Theoretical Issues in DSGE Modelling

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The paper examines the theoretical issues in DSGE Models. Reviewing relevant literature, it was observed that DSGE models are based on micro-founded and real business cycle models with theories of nominal frictions. The paper concludes that much of the development of the model in literature and policy circles, including central banks, focuses on the responses of macroeconomic variables to shocks and forecasting. Finally, the paper recommends the need to advance the DSGE model to capture movements in medium-term shocks and dynamics related to parameters like socio-economic, output, and unconventional monetary policies. These modifications would make the DSGE model more suitable for addressing the key issues confronting policymakers.

1. Introduction

Before the 1980s, large-scale Neo-Keynesian macroeconometric models were popular for policy analysis and forecasting. The beginning of these models can be traced to the late 1940s, and were most successful in the 1950s and 1960s (Klein & Goldberger, 1955). The 1970s, however, witnessed the beginning of the decline of the Neo-Keynesian models and their ad-hoc modelling approach for several reasons.

The Neo-Keynesian models collapsed as forecasting and policy analysis tools as they depended heavily on the trade-off between inflation and unemployment as expressed by the Phillips curve. Thus, it became difficult to explain the simultaneous increase in inflation and unemployment during the 1970s. Several empirical studies also pointed out the weak forecasting performance of Neo-Keynesian models, often suggesting

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that simple statistical extrapolation of time series, with no connection to economic theory, provides better forecasting performance than the structural Neo-Keynesian Models (Nelson, 1972).

Furthermore, economists became dissatisfied with the theoretical underpinings of the Neo-Keynesian models, criticising the lack of micro-foundations for their main assumptions of price and wage rigidities and the disequilibrium nature of the models. Also, with the introduction of the concept of rational expectations, economists became widely dissatisfied with the ad-hoc treatment of expectations in the form of adaptive expectations in these models (Muth, 1961). Following Lucas's critique of Neo-Keynesian models that centred on the fact that the parameters of the models are not structural and policy-invariant (Lucas, 1976), economists conclude that policy conclusions based on these models may be potentially ambiguous. Hence, the growth of Dynamic Stochastic General Equilibrium (DSGE) models is linked to the effort to obtain or derive a model immune to the Lucas critique.

DSGE models began to gain popularity in the 1980s, propelled by various impulses that originated in the 1970s. These impulses were mainly connected with the failure of large-scale neo-Keynesian macro-econometric models as forecasting tools and with the widened dissatisfaction of economists with the theoretical underpinning of these models. These models took the form of equations with ad-hoc assumed decision regimes for developing variables in the model inspired by the Keynesian macroeconomic theory.

The DSGE models are dynamic macroeconomic models of the business cycle behaviour of an economy, with the main features derived from the microeconomic foundations. The model assumes optimising agents with rational expectations who maximise their objective functions subject to constraints. These agents are representative households and firms. Households consume goods, supply labour, trade bonds, or accumulate capital to maximise their utility function subject to numerous constraints. On the other hand, firms produce goods, hire labour, and maximise profits subject to certain conditions. The models are complemented by a variant of the Taylor rule that describes the central bank's behaviour.

The micro-founded models and their parameters are functions of some coefficients, such as discount factor, the elasticity of substitution among goods, elasticity of intertemporal substitution, the elasticity of labour supply, etc. The studies by Lucas and Prescott (1971), and Lucas (1972) are considered the forerunners of DSGE models. Other studies brand these models as New-Classical models, which are referred to as the first generation of DSGE models (Diebold, 1998; Woodford, 2003). The DSGE models are categorised into New-Classical, Real Business Cycle (RBC), and New Keynesian (NK) models. The New-Classical models employ optimising agents' framework and partially focus on a part of an economy (Lucas & Prescott, 1971). The New-Classical model examines a firm's investment behaviour facing stochastic demand and is postulated as ad-hoc. Hence, it does not result from optimising the behaviour of households. Also, Lucas (1972) examines the optimising behaviour of households. However, the supply side of the economy is not explicitly modelled.

