

DEPARTMENT OF ECONOMICS

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Sisay Regassa Senbeta

UNIVERSITY OF ANTWERP
Faculty of Applied Economics



Stadscampus
Prinsstraat 13, B.226
BE-2000 Antwerpen
Tel. +32 (0)3 265 40 32
Fax +32 (0)3 265 47 99
<http://www.ua.ac.be/tew>

FACULTY OF APPLIED ECONOMICS

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RESEARCH PAPER 2011-016
OCTOBER 2011

University of Antwerp, City Campus, Prinsstraat 13, B-2000 Antwerp, Belgium
Research Administration – room B.226
phone: (32) 3 265 40 32
fax: (32) 3 265 47 99
e-mail: joeri.nys@ua.ac.be

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D/2011/1169/016

How applicable are the New Keynesian DSGE models to a typical Low-Income Economy?*

Sisay Regassa Senbeta[†]

University of Antwerp, Department of Economics

October 18, 2011

Abstract

This paper assesses the applicability of new Keynesian DSGE models to low income economies similar to those in Sub Saharan Africa. To this effect, we first review the development, criticisms and recent advances in DSGE modeling. Then we assess the implications that emanate from the assumptions of the standard small open economy New Keynesian DSGE model within the context of the economic environment of a typical low income economy. Our assessment shows the following two points. First, though there are many criticisms to these models, most recent advances seem to have addressed most of them. However, there are still some outstanding criticisms that seriously challenge not only the DSGE models but also all conventional economic models. Second, the current tendency of applying these models to explain or predict economic phenomena in low income countries without incorporating the structural specificities of these countries cannot be justified. Instead, for these models to be helpful to understand the economic events in low income countries, most of their components must be changed or modified. In this study we identify some of these components and suggest the possible changes or modifications.

JEL classification: E32, F41, O55

Keywords: New Keynesian DSGE, Open economy macroeconomics, Fluctuations, Sub-Saharan Africa

*I thank Professor Guido Erreygers who provided me with invaluable comments and suggestions throughout the development of this paper. I am also grateful to Professor Wim Meeusen who helped me see the downside of the DSGE models. I thank Dr. Tekie Alemu for many useful comments and suggestions. Earlier version of this paper was presented at a Seminar Series of the School of Economics of Addis Ababa University in August 2011. I thank seminar participants for useful comments and suggestions. Responsibility for all errors is mine.

[†]Stadscampus S.B. 135, Prinsstraat 13, 2000 Antwerp, Belgium. SisayRegassa.Senbeta@ua.ac.be

Macroeconomics was developed in, and for, industrialized countries. Both theory and policy were concerned with how monetary and fiscal policy should be used in industrialized economies to attain full employment, control inflation, and stabilize economic activity. ... Developing countries often use this corpus of knowledge, with its competing schools of thought, *without any significant modification*. But it's by no means clear that applying these theories to developing countries is either justified or appropriate. (Stiglitz et al, 2006: 52, Emphasis added)

1 Introduction

The debates on the applicability of conventional (macro)economic models to explain or predict economic events in developing countries date back to the 1960s. The literature attributes this to the emergence of the center-periphery argument in the 1950s, by Raul Prebisch and others, who argued that policy recommendations emanating from the then conventional economic models are detrimental to poor (peripheral) countries. However, the attempts to construct macroeconomic models specific to these countries have gained momentum since the early 1980s as many were interested in investigating why the Structural Adjustment Programs, championed by the international financial institutions, were not working as expected¹. The issue at the heart of the controversy is that macroeconomic models, or any other economic model for that matter, are developed on the basis of a specific underlying socioeconomic and political environment, and try to explain how different economic agents interact within that assumed environment.

However, if these models are applied to an environment substantially different from the one on the basis of which they are developed, they may provide wrong explanations and predictions of economic events. As was well expressed in the opening quotation, conventional macroeconomic models are built on the assumed behavior of economic agents and institutions in developed countries. Not surprisingly, policies guided by such conventional models when applied to low income economies might turn out to be ineffective and, still worse, they can bring about unintended negative results. This is well illustrated by Porter

¹Leff and Sato (1980) discuss other reasons for this increasing interest in macroeconomic modeling of low income countries at the time. They mention, for example, new research results on some aspects of the macroeconomy of these countries like the theory of financial repression by Shaw (1973) and McKinnon (1973).

and Ranny (1982) who construct an IS-LM-AS-AD model of a typical low income economy based on a list of characteristic features that make such an economy different from a typical developed economy. Their analysis of various policy instruments, in this simple but enlightening model, shows that some standard policy instruments have sometimes opposite outcomes when applied to a low income economy compared to their consequences in an advanced one. For instance, their analysis shows that contractionary monetary policy that is employed to stabilize inflation in a typical advanced economy may exacerbate inflation in low income economies leading to the situation of stagflation. Likewise, Leff and Sato (1980) posed specific question of macroeconomic adjustment after a shock to show, using the standard IS-LM framework, how standard policy prescriptions fail to work for a typical developing economy. These old results concur with recent argument by many such as Stiglitz et al. (2006).

