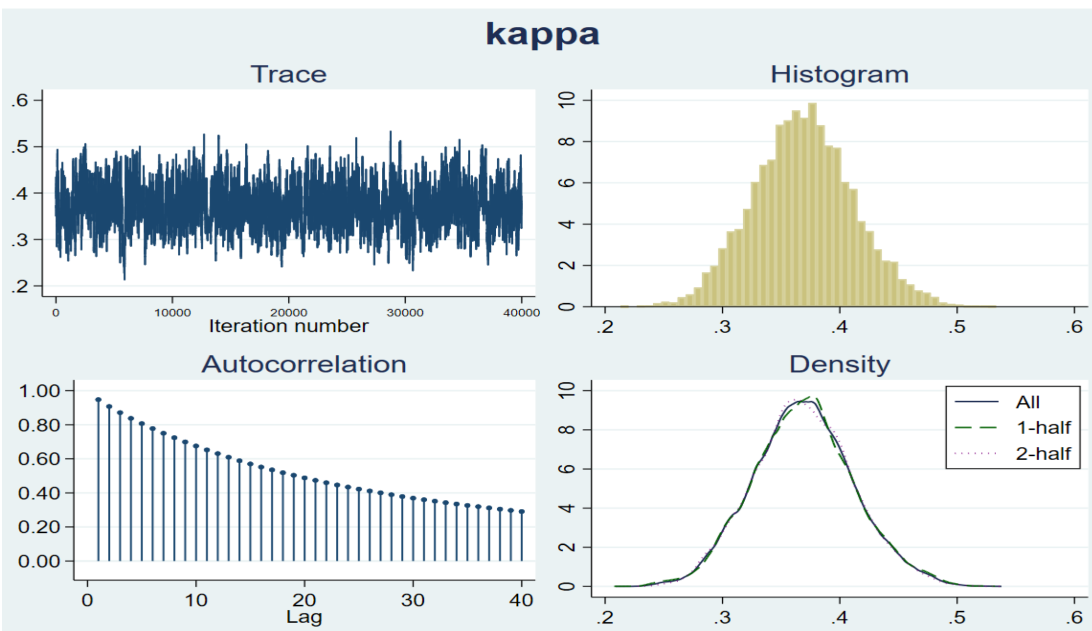

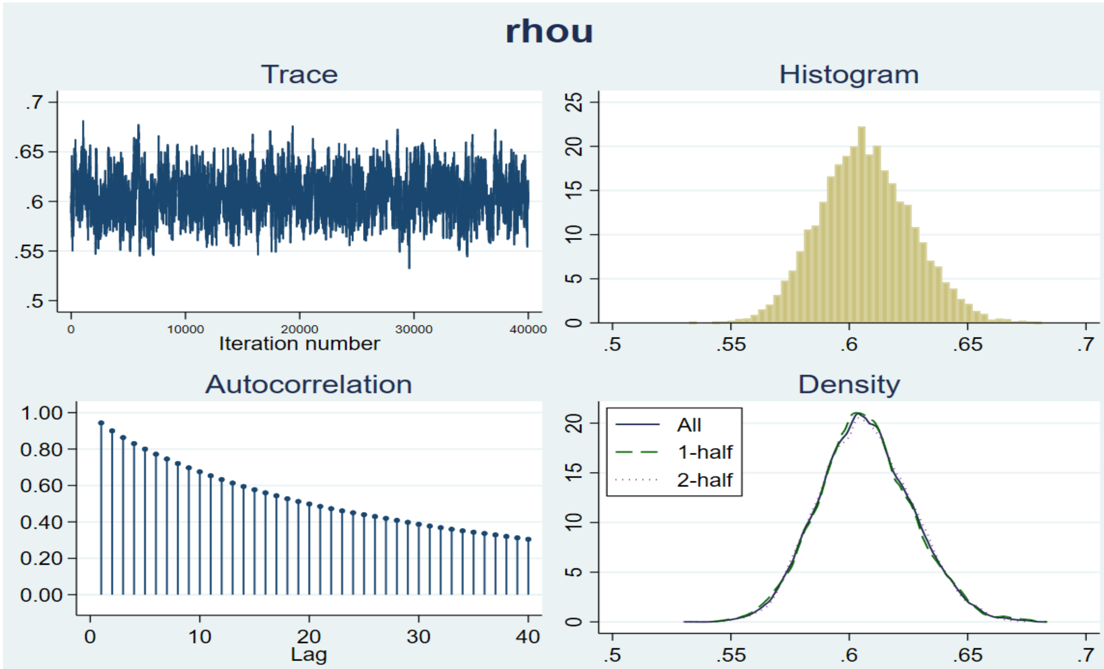
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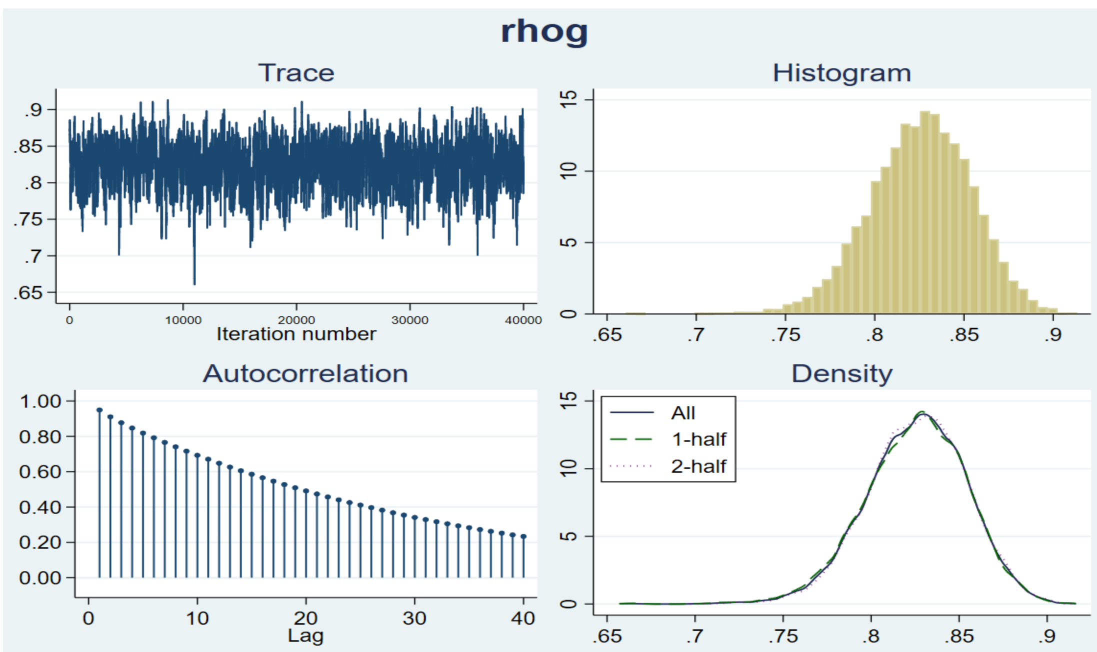
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APPENDIX B
(EFFICIENCY SUMMARIES)

Table 1B: Efficiency Summaries for the Estimated Parameters of the Closed Economy Model

	Without Block		With Block	
Parameters	***ESS***	***Efficiency***	***ESS***	***Efficiency***
β	19.33	0.0019	103.77	0.0026
κ	12.71	0.0013	42.76	0.0011
ρ_u	14.59	0.0015	42.35	0.0011
ρ_g	71.62	0.0072	656.51	0.0164
$\sigma_{e.u}$	88.69	0.0089	1136.96	0.0284
$\sigma_{e.g}$	145.36	0.0145	227.94	0.0057

Note: MCMC Size is 10, 000 with a burn-in length of 2,500 for the model without block, whilst MCMC Size is 40, 000 with a burn-in length of 6,000 for the model with block. Average efficiency for the model without block is 0.0059 but 0.0092 for the model with block.

Table 2B: Efficiency Summaries for the Estimated Parameters of the Open Economy Model

	Without Block		With Block	
Parameters	***ESS***	***Efficiency***	***ESS***	***Efficiency***
β	346.30	0.0346	5356.57	0.1339
κ	36.02	0.0036	437.43	0.0109
ρ_r	94.52	0.0095	345.78	0.0086
ρ_p	65.86	0.0066	611.25	0.0153
ϕ	71.94	0.0072	2810.36	0.0703
ρ_u	600.10	0.0600	427.16	0.0107
ρ_g	21.74	0.0022	729.71	0.0182
ρ_{es}	39.96	0.0040	7708.50	0.1927
$\sigma_{e.u}$	78.72	0.0079	387.41	0.0097
$\sigma_{e.g}$	56.77	0.0057	366.13	0.0092
$\sigma_{e.es}$	191.16	0.0191	7243.86	0.1811

Note: MCMC Size is 10, 000 with a burn-in length of 2,500 for the model without block, whilst MCMC Size is 40, 000 with a burn-in length of 6,000 for the model with block. Average efficiency for the model without block is 0.0146 but .0601for the model with block.

APPENDIX C
(IMPULSE RESPONSE FUNCTION TABLES)

A. Close Economy Case

Table 1C: Impulse Response Table for MPR Response to its Own Shock

Step	(1) irf	(1) Lower	(1) Upper
0	-0.083	-0.334	0.164
1	-0.053	-0.211	0.105
2	-0.034	-0.136	0.067
3	-0.021	-0.087	0.043
4	-0.014	-0.057	0.027
5	-0.009	-0.037	0.018
6	-0.006	-0.024	0.011
7	-0.004	-0.016	0.007
8	-0.002	-0.011	0.005

Note: irf represents the posterior means, whilst Lower and Upper represent 95% equal-tailed credible lower and upper bounds respectively.

Table 2C: Impulse Response Table for MPR Response to Productivity Shock

Step	(1) irf	(1) Lower	(1) Upper
0	1.151	0.969	1.375
1	1.005	0.856	1.185
2	0.877	0.746	1.037
3	0.766	0.641	0.918
4	0.670	0.545	0.820
5	0.586	0.459	0.737
6	0.513	0.384	0.665
7	0.449	0.321	0.602
8	0.394	0.267	0.547

Note: irf represents the posterior means, whilst Lower and Upper represent 95% equal-tailed credible lower and upper bounds respectively.

B. Open Economy Case

Table 3C: Impulse Response Table for MPR Response to its Own Shock

	(1)	(1)	(1)
Step	irf	Lower	Upper
0	-0.208	-0.410	-0.013
1	-0.725	-1.091	-0.405
2	-0.814	-1.207	-0.486
3	-0.682	-1.024	-0.408
4	-0.502	-0.772	-0.294
5	-0.344	-0.549	-0.195
6	-0.227	-0.377	-0.123
7	-0.146	-0.254	-0.075
8	-0.093	-0.169	-0.044

Note: irf represents the posterior means, whilst Lower and Upper represent 95% equal-tailed credible lower and upper bounds respectively.