The Kydland and Prescott (1982) model became the core of the real business cycle (RBC) theories. Some salient outcomes of the RBC models is that they assume perfect competition in the goods and labour markets, and flexible prices and wages. The models started extensive reactions to the methodological approach, successfully matching some business cycle patterns and policy implications of these models. They also successfully matched some patterns of unconditional second moments of several macroeconomic time series, including their relative standard deviations and correlations. In addition, the models suggest that real forces, especially productivity shocks primarily cause the business cycle . Also, given the primary assumption of the RBC models, that individuals and firms respond optimally to these shocks and that there are no frictions (nominal or real), recession is a result of optimal decisions of individuals in the economy. It does not, therefore, represent a period with an inefficient allocation of resources.

The empirical drawbacks of the RBC models are on the positive comovement of output, labour input, and productivity in response to technology shocks, the dominant source of business cycle fluctuations and neutrality of the monetary policy, suggesting that it has no effects on real variables even in the short run. The limitations of RBC models led to the evolution of the New Keynesian (NK) models. New Key-

nesian models assumed the methodology and the main structure of RBC models, that is, principles of optimising agents. But, unlike RBC models, NK models were enhanced with some "Keynesian" assumptions, namely monopolistic competition on the goods and labour markets, price, and wage rigidities, etc. The distinction between New Keynesian and RBC models is primarily based on price and wage rigidities assumptions.

Also, the inclusion of price and wage rigidities into the model leads to different implications. Monetary policy is no longer neutral in the short run. Because of the presence of nominal rigidities, changes in the short-term nominal interest rate are not offset by identical changes in the expected inflation, thus causing the real interest rate to vary over time. Shifts in real interest rates cause changes in consumption and investment, which in turn leads to changes in output and employment. The reason is that firms find it optimal to adjust their production to the new level of aggregate demand. In the long run, however, all prices and wages change, and the economy returns to its natural equilibrium.

The rest of this paper proceeds as follows: Section 2 presents the theoretical foundation of DSGE models; Section 3 discusses the uses and limitations of DSGE models, Section 4 presents the future of DSGE models, and Section 5 is the conclusion.

2.   Theoretical Foundations of DSGE Modelling

This section describes a DSGE model with real and nominal rigidities constructed to account for the main structure of the economy. The DSGE model is based on the dynamics of utility maximisation of a representative agent and expectations that agents make forecasts following information rooted in the model. This micro-founded model is thoroughly linked to the new open economy studies of Altig *et al.* (2003, 2004), Christiano *et al.* (2005), Galí and Monacelli (2005), Smets and Wouters (2003, 2007), Medina and Soto (2007), and the monetary policy rule linked to Lubik and Schorfheide (2007), Fernández-Villaverde and Ohanian (2009), Christiano et al. (2005 and 2009), Kiyotaki and Gertler (2010).

2.1   Key Assumptions of the Model

The DSGE models are large-scale versions of the New Keynesian model, highlight-

ing real and nominal rigidities and a role for aggregate demand. Other sets of critical assumptions include:

i. The behaviour of consumers, firms, and financial intermediaries, when present, is formally derived from micro-foundations.

ii. The economic environment of the DSGE model is that of a competitive economy but with several essential distortions added, from nominal rigidities to monopoly power and information problems.

iii. The model is estimated as a system rather than equation by equati on.

iv. A continuum of infinitely lived households inhabits the economy whose pizeroblem is to maximise a given intertemporal welfare function.

v. There is a continuum of profit-maximising firms operating in a perfectly competitive market, which means their profit will tend to zero in the long run.

2.2   Structure and Building Blocks

This section presents a medium-scale DSGE model that describes the salient features of an economy. The model comprises of six sectors of the economy, as in Omotosho (2019), which includes a household that seeks to maximise utility over a lifetime. Here, we assumed the aggregate consumption bundle to have oil and non-oil products as in Medina and Soto (2007), subject to budget constraints that are household-specific; firms who maximise profit are subject to three constraints (Production function, price setting, and demand curve); resource sector that is characterised by the dominant of oil as in Bergholt, *et al.* (2017). Others are the external sector that links the economy with the rest of the world, and the fiscal and monetary sectors. The model is based on New Keynesian assumptions- where the economy is characterised by imperfect competition and nominal Price and wage rigidities. We present a simple structure of the DSGE model.