The issue is that economic agents in developed countries, on whose behavior conventional macroeconomic models are built, interact within a macroeconomic environment that is significantly different from the one of low income economies. The institutions governing the interactions of economic agents in developed countries are either non-existent or at their early stage of development or, even more importantly, there are different sets of institutions that govern the economic interactions in low income countries. In other words, low income countries like those in Sub Saharan Africa (SSA) have their own peculiar characteristic features that they share among themselves (see Agenor and Montiel (2008), Frankel (2011), Stiglitz et al. (2006), Porter and Ranny (1982), and Leff and Sato (1980), among others). All these studies discuss a list of features that are unique to developing countries. Agenor and Montiel (2008: 14-31), for instance, discuss more than 14 characteristic features encompassing every aspect of the macroeconomy that make these countries different from the advanced countries assumed in the conventional model. Similarly, Stiglitz et al. (2006) provide a full chapter of discussion of why and how macroeconomics is different in advanced and developing countries. Thus, models employed to explain or predict economic events in these economies must incorporate these characteristic features. The implication is that conventional macroeconomic models require some form of modification or change to be meaningfully applied to these economies.

The New Keynesian version of dynamic stochastic general equilibrium (DSGE) models (also referred to as the New Neoclassical Synthesis, Goodfriend and King (1997)) has become the main workhorse of macroeconomic research. These models, as will be discussed

in detail in section 2, combine the New Classical and Real Business Cycle (RBC) theories with that of the New Keynesian economics. They inherit the microfoundations, rational expectations, and general equilibrium traits from RBC DSGE modeling, while market imperfections, sticky wages and prices are fingerprints of the New Keynesian economists. Thus, the New Keynesian DSGE models are based on the assumption of rational economic agents who form rational expectations about future values of macroeconomic variables of their interest. Furthermore, according to these models, economic agents maximize their objective functions intertemporally (though sometimes reference is made to rule-of-thumb agents, as will be discussed in section 4). The behavioral equations representing each of these economic agents and the assumptions about some basic institutions (like the structure of the financial markets and the rules governing these markets, the operation of different input and output markets, the integration of the economy to the international financial/asset markets etc.) are, therefore, crucial building blocks of such models, and the explanative and predictive capacity of the models depend on specifications of these behavioral equations and institutions. This poses some questions that we try to address in this paper: Do the building blocks of the New Keynesian DSGE models capture the behavior of economic agents in low-income countries? If not, what are the reasons: Differences in the behavior of economic agents or differences in the economic environment? What modifications or changes are needed to meaningfully apply these models to such countries and how can one best introduce them?

The main objective of this paper is, therefore, to critically assess the basic elements of the open economy New Keynesian DSGE model and to examine these elements within the context of the macroeconomic environment of a typical SSA economy. This will enable us to evaluate whether the standard New Keynesian DSGE model can be directly applied to such economies or whether it requires modifications to be practical under such circumstances.

The organization of the paper is as follows. In section 2, we examine more closely the historical development of the New Keynesian DSGE models and outline the small open economy version of these models. Section 3 discusses the criticisms to and recent advances in the New Keynesian DSGE models. In section 4, we discuss the component parts of the standard open economy New Keynesian DSGE model outlined in section 2 and assess the implications of the assumptions that underlie each component when applied to a typical SSA economy. This discussion will enable us to achieve our objective; that is, establish

whether the standard open economy New Keynesian DSGE model can be applied to low income economies or needs modifications to be of practical use to such economies. In section 5, we discuss the works conducted so far in an attempt to construct and estimate New Keynesian DSGE models for SSA countries. Section 6 concludes.