Table 4C: Impulse Response Table for MPR Response to Productivity Shock

	(1)	(1)	(1)
Step	irf	Lower	Upper
0	0.824	0.686	1.000
1	1.220	1.020	1.472
2	1.281	1.064	1.556
3	1.186	0.968	1.461
4	1.037	0.820	1.310
5	0.883	0.665	1.153
6	0.742	0.528	1.006
7	0.620	0.413	0.878
8	0.517	0.322	0.766

Note: irf represents the posterior means, whilst Lower and Upper represent 95% equal-tailed credible lower and upper bounds respectively.

Table 5C: Impulse Response Table for MPR Response to Demand Shock

Step	(1) irf	(1) Lower	(1) Upper
0	0.183	0.109	0.278
1	0.193	0.115	0.295
2	0.139	0.080	0.220
3	0.085	0.046	0.143
4	0.048	0.024	0.086
5	0.025	0.011	0.049
6	0.013	0.005	0.027
7	0.006	0.002	0.015
8	0.003	0.001	0.008

Note: irf represents the posterior means, whilst Lower and Upper represent 95% equal-tailed credible lower and upper bounds respectively.

APPENDIX D
(PRIOR AND POSTERIOR DENSITY GRAPH OF THE PARAMETERS)

A. Closed Economy Case

Figure 1D: Density of Beta

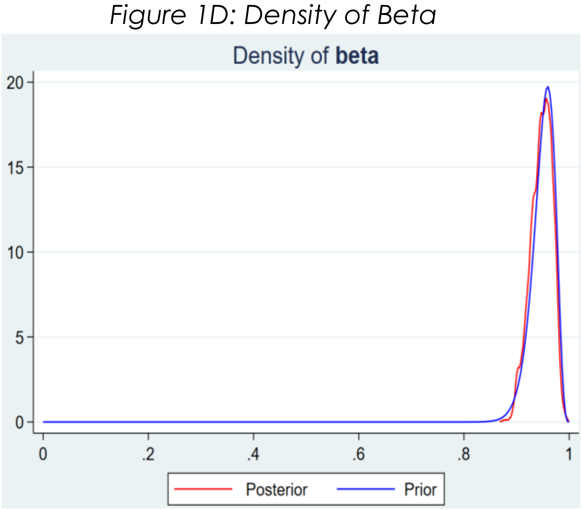
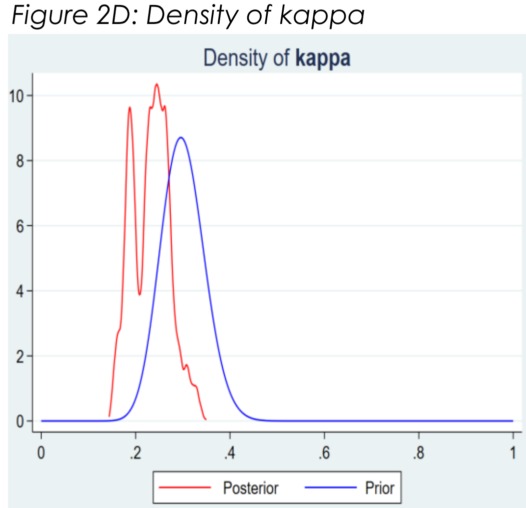


Figure 2D: Density of kappa



B. Open Economy Case

Figure 3D: Density of Beta

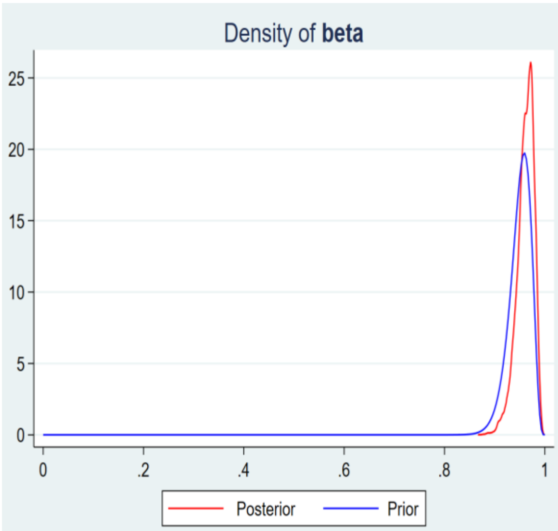


Figure 4D: Density of kappa

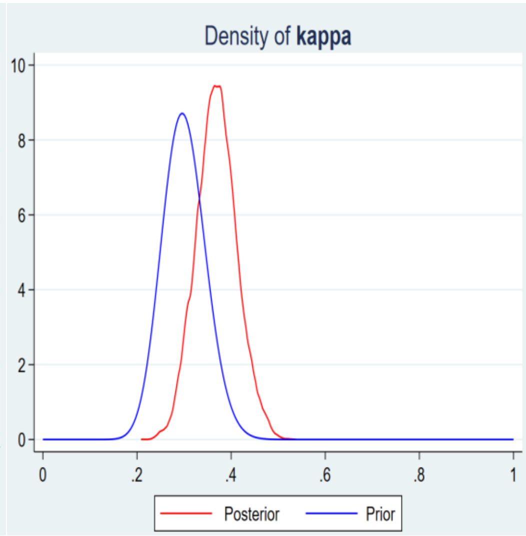


Figure 5D: Density of Beta

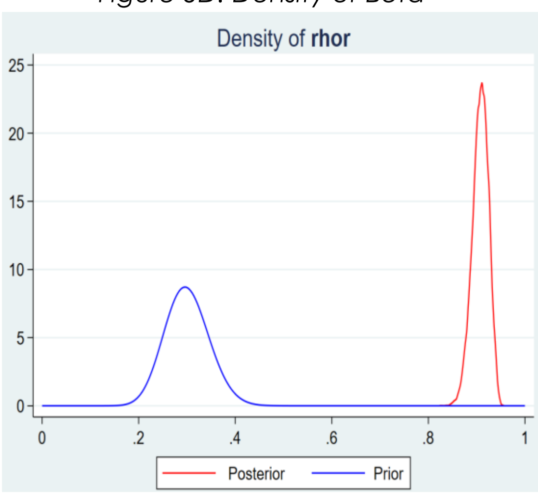


Figure 6D: Density of kappa

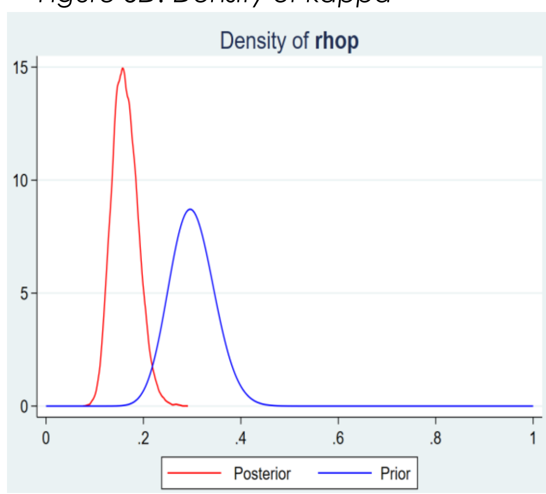


Figure 7D: Density of Phi

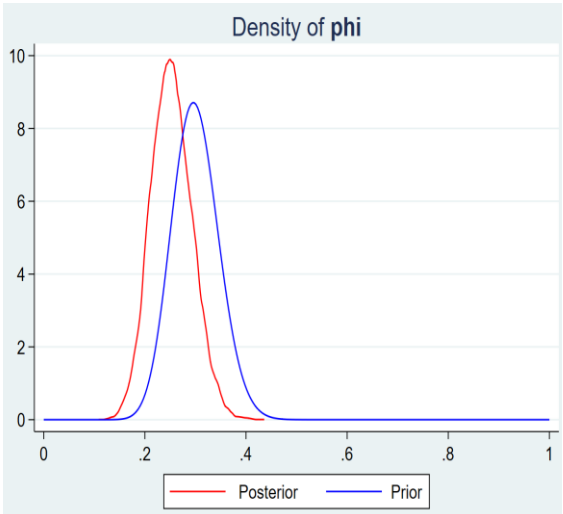


Figure 8D: Density of rhou

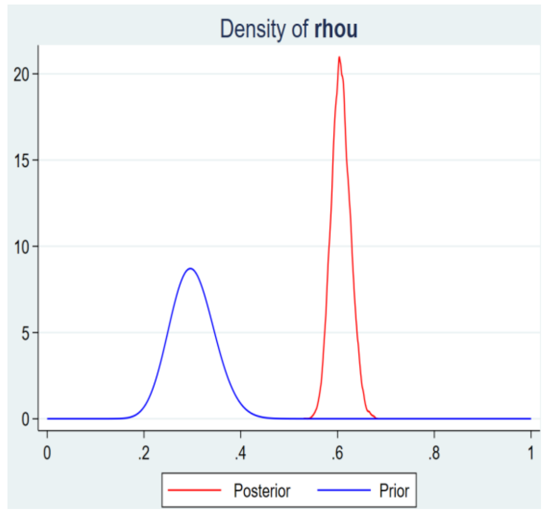


Figure 7D: Density of rhog

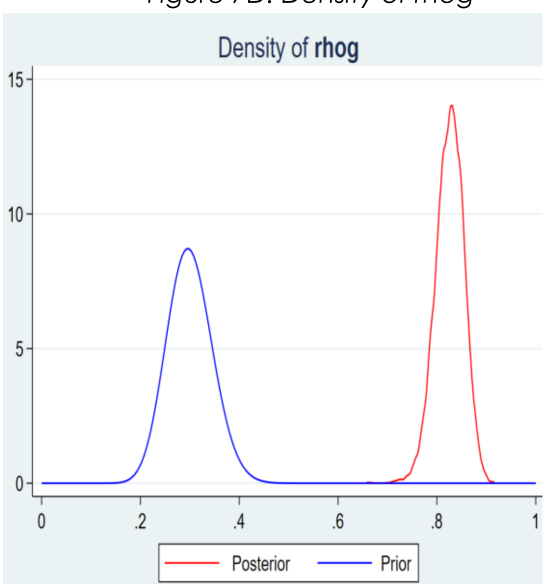
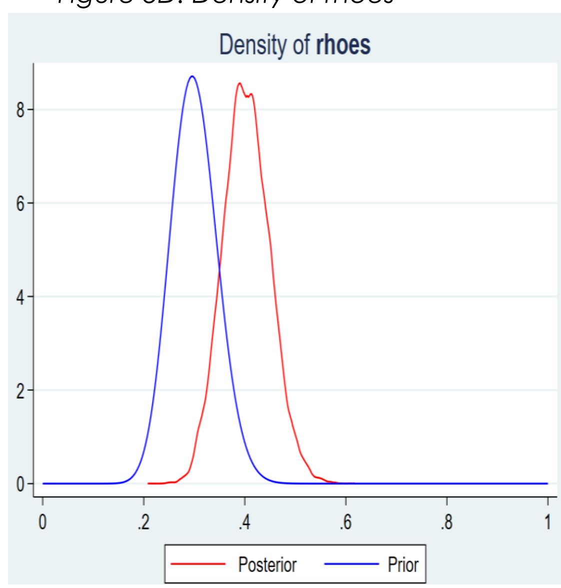


Figure 8D: Density of rhoes



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

Rajie R. Adnan*[1], Michael D. Titoe, Jr.2, John A. Lewis, Jr. 3, John M. Collins Jr. 4

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.