We assume that the domestic economy is open and small vis-a-vis the rest of the world (see Figure 1). The latter assumption suggests that domestic agents' decisions are not affected by international prices, interest rates and foreign demand, and prices

and wages are sticky. The introduction of rigidities in wages and prices is critical in our model because it increases the realism of the model implies a more robust trade-off between inflation and output fluctuations (Erceg *et al.*, 2000; Blanchard & Galí, 2005).
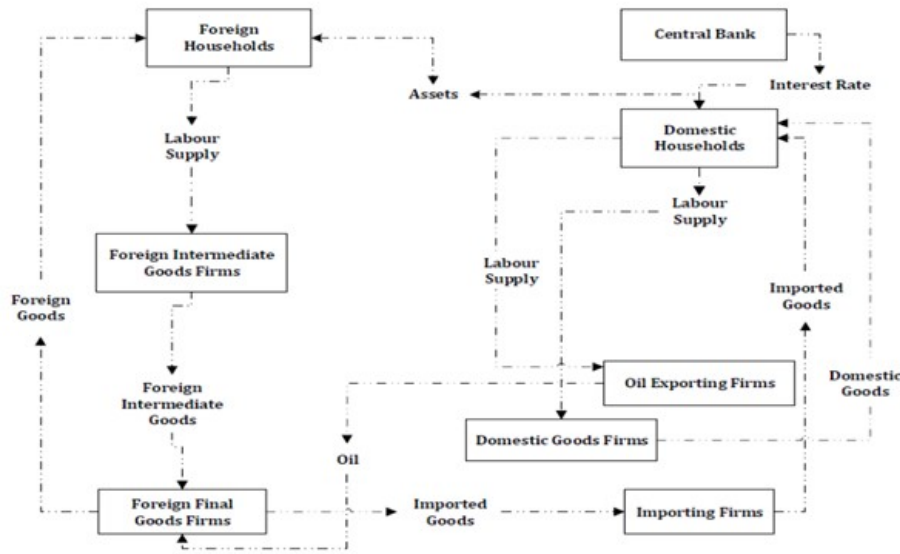

Figure 1: Structure of the DSGE Model

2.2.1 Household

(i) The utility function

In this model, the household seeks maximum utility over a lifetime, which is given as:

$$E_0 \sum_{t=0}^{\infty} \beta^t U\left[C_t - (1 - L_t)\right] \tag{1}$$

Where β^t is the discount factor, C_t is private and public consumption, and L_t is labour-leisure choice of the household. The aggregate consumption bundle comprises oil and non-goods which are either produced locally or imported from the rest of the

world. This is given as:

$$C_t = (1-\beta)^{\frac{1}{n}}[C_{non,t}]^{\frac{n-1}{n}} + \beta^{\frac{1}{n}}[C_{o,t}]^{\frac{n-1}{n}} \tag{2}$$

And the index of non-oil and oil goods is given as:

$$C_{non,t} = (1-\delta_C)\left[\frac{P_{non,t}}{P_t}\right]^{-nc} Y_t \tag{3}$$

$$C_{o,t} = \delta_C\left[\frac{P_{o,t}}{P_t}\right]^{-nc} Y_{o,t} \tag{4}$$

Where C_t is the overall consumption in the economy, $C_{non,t}$ is the non-oil consumption at time t which is defined as a ratio of the price index of non-oil goods $P_{non,t}$ to the general price level (P_t). $C_{o,t}$ is the price index of domestic oil consumption which is defined as the ratio of oil price ($P_{0,t}$) to the general price level, *nc* is the elasticity of substitution between oil and non-oil consumption which is constrained to be positive. The δ represent the degree of openness of the economy. The closer the value is to unity the more the oil consumption and vice versa.

(ii) Budget constraint

We assumed the presence of two types of consumers. The first set is endowed with assets either through inheritance or personal savings. The second are do not have any form of assets and consume whatever income they generate, and this group is referred to as hand-to-mouth consumers. The only source of income for this category of consumers is through employment and/or government transfers. These households are faced with budget constraints in real terms as presented in equations 4 and 5.

$$\frac{P_{o,t}C_{o,t}}{P_t} + \frac{P_{non,}C_{non,t}}{P_t} + T_t + \frac{M_t}{P_t} + \frac{B_t}{P_t} \le \left(\frac{W_t}{P_t}\right)N_t + \frac{M_{t-1}}{P_t} + (1+r)S_t + \frac{B_{t-1}}{P_t}(1+r) \tag{5}$$

$$\frac{P_{o,t}C_{o,t}}{P_t} + \frac{P_{non,}C_{non,t}}{P_t} = \left(\frac{W_t}{P_t}\right)N_t + \tau_t \tag{6}$$