2 Review of standard New Keynesian DSGE model

2.1 Historical developments

The DSGE models are macroeconomic models that have their origin in the researches pioneered by Kydland and Prescott (1982). These models have micro-foundations, which their antecedent, the Keynesian models, were blamed to lack. DSGE models are based on the explicit assumption and modeling of intertemporal optimization behavior by economic agents under their respective constraints. That is, households maximize their life-time utility subject to a sequence of lifetime budget constraints, while firms maximize discounted profits subject to input prices and technology. Economic agents are also assumed to be forward looking and, therefore, form rational expectations about the future value of macroeconomic variables of interest. This addressed the Lucas critique against the macroeconomic models that were dominant research methods in use prior to the development of DSGE models.

The Lucas critique can be stated as follows: the evaluation of a proposed policy based on macroeconomic models with parameters estimated from past data is futile, since the structure of the economy *ex post* is different from its structure *ex ante*, given economic agents that are forward looking. Lucas (1976: 41) argues that “given that the structure of an econometric model consists of optimal decision rules of economic agents, and that optimal decision rules vary systematically with changes in the structure of series relevant to the decision maker, it follows that any change in policy will systematically alter the structure of econometric models”. The argument is that proposed policy changes affect the behavior of economic agents since any policy change affects the current or future constraints that economic agents face which implies that the parameters of the model will also change. Or equivalently, the parameters are not policy invariant. The DSGE models address this problem as the parameters that govern the behavior of economic agents are policy invariant, if the model is correctly specified (Cogley and Yagihashi, 2010)².

²The qualification in this statement deserves attention. Cogley and Yagihashi (2010) argue that the

The basic DSGE model developed in the tradition of RBC economics assumes that markets always clear and both booms and busts in the economy are the results of optimal intertemporal decisions by economic agents. According to the basic RBC model, economic fluctuations are due to real factors, specifically random and large shocks in technology that are propagated by intertemporal substitutions between labour and leisure, on the one hand, and between consumption and saving, on the other (Snowdon and Vane, 2005: 294-344). Therefore, according to this basic model, monetary fluctuations cannot explain fluctuations in aggregate variables, or as is commonly referred to in the literature, money is neutral. Furthermore, this model asserts that any fluctuation in aggregate variables is optimal since it is the outcome of decisions of rational economic agents and hence, by implication, there is no need for economic policy to correct these fluctuations.

However, there were many criticisms to these conclusions of the basic RBC model. Specifically, the assertion of the neutrality of money faced serious challenges from many economists whose arguments have been based on solid empirical evidence. There is much empirical work that documented the importance of monetary fluctuations in explaining fluctuations in real macroeconomic variables that is contrary to the assumption of the basic RBC model where money is neutral (see references in Gali, 2008 and Woodford, 2003). This argument about the non-neutrality of money is also well stated in Fernandez-Villaverde (2010: 5) where he argues that “after one finishes reading Friedman and Schwartz (1971) *A Monetary History of the U.S.* or slogging through the mountain of Vector Autoregressions (VARs) estimated over 25 years, it must be admitted that those who see money as an important factor in business cycles fluctuations have an impressive empirical case to rely on”. The argument about the non-neutrality of money is crucial since it implies that either prices and/or wages are not flexible or economic agents suffer from money illusion or both. Again these are in contradiction with the RBC wisdom³.

Cognizant of these weaknesses of the basic RBC version of the DSGE models, econo-policy invariance argument of the structural parameters in DSGE models is based on the idea that the DSGE approximating models are correctly specified. In this case, they argue that the parameters are approximately policy invariant. But, in case of incorrectly specified models, there will be no ground for this claim of approximate invariance.

³It is important to note that the New Keynesian economics introduced the existence of nominal and real rigidities that emanate from the decisions of rational economic agents to help explain how changes in monetary policy affect real variables. However, rational economic agents that are modeled in the New Keynesian models worry only about real values and therefore do not suffer from money illusion. As will be discussed in the next section this is one of the important drawbacks of the New Keynesian DSGE models.

mists continue to introduce different extensions. Most of these are attempts to incorporate the New Keynesian assumptions of imperfect competition where economic agents have some form of market power in input and output markets (unlike the RBC model where perfect competition is assumed). For various reasons such as menu costs, aggregate demand externalities, coordination failure, staggered price contracts etc. (Snowdon and Vane, 2005: 357-432) that are well entrenched in the New Keynesian literature, in the short run firms do not automatically adjust their prices in response to changes in economic conditions. In addition, the New Keynesian economics shows that different imperfections discussed above and institutional arrangements in the labour market lead to rigidity of wages in the short-run, which is contrary to perfectly flexible wages in the basic RBC model. This implies that prices and wages are rigid in the short-run, and most importantly these rigidities are the outcome of the decisions of rational economic agents, who attempt to maximize their respective objective functions. That is, the rigidities are now given micro-foundations which they were blamed to lack in the old Keynesian paradigm. The existence of these rigidities in nominal wages and prices, in the short-run, implies that monetary policy can affect real activities since changes in the money supply will not result into the same proportionate change in prices as argued by the proponents of New-classical and RBC economics.