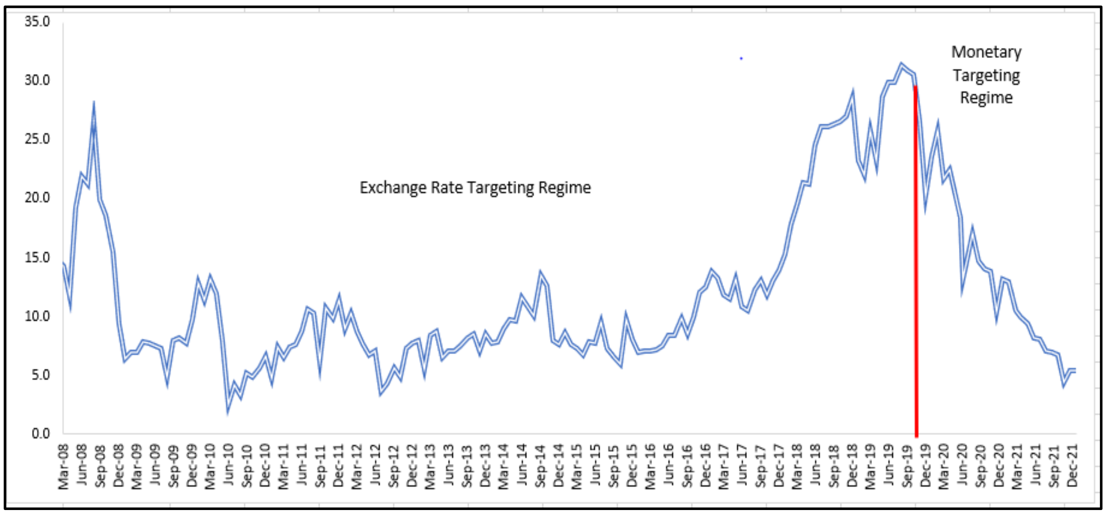
Monetary policy regimes that are operated by central banks vary according to the environment and economic conditions associated with a country. Monetary policy decisions often affect prices and outturn via important financial variables, including lending rate, asset prices, credit, exchange rates, etc. 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.

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

$e_t = es_t$ (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.

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

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

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

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

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

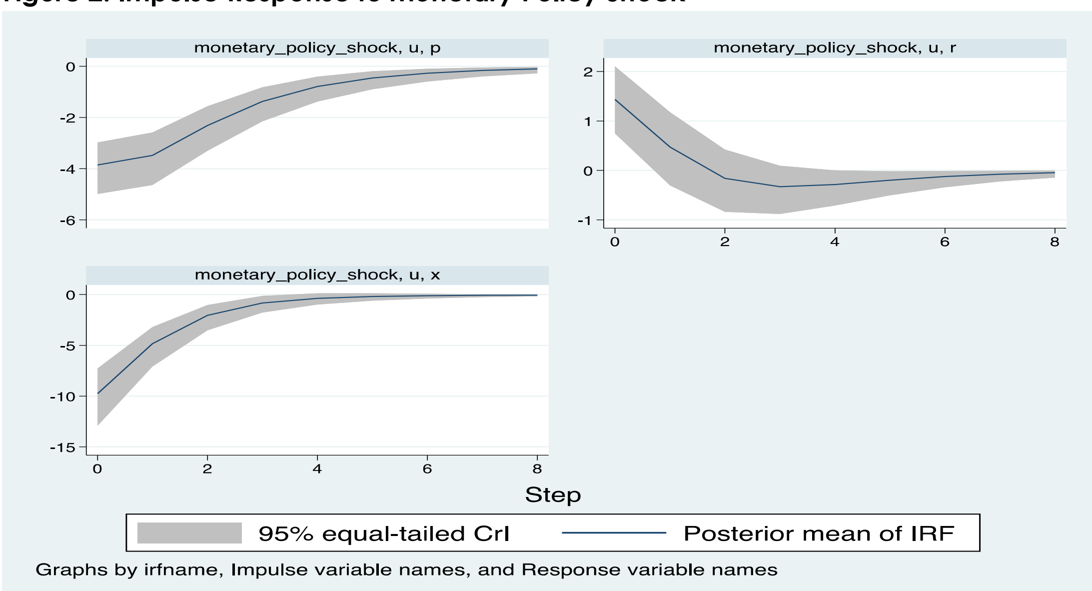
	Model (without block)		Model (with block)	
Parameters	Mean	95% interval	Mean	95% interval
ρ_r	0.5540	[0.4930 0.6136]	0.5810	[0.5016 0.6552]
ψ	0.4720	[0.3966 0.5484]	0.3988	[0.3110 0.4925]
ρ_p	0.2534	[0.1862 0.3209]	0.3129	[0.2321 0.3955]
β	0.9471	[0.8928 0.9825]	0.9444	[0.8885 0.9815]
κ	0.2622	[0.1939 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.

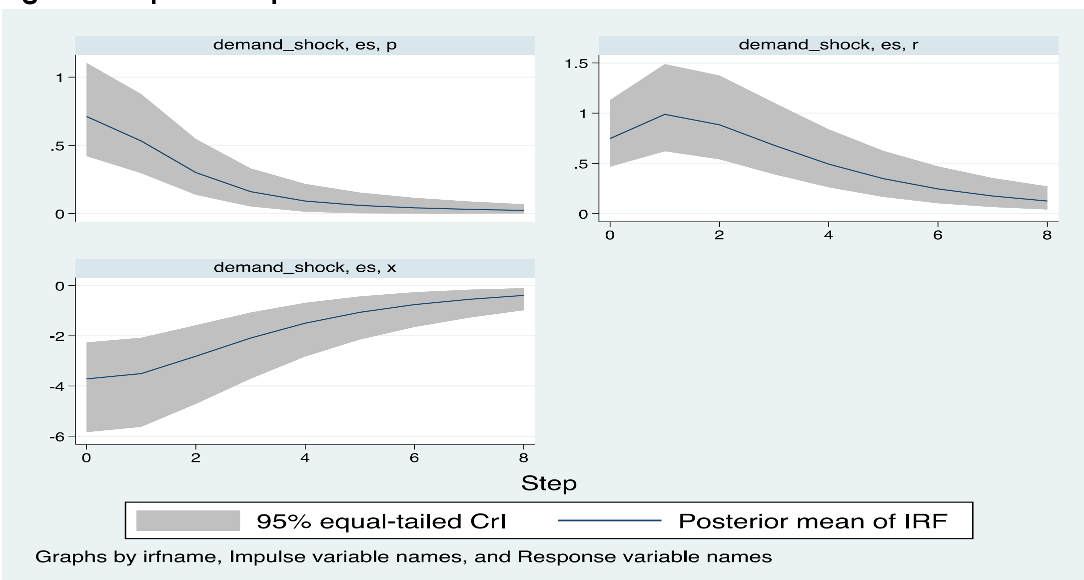
Figure 2: Impulse Response to Monetary Policy Shock



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.

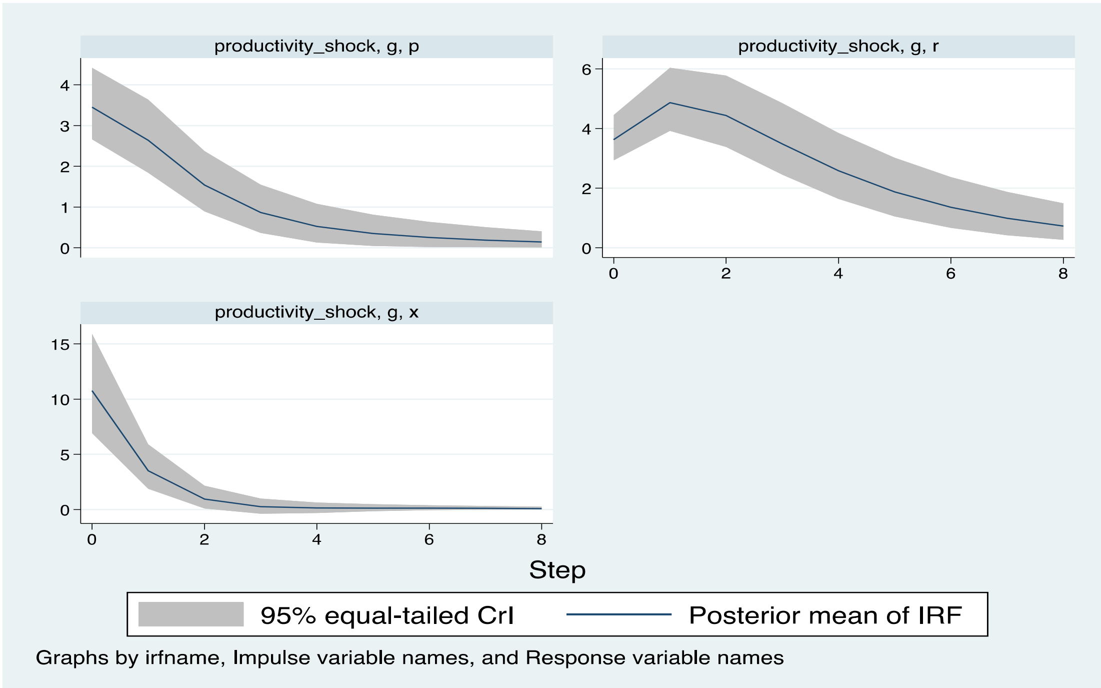
Figure 3: Impulse Response to Demand shock