Equation 5 presents the budget constrain of households who are endowed with an asset at period t, while equation 5 is the budget constrain for the hand-to-mouth Household who are without any form of asset. The left-hand side of the equations

represents the expenditure of the household which comes either in the purchase of oil and/or non-oil goods for the hand-to-mouth household while in addition to the payment on consumption, the endowed household buy some bonds and hold some real cash balances. this category of household also pays taxes to government unlike the hand-to-month consumers who doesn't pay any form of tax. The right-hand side indicates the income of the household which comes from employment, interest earnings from savings and bond holdings and inflation gain for the endowed household. The hand-to-mouth only earn income from employment and government transfers. for the relationship between the left and the right hand-sides of the constraints, we assumed that the endowed household income is greater than or equals their expenditure hence they have money to save and/or invest in period t+1 that will give a return. However, the hand-to-mouth household spends all their income at any given time.

2.2.2 Firms

The objective of firms in Nigeria like in any other jurisdiction is to maximize profit. Hence, all firms in this study are assumed to have a single objective function. However, the firms face different constraints. Here, we assumed the existence of two groups of firms, that is, those firms that use purely domestic inputs to produce goods and those that use intermediate foreign inputs to produce output. The former group of firms faces three constraints: the production function, the demand curve, and price setting. Whereas the latter group faces an exchange rate adjustment problem in addition to the three constraints faced by the first group.

The objective of firms is to pick a price level that maximizes profit which is given as:

$$\pi_t = E_t \sum_{i=0}^{\infty} \omega^i \Delta_{i,t+1} \left[\left(\frac{P_{j,t}}{P_{t+i}} \right)^{1-\theta} - \varpi_{t+1} \left(\frac{P_{j,t}}{P_{t+i}} \right)^{-\theta} \right] C_{t+i} \qquad (7)$$

Equation 6 presents the objective function of firms.

$\Delta_{i,t+1}$ is the discount factor. We assumed that firms in this model produce differentiated products, face the same demand curve and equal demand elasticities, and same production technology.

(i) Demand function

The demand function is the same as the composite of the consumption which is given

in equation 2.

$$C_t = (1-\beta)^{\frac{1}{n}} \left[C_{D,t}\right]^{\frac{n-1}{n}} + \beta^{\frac{1}{n}} \left[C_{f,t}\right]^{\frac{n-1}{n}} \tag{8}$$

(ii) Price adjustment

Firms under the new Keynesian model usually follow Calvo (1983) price-setting which belongs to the time-dependent price models, although this is not the only model in this group, however, it has the highest usage due to its trackability. Other models in this category include Taylor (1980) of stagged nominal price adjustment and Bonomo and Carvalho (2004) endogenous price adjustment process, among others. These models assume that firms adjust their price as a function of time not on the state of the economy, that is, the probability that a firm changes its price does not depend on significant change in economic fundamentals, instead, on how long since the last adjustment.

However, the above price adjustment despite its appealing feature of trackability does not reflect the true price adjustment mechanism for a typical Nigerian firm. Therefore, a state-dependent type model will be used in this study. According to this group, price adjustment depends on the state of the economy, that is, firms adjust prices because it is profitable to do so. The models in this class include Cecchetti (1986), Dotsey *et al.* (1999), and Gertler and Leahy (2008). we use (Dotsey, King, and Wolman,1999) (henceforth DWK) as the price adjustment process for firms in Nigeria.

According to the DWK model, firms face a cost of price adjustment which is random and varies across firms and time. Let a vintage 1 denote firms that adjusted its price in j period ago. Let θ be a fraction of firms of vintage 1. Initially, the firms will have the same price. However, among firms in vintage 1, there is the cost of price adjustment. The firms with smaller costs adjust their price while those with larger cost of adjustment leave their prices unchanged. Let $\delta_{i,t+1}$ be the fraction of firms in vintage 1 that adjust their price. Then, in period t+1, the fraction of firms that become i+1 is equaled to $1-\delta_{it}$ multiple by the fraction of firms that were of vintage 1 at time *t*.