This extended model, referred to as the New Keynesian DSGE model, maintains the basic elements of the RBC model such as rational expectations and the general equilibrium assumptions, as a result of which Goodfriend and King (1997) coined the name “New Neoclassical Synthesis” for this class of macroeconomic models. They argue that

The New Neoclassical Synthesis inherits the spirit of the old, in that it combines Keynesian and classical elements. Methodologically, the new synthesis involves the systematic application of intertemporal optimization and rational expectations as stressed by Robert Lucas. In the synthesis, these ideas applied to the pricing and output decisions at the heart of Keynesian models, new and old, as well as to the consumption, investment, and factor supply decisions that are at the heart of classical and RBC models. (p. 232)

Over the years, researchers from both sides of the spectrum have incorporated many issues so that these models better mimic the real world. Nevertheless, the applicability of these models to policy analysis was constrained by the difficulty to estimate their pa-

rameters from actual data. Consequently, researchers relied entirely on calibration of the parameters where the parameter values are calculated based on some theoretical properties (the balanced growth path property) of the economy or borrowed from other microeconomic studies or previously calibrated models. This method led to a protracted debate among macroeconomists, the discussion of which we will defer to the next section. However, recent developments seem to show that this is no longer the problem, at least since the influential works of Smets and Wouters (2003 and 2007) and Christiano et al. (2005). It is now common to see estimated small and medium scale models for different countries. The fact that these models are estimated from actual data and perform as well as the VAR models that are blamed to lack theory, according to the proponents of DSGE models (see, among others, Christiano et al. (2011), Fernandez-Villaverde (2010), Gali et al. (2011)), made them popular at central banks and policy research institutions⁴. However, despite their success stories, there are criticisms to these models which are gaining momentum since the recent economic crisis, which we will discuss in section 3. Next we will turn to outline the component parts of a small open economy New Keynesian DSGE model to facilitate the discussions in the later sections.

2.2 The Small Open Economy New Keynesian DSGE model

To make this paper self contained and ease the discussions in the next sections, in this section we develop the basic small open economy New Keynesian DSGE model⁵. The model presented in this section is well discussed else where, for example, in Gali (2008, ch. 7) and Walsh (2010, ch. 9). The structure and notation in this paper follows that of Senbeta (2011) which, in turn, follows that of Santacreu (2005) and Matheson (2010). However, unlike Senbeta (2011) where the multi-sector economy is modeled, in this paper we assume an economy that produces a single tradable commodity. There are two types of domestic firms: producers and importers. Producer firms produce tradable goods that are consumed by both domestic consumers and the rest of the world. Importing firms import and distribute foreign goods. Both group of firms are monopolistically competitive firms. The households in the domestic economy consume both domestically produced and imported goods. There is monetary authority that employs the Taylor-type interest rate

⁴For the list of Central Banks and multilateral institutions that employ DSGE models for policy analysis and forecasting, see the references in Tovar (2009).

⁵The discussion in this subsection is taken from Senbeta (2011).

rule. The domestic economy is assumed to be small relative to the foreign economy or the rest of the world. Hence, key macroeconomic variables of the rest of the world can be assumed to be exogenous to the domestic economy.

2.2.1 Households

The household sector is modeled as a representative, infinitely lived household that maximizes intertemporal utility subject to a sequence of budget constraints. The household maximizes the following objective function:

$$E_0 \sum_{t=0}^{\infty} \beta^t U_t \quad (2.1)$$

where E is the expectation operator and β is the subjective discount factor of the household. We assume that the representative household has an isoelastic instantaneous utility function and derives utility from consumption of composite goods and leisure:

$$U_t = \frac{(C_t - hC_{t-1})^{1-\sigma}}{1-\sigma} - \eta \frac{(L_t)^{1+\varphi}}{1+\varphi} \quad (2.2)$$

where C_t and L_t , respectively, represent household consumption and labour time supplied to market activities. σ is the inverse of the elasticity of intertemporal substitution in consumption, h the coefficient of habit persistence, φ the inverse of the elasticity of labour supply and η the marginal disutility (utility cost) of participating in the labour market.