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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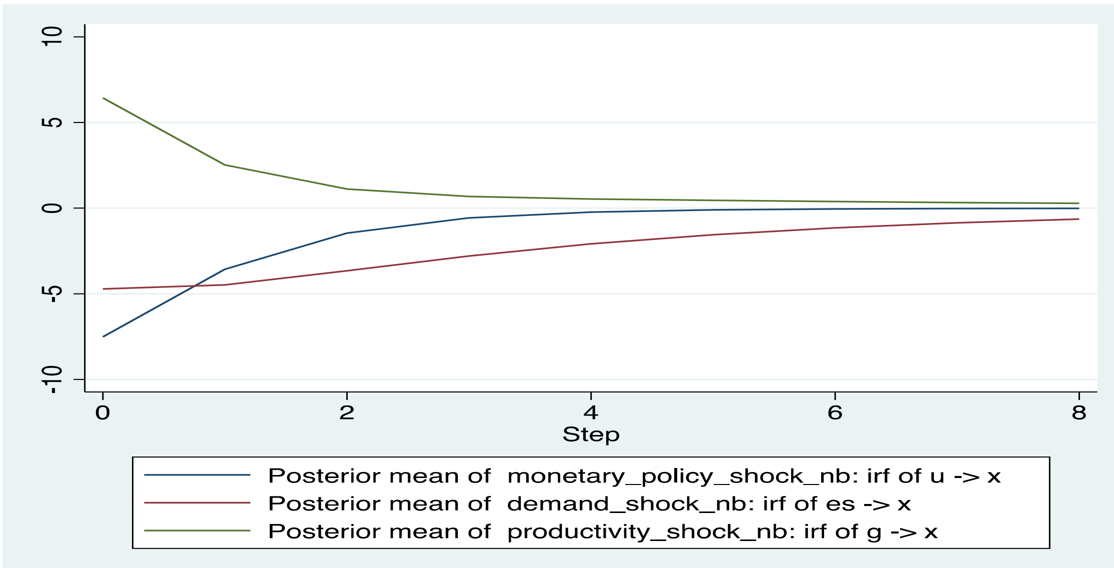
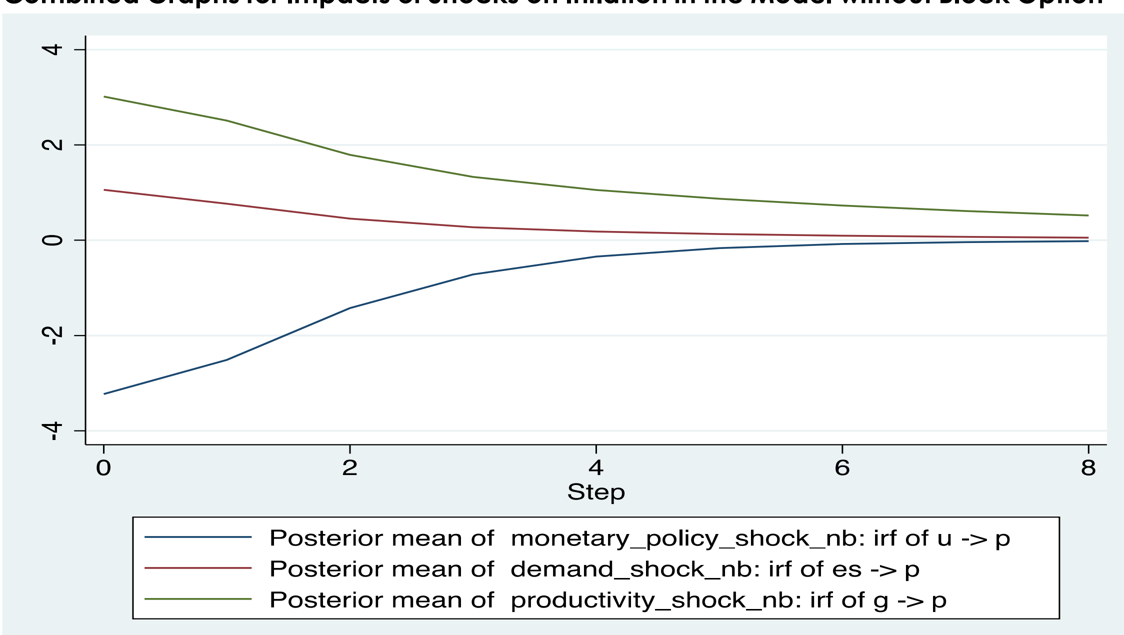
Appendix

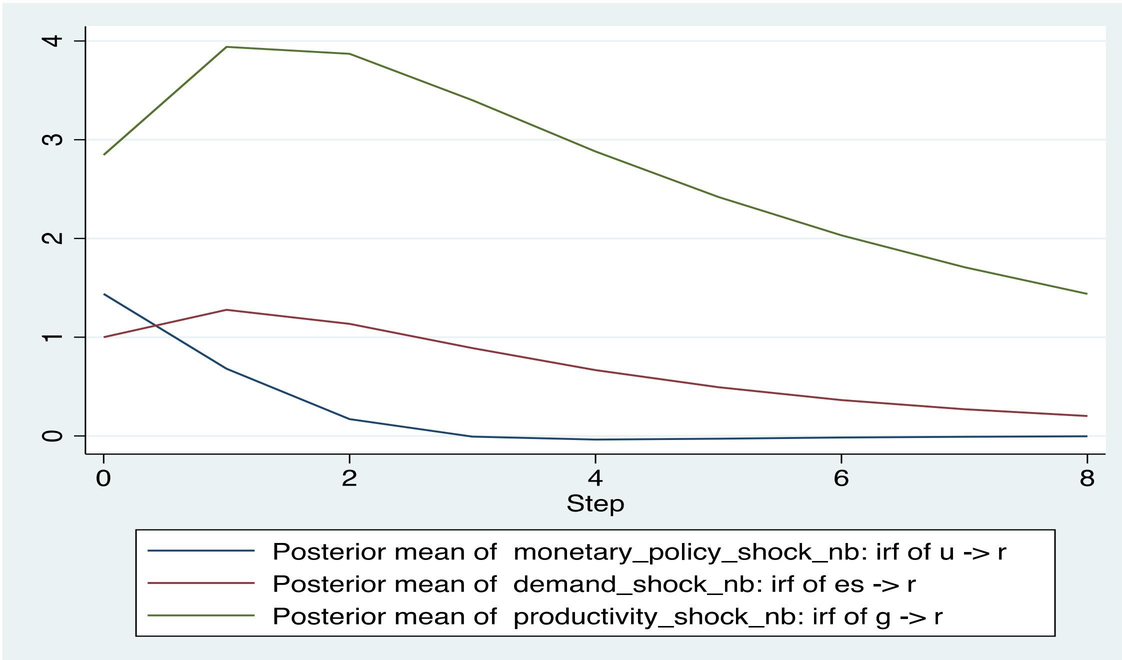
Combined Graphs for Impacts of Shocks on Output Gap in the Model without Block Option



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



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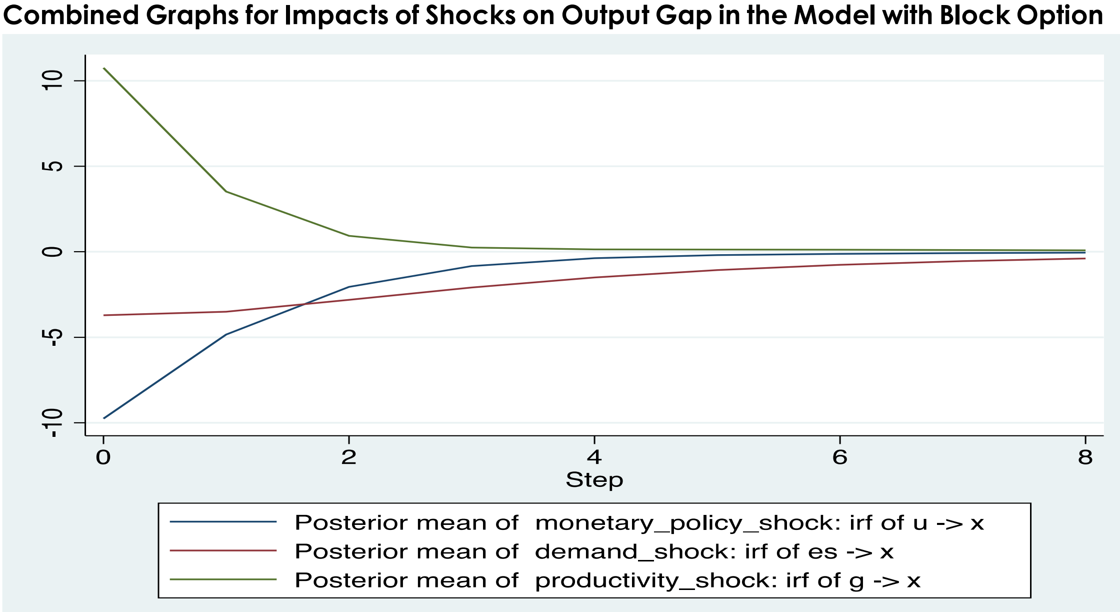