The valued function for the adjustment and non-adjusting firms of vintage 1 are given respectively in equations 9 and 10:

$$
U_{0,t} = \max_{P_t^*} [P_t^* - P_t V_t] \left[\frac{P_t}{P_t^*}\right]^{\frac{1}{1-q}} Y_t
$$
$$
+ \theta E_t (1 - \delta_{1,t+1}) U_{1,t+1} + \theta E_t \delta_{1,t+1} U_{0,t+1} - \delta E_t C_{1,t+1} \quad (9)
$$

$$
U_{i,t} = \max_{P_t^*} \left[P_{t-i}^* - P_t V_t\right] \left[\frac{P_t}{P_{t-i}^*}\right]^{\frac{1}{1-q}} Y_t
$$
$$
+ \theta E_t (1 - \delta_{i+1, \ne 1}) U_{i+1,t+1} + \theta E_t \delta_{j+1,t+1} U_{0,t+1} - \delta E_t C_{i+1,t+1} \quad (10)
$$

Where V_t is the marginal cost of production, P_t^* is the optimal price level and P_t is the current price level. The $E_t C_{1,t+1}$ is the present value of the next period adjustment cost, $\delta_{1,t+1}$ is the probability that firms adjust their price at period $t+1$ and become a vintage 1 firm. The $1 - \delta_{1,t+1}$ is the probability that firms don't adjust at $t+1$ period and remain a vintage 0 firm. θ is the expected future inflation which should be less than unity.

(iii) Production function

The third constraint faced by firms is the production function which is assumed to be the same for all firms. In this paper, we assumed the existence of two groups of firms. The first group are those who use domestic inputs to produce output while the second group uses imported intermediate inputs in addition to the local input to produce the final goods.

(A) Endogenous final goods firms

Equation 11 presents the production technology of the firms that locally source its inputs (labor, capital, and technology) for production. We assumed that the production function of this group of firms follows the normal Cobb-Douglass production function with α defining the degree of substitution between labor and capital while A_t defines the efficiency of the entire production process and $O_{yi,t}$ denotes oil con-

sumption.

$$Y_t = A_t K^\alpha K^{1-\alpha} O_{yi,t} \tag{11}$$

(B) Foreign intermediate final goods firms

In this group of firms, we slightly modified the Gawthorpe (2019) production function, where in addition to the locally sourced inputs, we assumed that firms also use foreign intermediate goods as input to the production process. The production technology of firms is specified as follow:

$$Y_{i,t} = Z_{i,t} K_{i,t}^\alpha L_{i,t}^{1-\alpha} M_{i,t} O_{yi,t} \tag{12}$$

where, $Y_{i,t}$ describes the production technology at time t. The level of technology (Z), and foreign intermediary inputs (M) of these firms are assumed to follow an exogenous process.

$O_{yi,t}$ is the oil used in the production process which is common for the two groups of firms. The firms' demand schedule for oil is given as:

$$yi,t = \frac{\theta_0}{1-\theta_0}\left(\frac{P_{ro}}{RMC_{,t}}\right) \times Y_{os,t} \tag{13}$$

(C) Oil sector

The oil and gas sector accounted for 10% of the total GDP of the Nigerian economy[12]. However, the sector contributed 86% of the foreign exchange earnings. The onshore operation is largely dominated by foreign firms who extract the oil on behalf of the state-owned Nigerian National Petroleum Corporation (NNPC) under joint venture partnership. The output is shared between the NNPC representing Nigeria and the oil giants. There are five major operators in the onshore oil sub-sector. The Shell Petroleum Development Company of Nigeria producing 899,000 barrel per day and the production sharing agreement is 55% for Nigeria and 45% for the conglomerates that jointly participate in the extraction. The remaining onshore operators are Chevron Nigeria LTD, Mobil Producing Nigeria Unlimited, Nigerian Agip Oil Com-

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[12]Assuming the Nigerian Case.

pany LTD and Elf Petroleum Nigeria LTD. The NNPC has a 60% share of the total output produced by these companies.

The objective of the operators (NNPC & extraction companies) is to maximize the expected stream of cash flows given as:

$$E_t \sum_{s=t}^{\infty} M_{t,s} \pi_{0,t} = E_t \sum_{s=t}^{\infty} M_{t,s} \left| S_s OP_s Y_{O,t} - PIG_s \alpha U(U_{o,s}) F_{o,s} - PIG \times I_{o,s} \right| \quad (14)$$

Where $M_{t,s}$ is the discount factor that approximates the lifetime profit of the firms. S_s is the real exchange rate, OP_s is the oil price at the international market expressed in USD, $Y_{o,t}$ is the oil output. These three terms sum up the total revenue of the agents operating in the industry. The expenditure comes from the price of investment goods (PIG), and $\alpha U(U_{o,s}) F_{o,s}$ is a function that approximates the firms' accumulation of future capacity.