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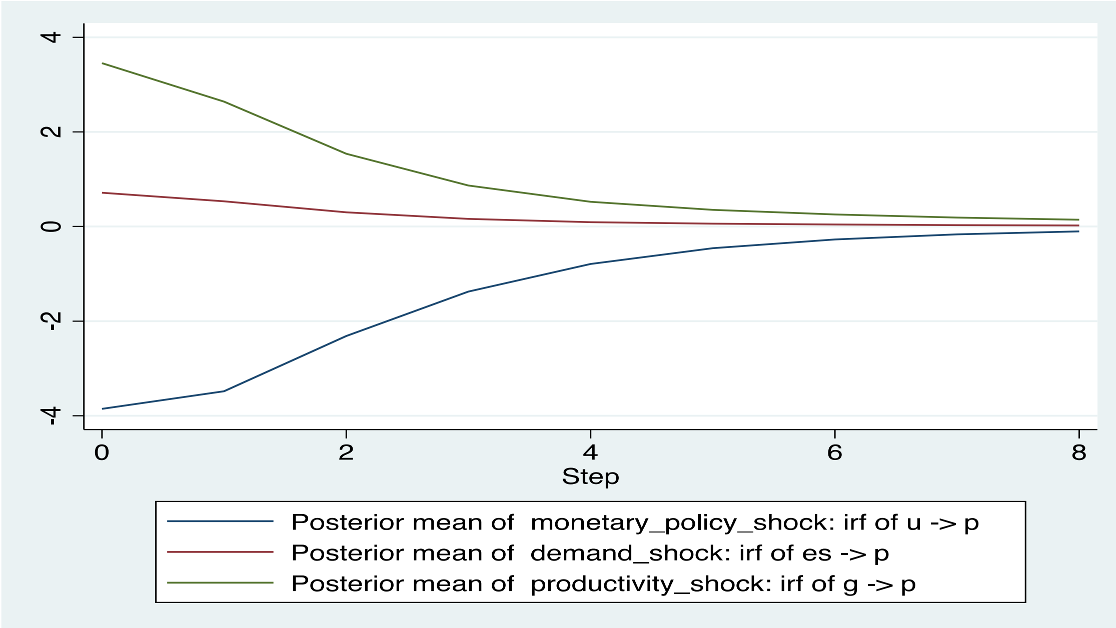
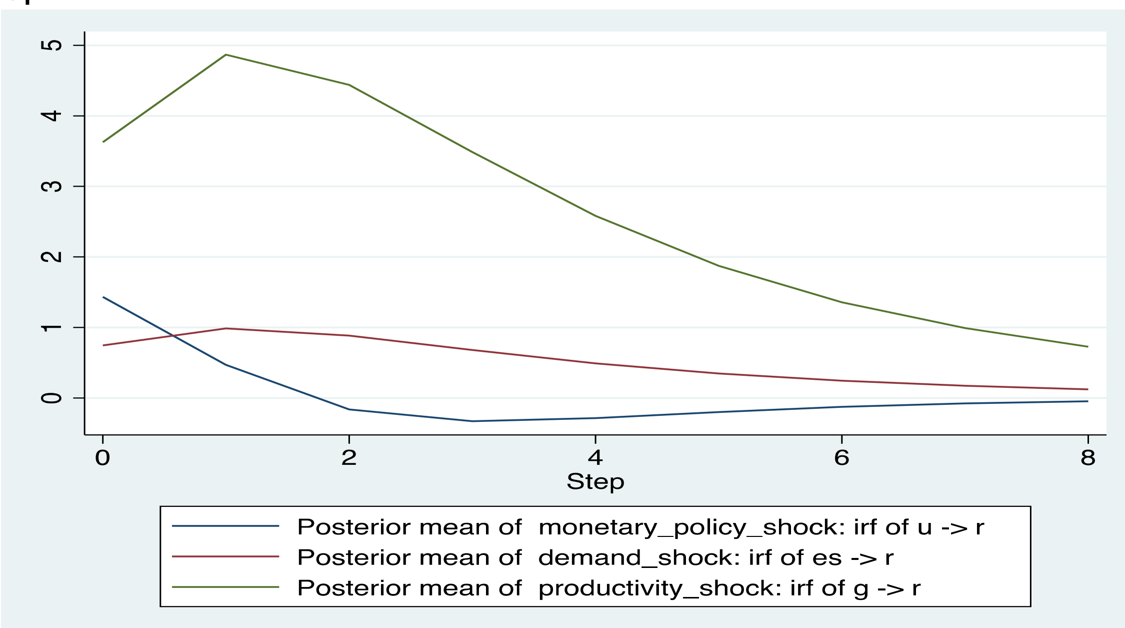
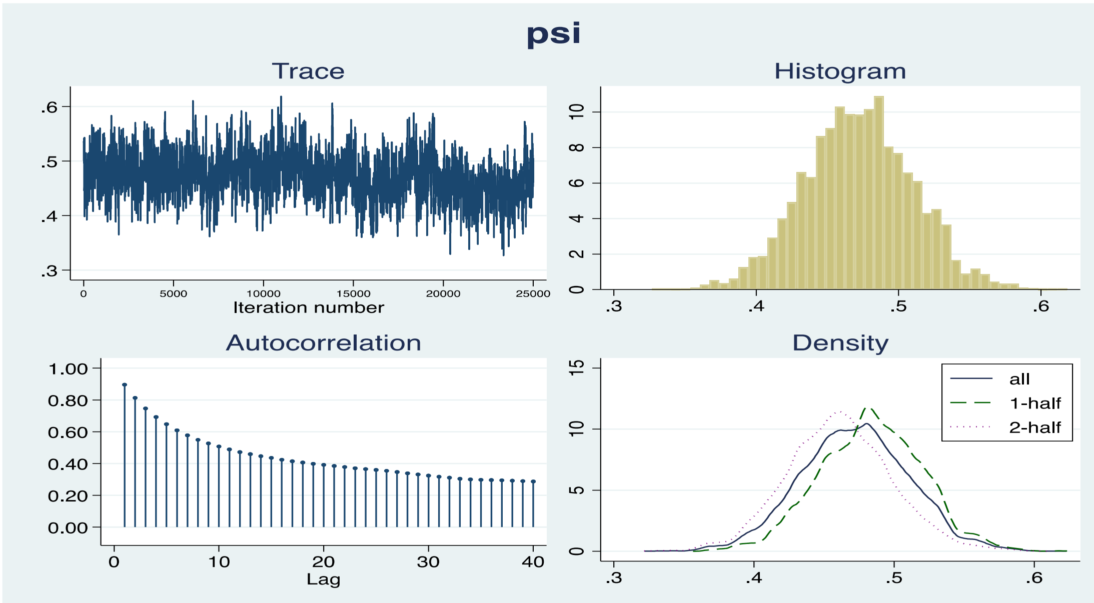
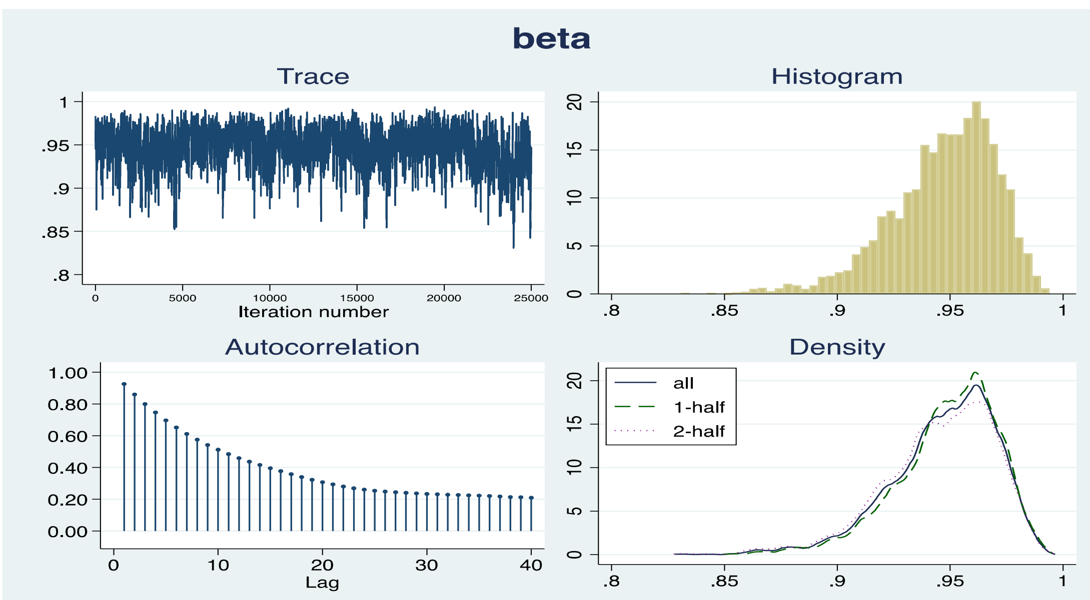


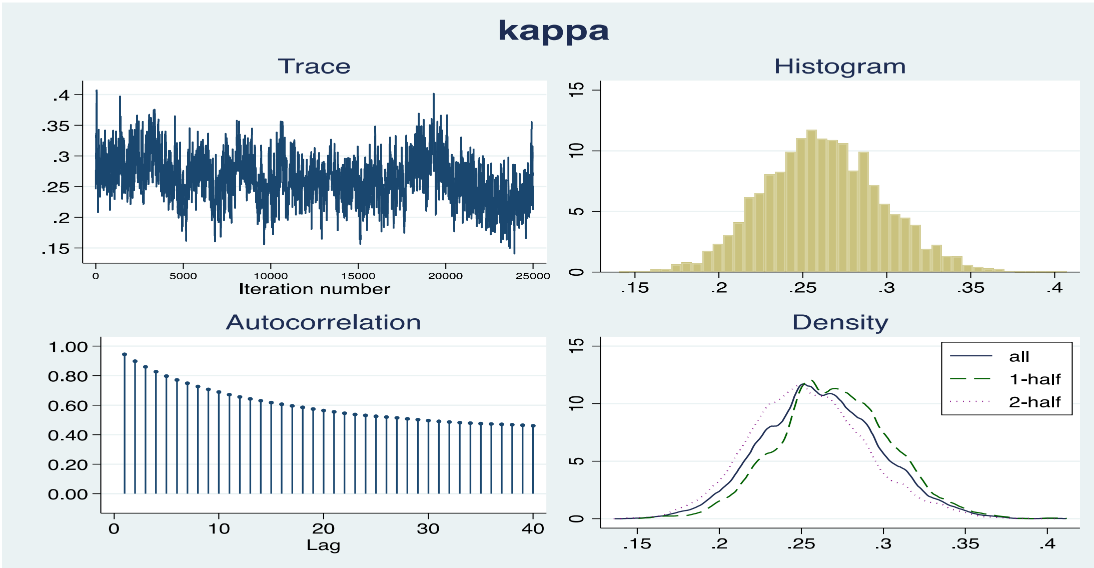
Combined Graphs for Impacts of Shocks on the Policy Rate in the Model with Block Option



Convergence Diagnostics for Model without Block Option



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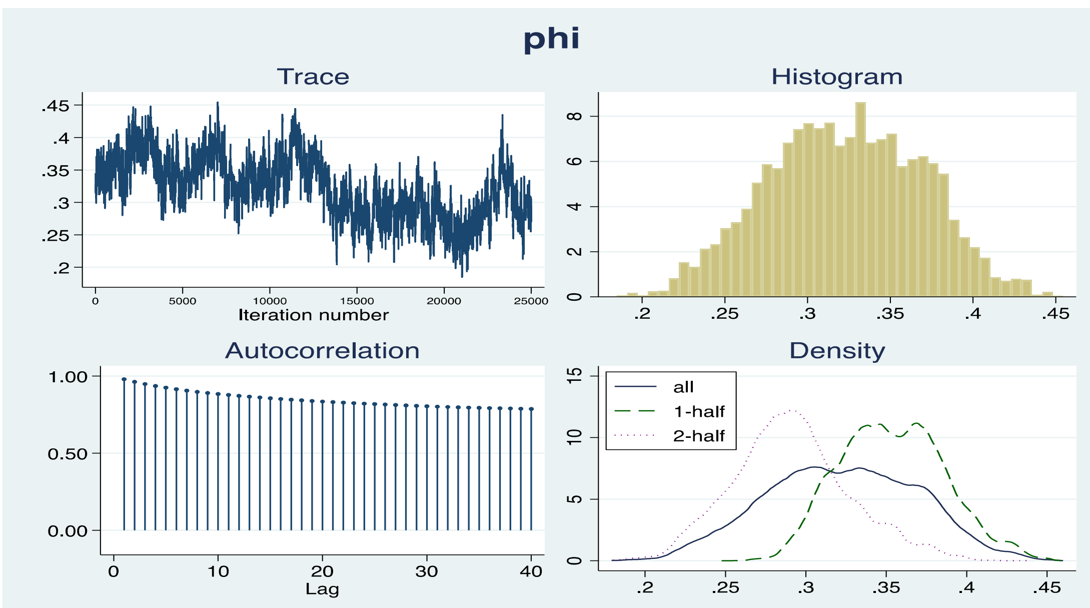
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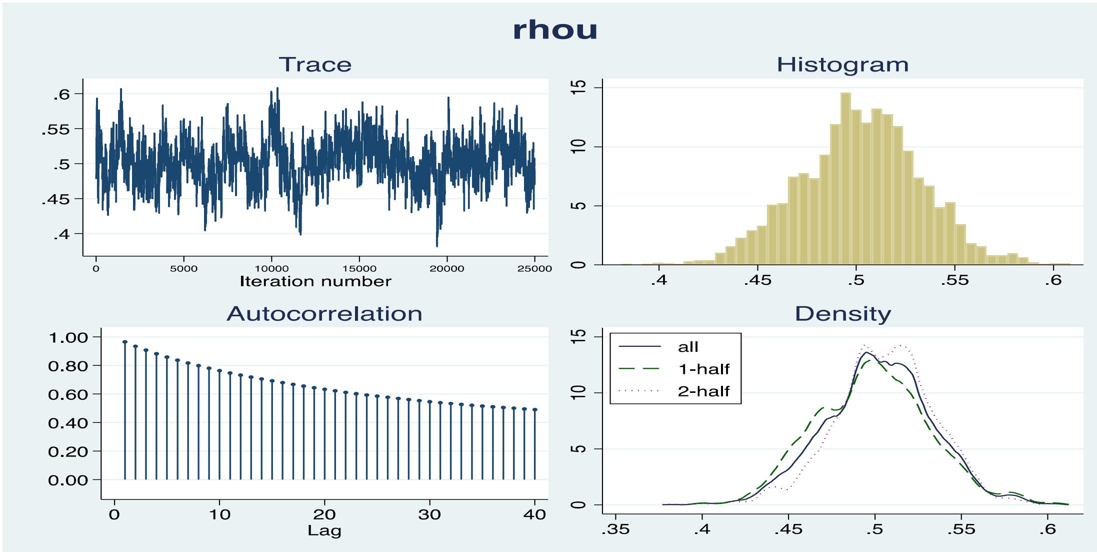
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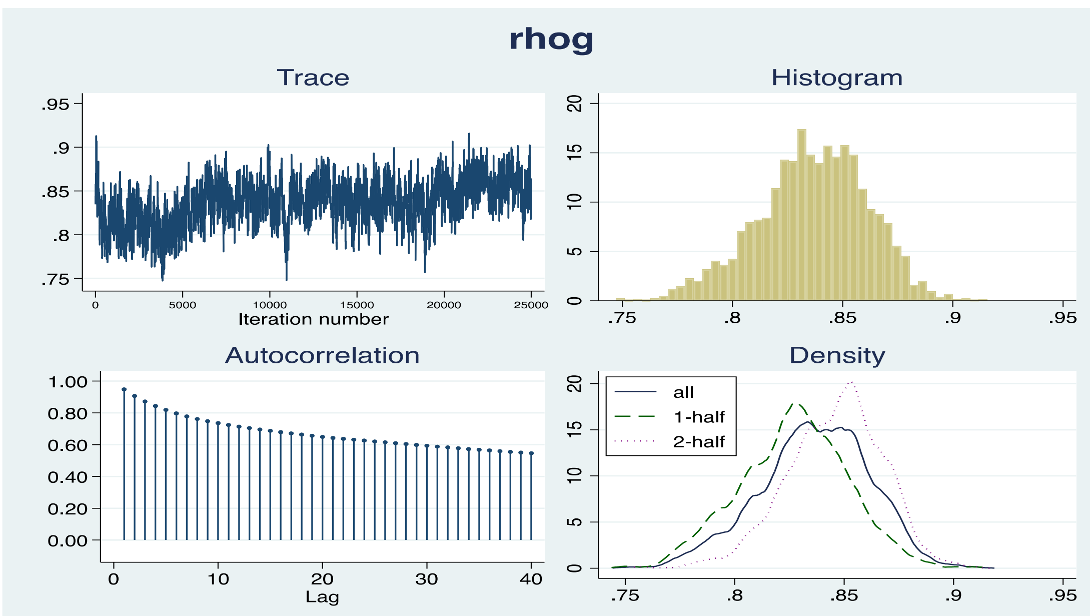
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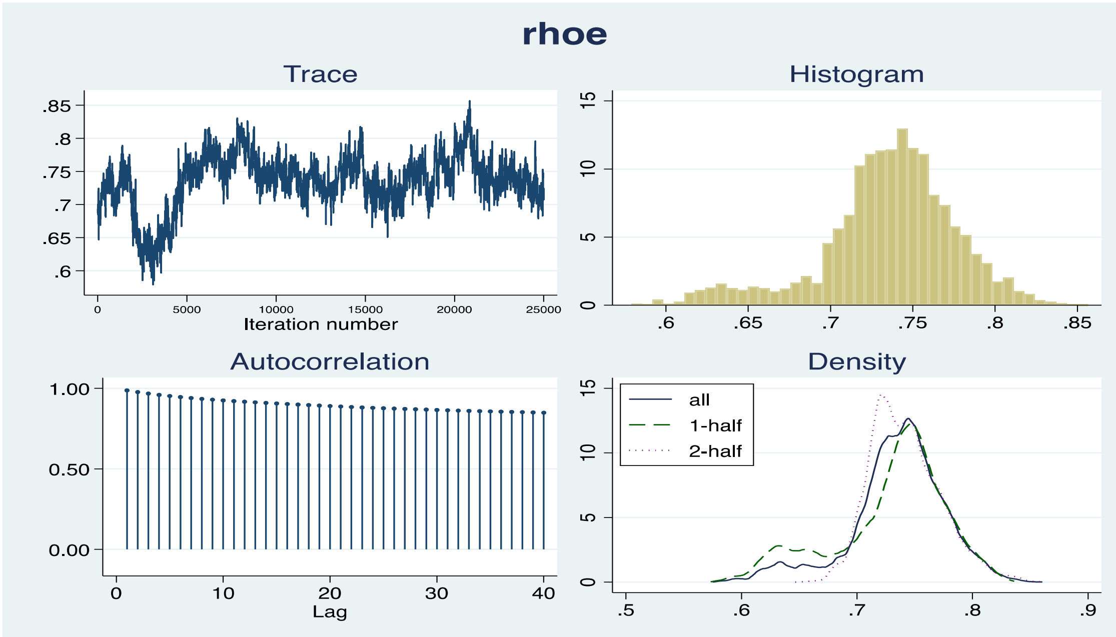
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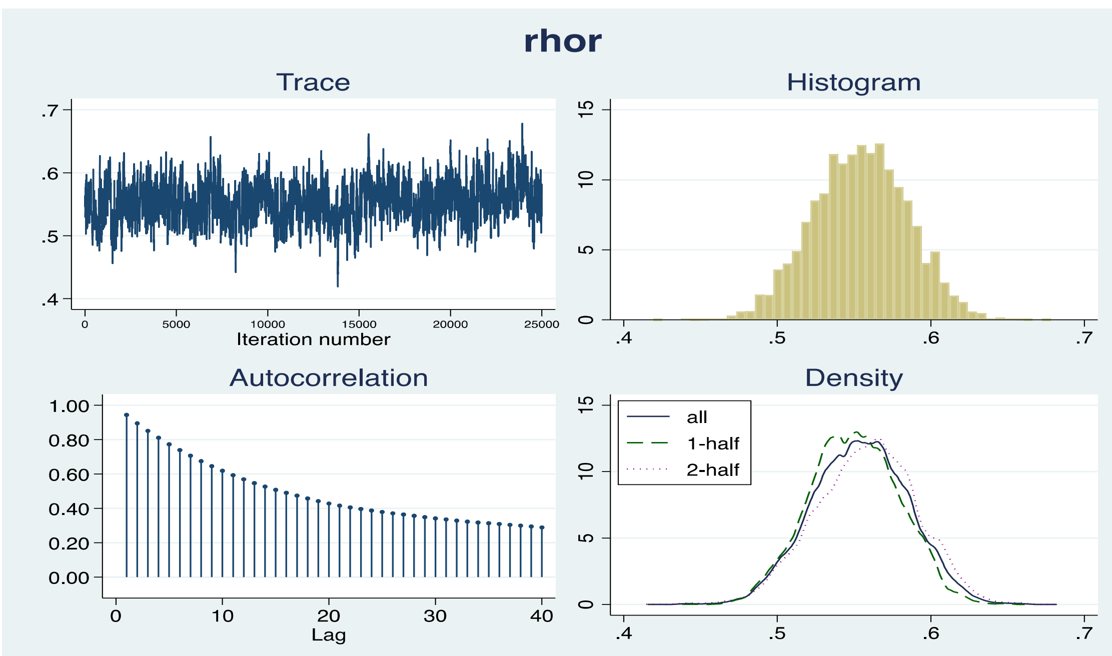
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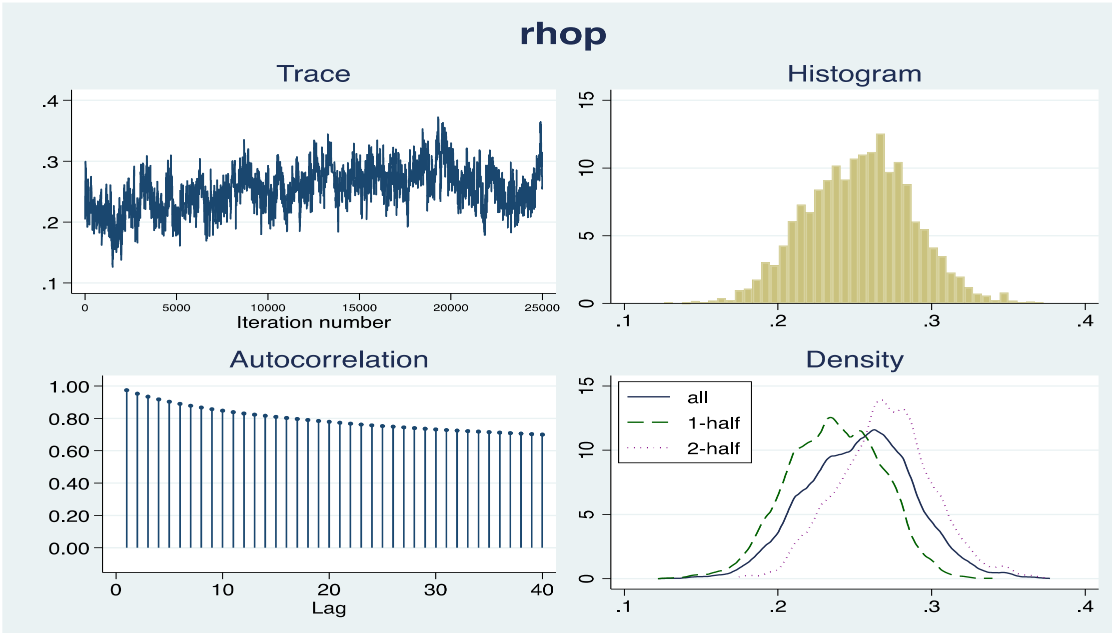
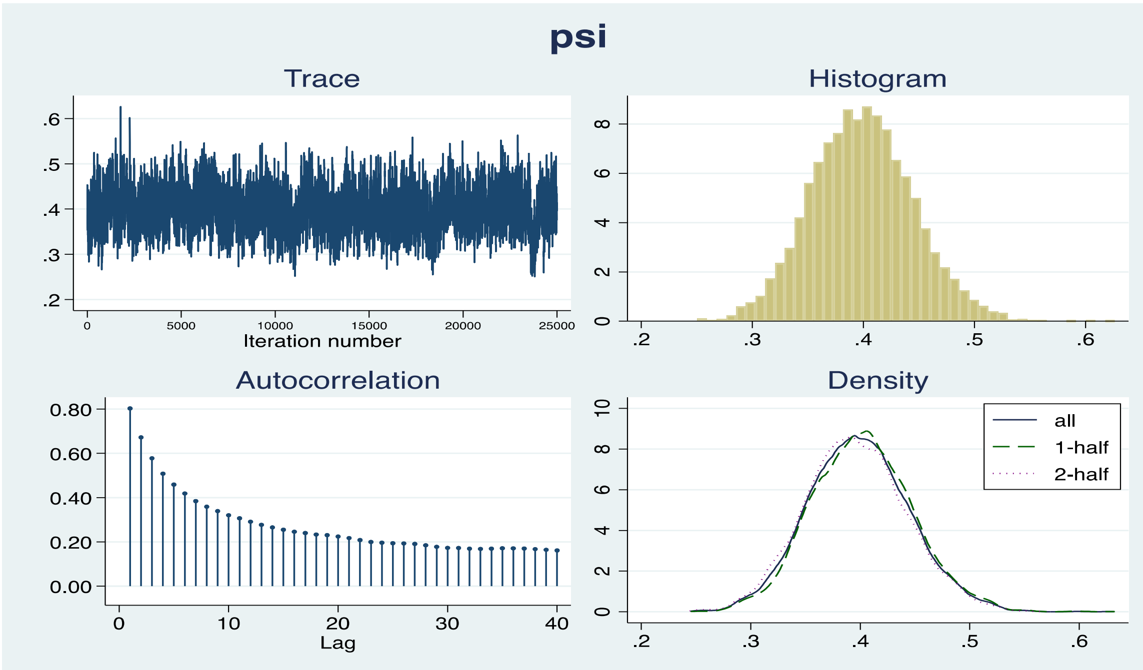
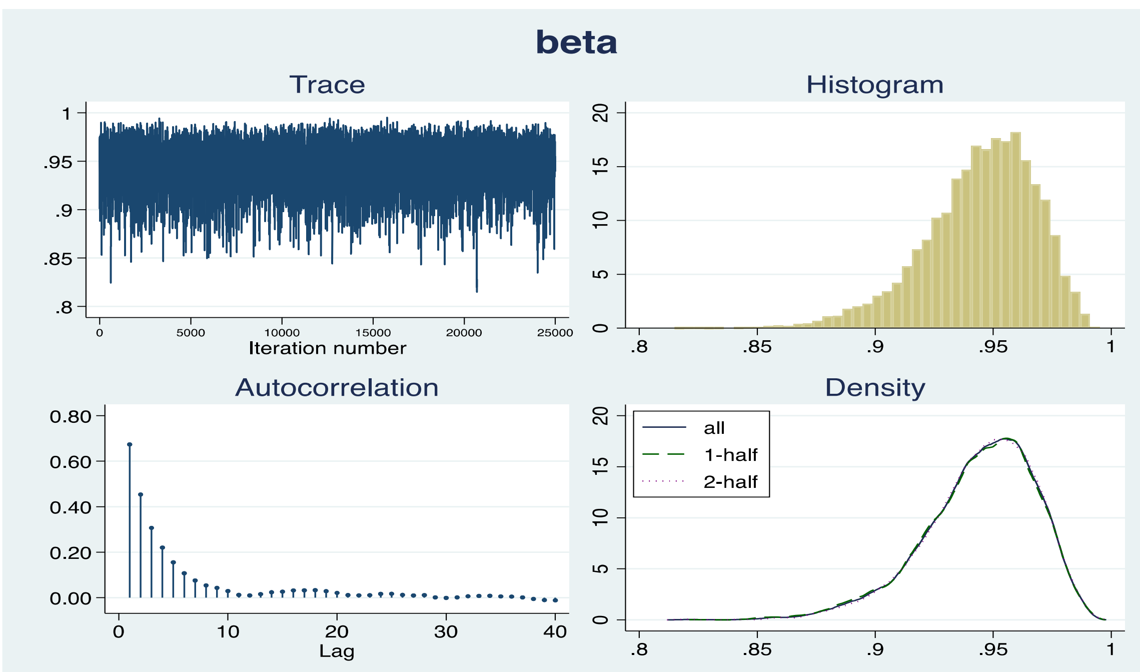