The firms in the oil extraction industries face two constraints: The production function and the demand curve. The production function summarizes the input combination that is required to produce oil and is given as:

$$Y_{o,t} = Z_{o,t} X_{o,t}^{1-\beta} F_{o,t}^{\beta_0} n \quad (15)$$

$Y_{o,t}$ represents the oil extracted, $Z_{o,t}$ is the productivity shock at a given time. X is the total oil reserve on the ground at a given time t. F is the effective oil ring service. The overall oil demand comes from domestic and foreign households and firms, and the oil reserve.

$$Y_{0,t} = C_{O,t} + O_{y,t} + Y_{fh,t} + Y_{ff,t} + Y_{r,t} \quad (16)$$

where $C_{O,t}$ and $Y_{fh,t}$ is the domestic and foreign household consumption of oil. $O_{y,t}$ is the domestic firms' consumption of oil, the foreign demand of oil by firms is given by $Y_{ff,t}$. The country oil reserve is given by, $Y_{r,t}$.

In this model we assumed that the foreign demand oil for household and firms is

exogenous in the model while the domestic demand of oil from household and firms are determined endogenously as shown in equations 11 and 12 respectively. Furthermore, in terms of price determination, since Nigeria is a member of OPEC that determines the supply quota, the price of oil is also assumed to be exogenous in the model.

2.2.3 Fiscal Sector

The fiscal sector is characterized by the government that purchase goods and services and provide social services to people. To do so, the government generates revenue from different sources. To understand this, consider the following identity for government:

$$G_t + \tau_t + i_{t-1}D_{t-1}^T = T_t + \left(D_t^T - D_{t-1}^T\right) + RCB_t + S_sOP_sY_{O,t} \tag{17}$$

The left side represents the expenditure components of government with G_t representing the government purchase of goods and services, τ_t government direct transfers to household, $i_{t-1}D_{t-1}^T$ is the interest payment on the existing debt. The right-hand side indicates the revenue of the government which comes from all forms of taxes, T_t, change in the debt stock, $D_t^T - D_{t-1}^T$, ways and means advances from the central bank, RCB_t, and the oil revenue, $S_sP_sY_{O,t}$.

From equation 17, it is evident that all the component from the right-side which represent the revenue aspect of the budget identity are exogenous to the government. Therefore, it can only choose policy instruments from the right side. The largest and most important component in the right-side is the government expenditure which for the sake of this study is used as fiscal policy instrument. To describe the evolution of government expenditure in Nigeria, we modify the work of Bergholt *et al.* (2017) which is given as:

$$\frac{G_t}{G} = \left(\frac{G_{t-1}}{G}\right)^{\omega_g}\left[\left(\frac{Y_t}{Y_{t-1}}\right)^{\kappa_{gy}}\left(\frac{RCB_t}{RBC}\right)^{\kappa_y}\right]^{1-\omega_q} Z_{G,t} \tag{18}$$

$Z_{G,t}$ is the fiscal demand shock which is assumed to follow the AR process.

2.2.4 External Sector

In this study, we modeled Nigeria as a small open economy. This implies that the activities of Nigeria (import and export) can not affect the global economy, likewise the activities of other economies except the US do not affect the Nigerian economy. In other word, we assumed a symmetric relationship between home and foreign economies. Following the works of Gali and Monacelli (2004), Lubik and Schorfheide (2005), and Omotosho (2019), we defined some identities to represent the external sector of the economy. The identities are the real exchange rate, terms of trade, and international risk sharing. The real exchange rate is defined as:

$$\left(\frac{P_t^*}{P_t}\right)e_t \tag{19}$$

where P_t is the domestic consumer price index, P_t^* is the foreign consumer price index and e_t is the nominal exchange rate. Secondly, we expect the existence of law of one price gap for the term of trade. This implies a different term of trade between countries. However, since we are interested in Nigeria's interaction with the rest of the world, we present the domestic terms of trade in equation (20) Which is given as the ratio of the domestic price of export on the foreign price of import.