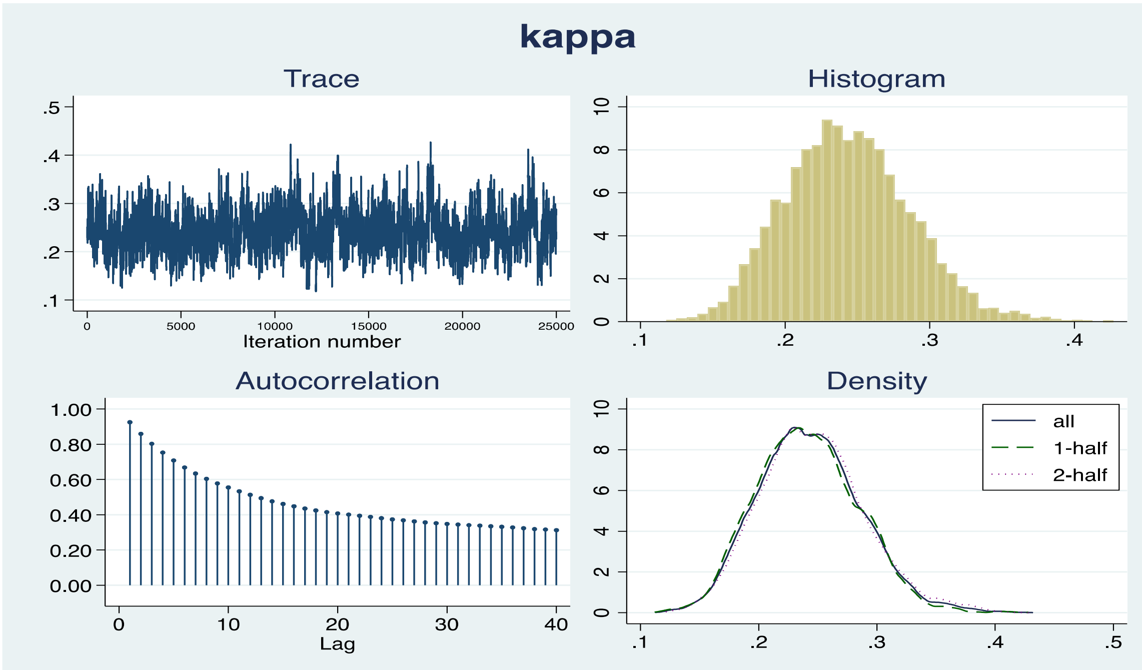

```
Efficiency summaries    MCMC sample size =    25,000
                        Efficiency:  min =   .001399
                                     avg =   .003676
                                     max =   .007455
```

	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



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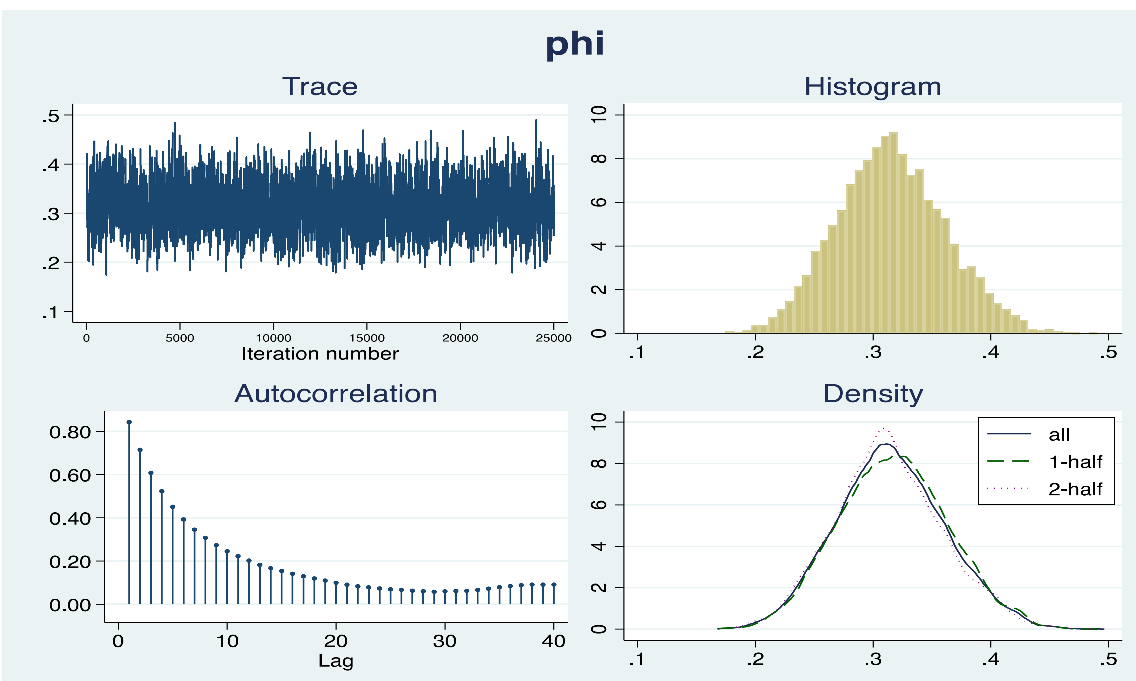
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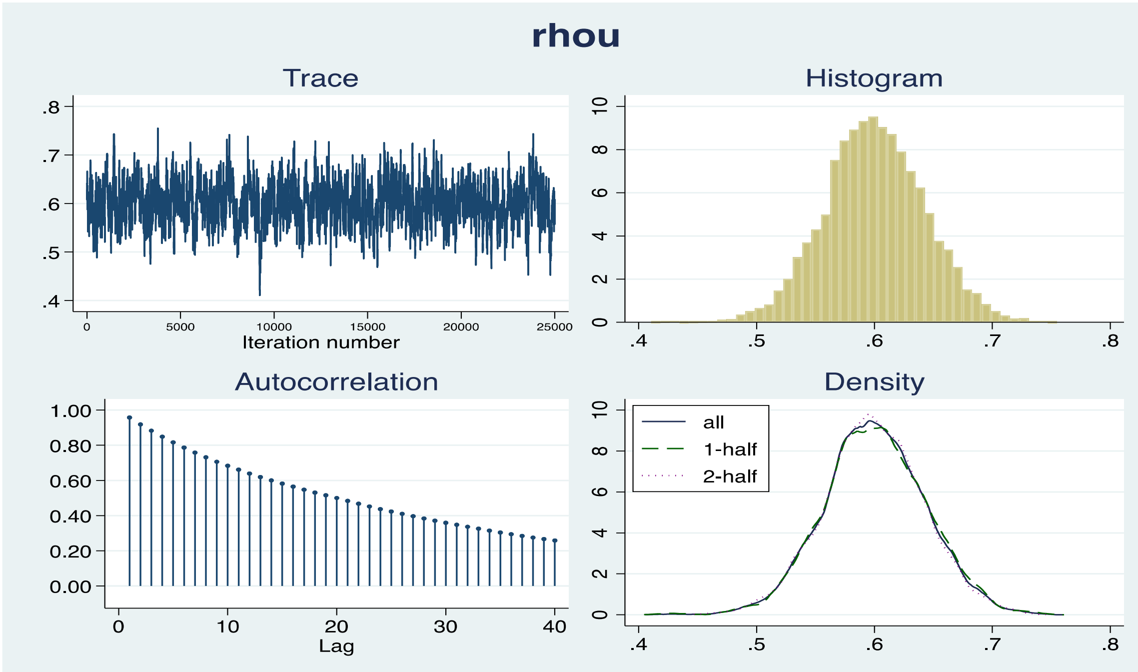
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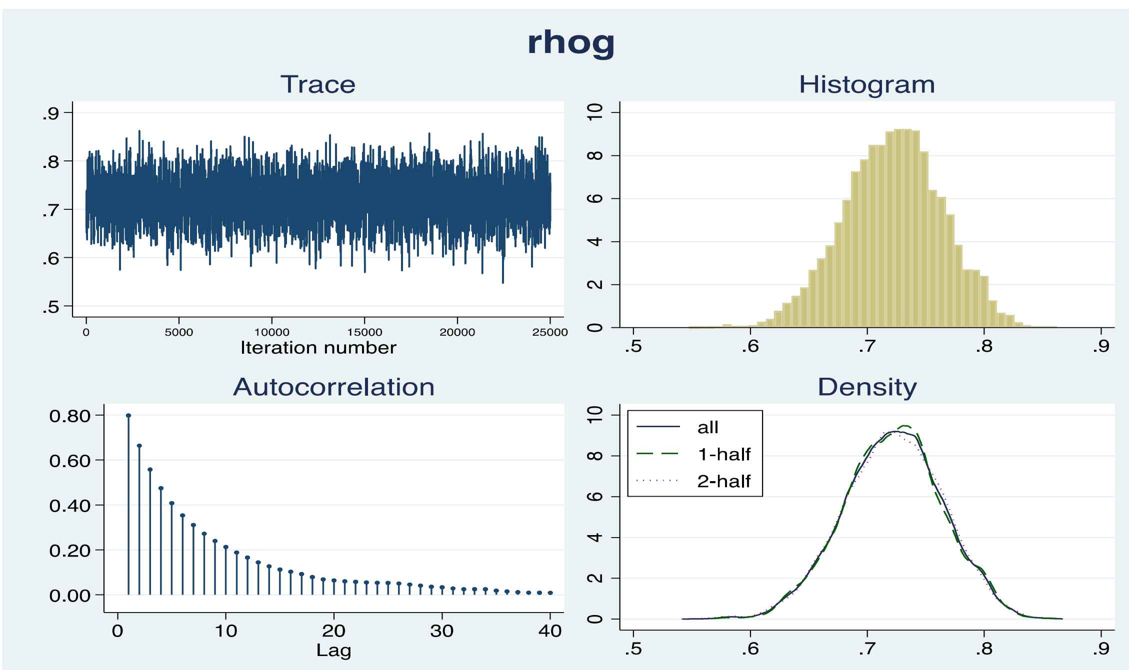
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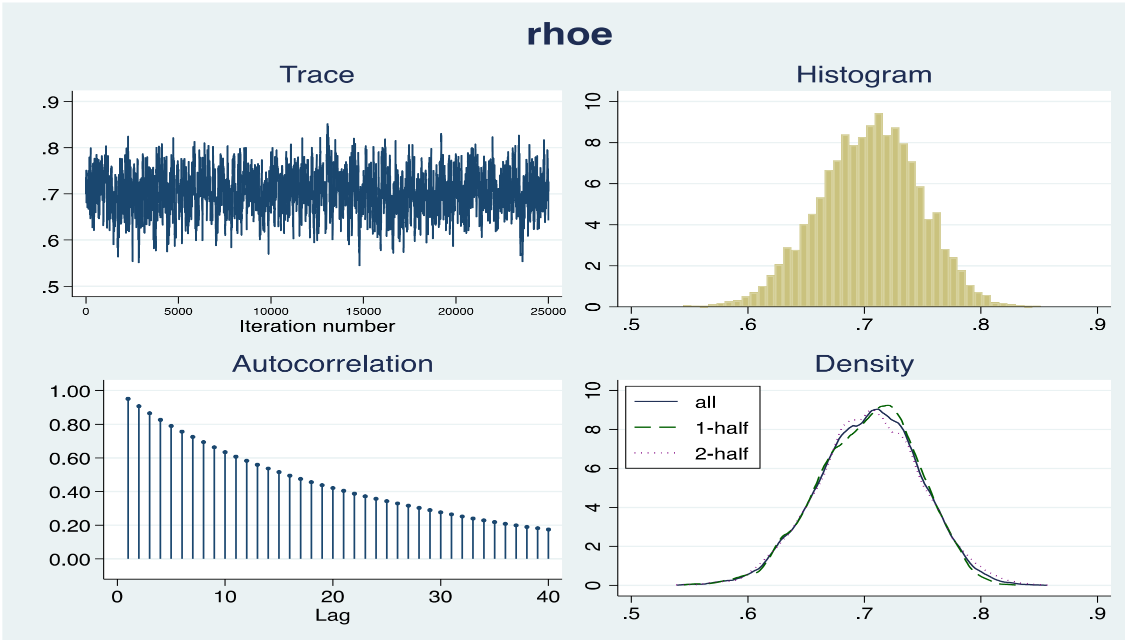
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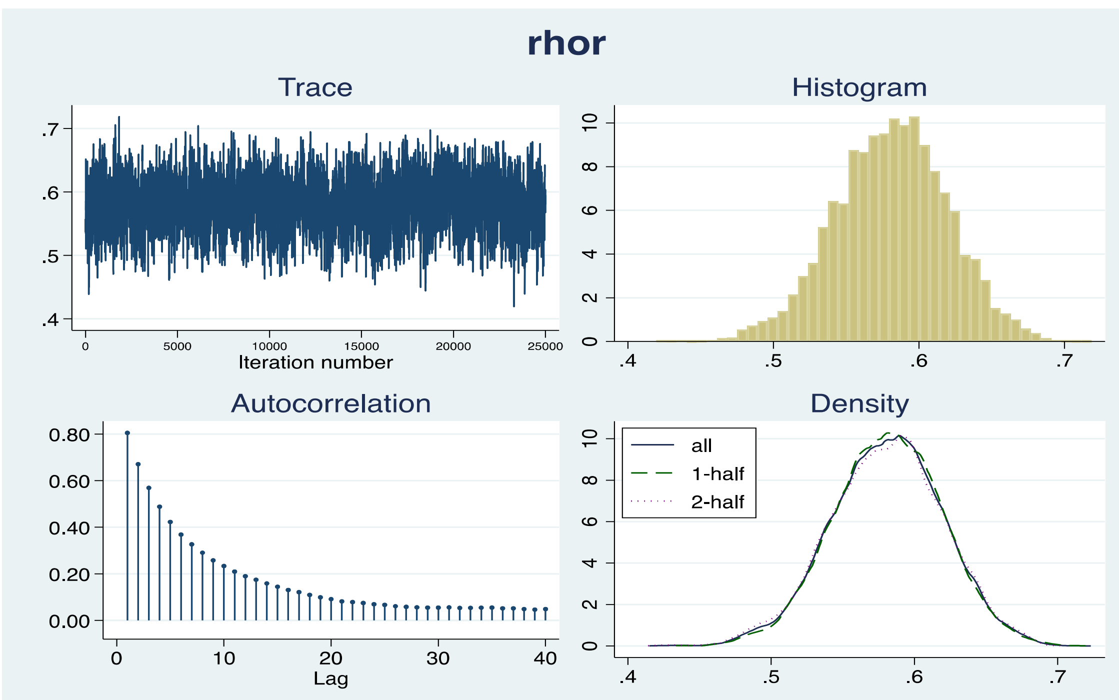
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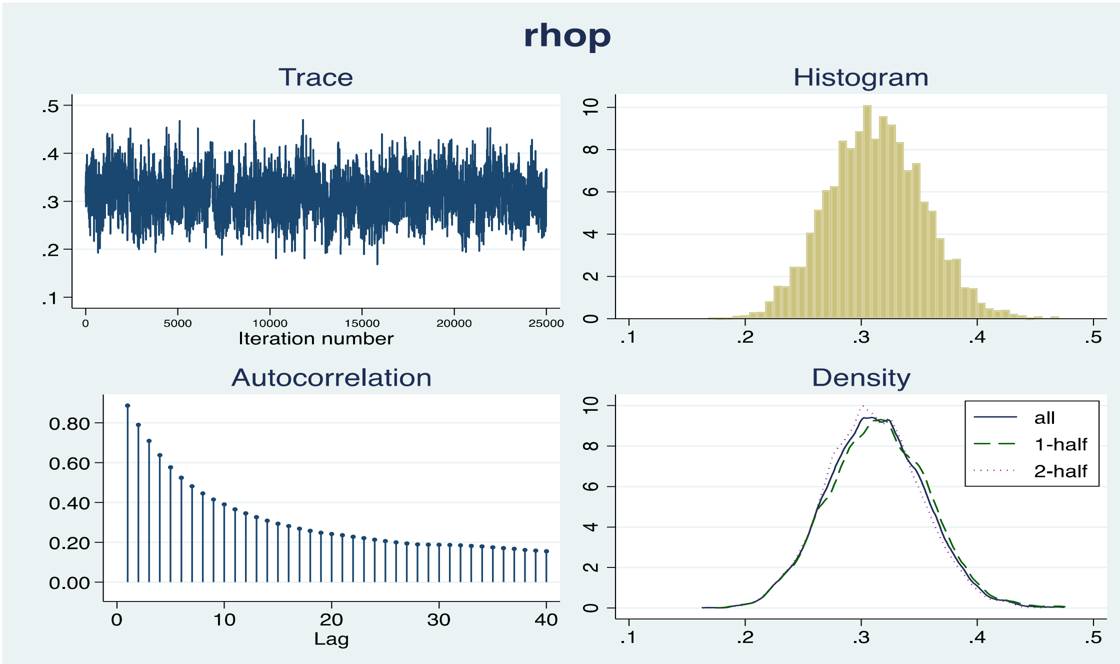


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Efficiency summaries    MCMC sample size =     25,000
                        Efficiency:  min =    .004634
                                     avg =     .04142
                                     max =      .1902
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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

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