$$\frac{P_{H,t}}{P_{F,t}} \tag{20}$$

Finally, we define the identity to represent the international risk sharing that arises due to cross-border liquidity flows. The risk-sharing can be symmetric when the risk is spread equally among countries and asymmetric when some countries are heavy hit more than others when there is upside or downside risk. This will depend on the level of trade (visible and invisible) between the countries. Therefore, following the work of Omotosho (2019) the international risk sharing identity linking the domestic consumption with the rest of the world is given as:

$$C_t^R(J) - \psi_c C_{t-1} = \upsilon S_t^{\frac{1}{\delta}}\left(C_t^F(j) - \psi C_{t-1}^F\right) \tag{21}$$

2.2.5 Monetary Sector

This subsection describes the behavior of the central bank. The monetary authority may decide to use optimal policy rule as developed by Svenson (1999) where the central bank forecast the targeted variables condition on a given policy path. Alternatively, the central bank responds to changes in the deviation of the policy target as in the Taylor rule. The Taylor rule, although not micro-founded but has a lot of application in empirical studies because of its simplicity and trackability. The frequent usage of the rule has led to a lot of improvement from the initial Taylor (1993) specification. Researchers considers different weight for inflation and resource utilization and modified how the targeted variables entered into the equations (Current, backward, or forward-looking assumptions on the variables). Here, we assumed that the Central Bank of Nigeria uses a Taylor-type feedback rule to stabilize the variables of interest. The assumption is that the bank has an instrument that is directly under its control which has close relation with the policy targets (Operating and intermediate) and by extension affect the policy objectives. Therefore, when there is a deviation of the target variables from the goal, the central bank reacts by adjusting the policy instrument.

We assumed that the CBN target inflation, output, and exchange rate in the policy equation. At any point in time, the Bank responds to deviation of output from the target, inflation from the targeted value and exchange rate from its target. We assumed that the CBN uses the following policy rule:

$$i_t = \xi i_{t-1} + \xi_\pi \left(\pi_{t-1} - \pi^\odot \right) + \xi_y \left(y_{t-1} - y^\odot \right) + \xi_e \left(e_t - e^\odot \right) \tag{22}$$

where i_t is the policy instrument, monetary policy rate, or base money in the case of Nigeria, $\pi_{t-1} - \pi^\odot$ is the inflation gap defined as the difference between the actual and the targeted inflation. $y_{t-1} - y^\odot$ is the deviation of output from its potential. $e_t - e^\odot$ stands for the exchange rate gap. Finally, i_{t-1} is the lag value of the policy variable, which is included to correct previous policy mistakes, it is termed as interest rate smoothing. The coefficients ξ_π, ξ_y and ξ_e represents the response of monetary policy to deviations in inflation, output, and exchange rate.

3. Uses and Limitations of DSGE Models

The limitation or the uses of the current DSGE models can be drawn from the works of Blanchard (2018), Wren-Lewis (2018), Stiglitz (2018), Krugman (2018), Haldane and Turrell (2018), Linde (2018) and Wright (2018). The issues can be grouped into four strands.

First is the issue of micro-foundations hegemony as pointed out by Wren-Lewis (2018). There are other models that are micro-founded such as the Lucas Island model, and the Money in the Utility (MIU) function that are not founded based on DSGE methodology but are general equilibrium models with micro-foundations capable of describing the behaviour of economic agents.

Current DSGE models are flawed, which is why they failed to predict major economic crises such as global financial crisis (GFC) but there's little agreement on what alternative future paradigm should be pursued. Also, the models contain the right foundations and must be improved rather than discarded. Furthermore, according to the mainstream macro-models do a good job explaining many phenomena, although its inability to predict the GFC does not disprove such a theory. To understand crises better under the framework, it is necessary to incorporate other factors related to money, credit, and liquidity.

There are different types of macroeconomic models serving different purposes. The ad hoc Keynesian models, the overlapping generation models, the structural equation models (SEMs), and the data-driven models such as vector autoregressive (VAR), factor augmented VAR (FAVAR), and DSGE models can be used for different purposes. For example, if the interest is in forecasting, models that are data-driven like VARs will perform better than structural models like DSGE[13]. To further add to this debate, Wren-Lewis (2018) argued that Macroeconomics will develop more rapidly if micro-founded models like DSGE and more traditional SEMs are used to complement one another.

Finally, DSGE models require that all components of the model be micro-founded. However, in most of the DSGE specifications, the typical behaviour of central banks

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[13]For a detailed discussion on this see Blanchard (2018)

is described by a feedback rule such as the Taylor type. These feedback rules are ad hoc and, hence are not micro-founded. This raises the issue around the internal consistency of the DSGE models with the instrumental type of policy rule. For a detailed discussion on this see Wren-Lewis (2018) and Svenson (2005). On this strand, some of the DSGE models that tried to incorporate the new developments like the issues of frictions (financial market, labour market, and information), heterogeneous agents, and liquidity constraints into the methodology were based on the However, a multi-disciplinary agent-based approach is important for the required micro-foundation. DSGE should take inputs from behavioural economics, information economics, and theories of consumer and firm behaviour. These models are complementary and suited to answering macroeconomic questions where complexity, heterogeneity, networks, and heuristics play important roles.

4. The Future of DSGE Models

One of the promising future contributions of DSGE models, particularly in model development, is the transition from models in discrete time to models in continuous time (Brunnermeier & Sannikov, 2014; Achdou *et al.,* 2017). The flexibilities inherent in continuous time models are appealing, easier to solve and powerful in numerical optimization. Fernandez-Villaverde *et al*. (2019) posits that the theory of stochastic differential equations will provide DSGE modellers tools and techniques for numerical optimization of the nonlinear equations that have been characterized with structural estimation of the DSGE. Fernandez-Villaverde *et al.* (2019) show how to take advantage of the mathematical structure of a continuous-time model to build its associated likelihood with next-to-no computational effort.

Another promising area of exploration in DSGE modelling, as discussed, in Gornermann *et al*. (2012), Blanchard (2016), and Kaplan *et al*. (2018), and more recently, in Azinovic *et al*. (2020), lies in variational inference. These modern techniques allow for the estimation of heterogenous agents models, such as Heterogeneous Agent New Keynesian (HANK) and/or Two Agent New Keynesian (TANK), as pioneered by Kaplan *et al*. (2018). These models enjoy sudden burst of popularity and are currently undergoing a boom in policy analysis, structural inference, and forecasting exercise. The estimation of these models is difficult because solving them is computationally

hard and challenging as they require likelihood function to be optimized. With variational inference, likelihood function can be optimized for both closed-ended and open-ended forms. This is an area where DSGE modellers can explore for future research due to its flexibility and its ability to optimize generic likelihood function.

Recently, as identified by Goodfellow *et al.* (2016), DSGE models can successfully be incorporated with Machine Learning (ML) methods. Algorithms applied and used in ML can also be used to estimate DSGE models. This will enhance the predictability of the DSGE models in crisis detection and controls. The ML algorithms can be utilized in DSGE in at least two ways.

As ML is particularly used in approximating high-dimensional functions, such as the state-space representation of Fernandez-Villaverde and Rubio-Ram–rez (2008), the ML algorithms can be as a solution in DSGE. Deep neural network, for example, which is an algorithm in ML, can address the concern of large economies DSGE. For a comprehensive review of ML and large DSGE models, especially with application in HANK models, you can explore Fernandez-Villaverde *et al.* (2019), Maliar *et al.* (2019), and Azinovic *et al.* (2020).

The second way through which ML can be incorporated in the use of DSGE models can be thought of as a "process" to unstructured data (such as satellite image, social media activity, and text). Put differently, DSGE models can leverage unstructured data of ML which can be used as additional observables in the DSGE model estimation. For example, public opinion and statement about monetary policy from central banks can provide sentiment and information about the expectations of agents in the economy. This would be difficult to elicit from macroeconomic data. However, with ML algorithm that process unstructured data, this can easily be integrated to DSGE models. A clear reference to this development can be referred to the work of Casella et al. (2020) which illustrated how estimation of structural DSGE models with unstructured data can be accomplished by merging techniques for text data in an augmented state-space representation.

5. Conclusion

The paper examines the theoretical issues in DSGE Models. Reviewing relevant lit-

erature, the paper suggests that the origin of current DSGE models was based on micro-founded and real business cycle models with theories of nominal frictions. The goal was to create a new generation of macroeconomic synthesis that combines factors that influence aggregate supply and demand in a coherent framework. The paper further concludes that much of the development of the model in the literature and policy circles, including central banks, focused on data regarding the responses of macroeconomic variables to shocks and forecasting. Finally, the paper recommends the need to advance the DSGE model to capture movements in medium-term shocks and dynamics related to other parameters like socio-economic, output, and unconventional monetary policies. The paper suggests that those modifications would make the DSGE model more suitable for addressing the key issues confronting policymakers.

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