Consumption C_t is a composite good consisting of domestically produced and imported goods that can be given by the following CES aggregator:

$$C_t = \left[(1 - \gamma_1)^{\frac{1}{\theta_1}} C_{H,t}^{\frac{(\theta_1-1)}{\theta_1}} + \gamma_1^{\frac{1}{\theta_1}} C_{F,t}^{\frac{(\theta_1-1)}{\theta_1}} \right]^{\theta_1/(\theta_1-1)} \quad (2.3)$$

where $C_{H,t}$ and $C_{F,t}$ denote consumption of domestically produced and imported goods, respectively. The parameter θ_1 measures the elasticity of intratemporal substitution of consumption between domestically produced and imported goods. Larger value of θ_1 implies that the goods are substitutes (with $\theta_1 \rightarrow \infty$ the goods become closer substitutes). γ_1 measures the proportion of imported goods in the consumption of households. The representative household aims at maximizing the utility from consumption of both domestic and imported goods by minimizing the expenditure on these two varieties while maintaining a certain target level of consumption. Solving this problem of optimal allocation of expenditure on domestically produced and imported goods yields the following demand

functions for these goods:

$$C_{H,t} = (1 - \gamma_1) \left(\frac{P_{H,t}}{P_t} \right)^{-\theta_1} C_t \quad (2.4)$$

$$C_{F,t} = \gamma_1 \left(\frac{P_{F,t}}{P_t} \right)^{-\theta_1} C_t \quad (2.5)$$

where $P_{H,t}$, $P_{F,t}$, P_t are the price indices of domestic goods, imported goods and overall consumer goods, respectively. The overall consumer price index is given by

$$P_t = \left[(1 - \gamma_1) (P_{H,t})^{1-\theta_1} + \gamma_1 (P_{F,t})^{1-\theta_1} \right]^{1/(1-\theta_1)} \quad (2.6)$$

Total consumption expenditure by households is given by the sum of the expenditures on domestically produced and imported goods they consume

$$P_t C_t = P_{H,t} C_{H,t} + P_{F,t} C_{F,t} \quad (2.7)$$

The households in this model own the firms in the economy and hence earn dividends. They also earn wage income from the supply of their labour. In this basic model there is no investment (as will be discussed later) and therefore no rental income from capital services. There is also no financial intermediation; it is assumed that households directly lend to the public sector. Therefore, the households try to maximize their lifetime utility subject to a sequence of budget constraints of the form:

$$P_t C_t + B_t \leq W_t L_t + D_t + R_{t-1} B_{t-1} \quad (2.8)$$

where R_{t-1} is gross nominal return on bonds. This budget constraint implies that the household expenditure, as given by the left hand-side, consists of expenditure on consumption C_t , and purchase of public bonds, B_t . The flow of income, as given by the right-hand-side of the budget constraint, is composed of dividends, D_t , wage income from labour services, and receipt of principal and interest income on the bond held in the previous period, B_{t-1} .

The optimization problem faced by the representative household can now be summarized by the following Lagrange function:

$$\text{Max}_{C_t, L_t, B_t} \sum_{t=0}^{\infty} \beta^t \left\{ \begin{array}{l} \frac{(C_t - hC_{t-1})^{1-\sigma}}{1-\sigma} - \eta \frac{(L_t)^{1+\varphi}}{1+\varphi} \\ -\lambda_t [P_t C_t + B_t - D_t - W_t L_t - R_{t-1} B_{t-1}] \end{array} \right\} \quad (2.9)$$

The first order conditions of the optimization problem of this household are given by

$$(C_t - hC_{t-1})^{-\sigma} = \lambda_t P_t \quad (2.10)$$

$$\eta(L_t)^\varphi = \lambda_t W_t \quad (2.11)$$

$$\beta E_t \lambda_{t+1} R_t = \lambda_t \quad (2.12)$$

To prepare the model for numerical solution and ease the derivations in subsequent sections, we log-linearize some of the model equations introduced so far. To do so, we need a point around which the log-linearization is performed. Hence, we assume that there exists a unique steady-state of the original model economy and replace the model equations by first order Taylor approximation around this steady-state.⁶

The optimality conditions of the representative household in (2.10)-(2.12) can be log-linearized to give the following equations.

$$\varphi l_t + \frac{\sigma}{1-h}(c_t - hc_{t-1}) = w_t - p_t \quad (2.13)$$

$$c_t = \frac{h}{1+h}c_{t-1} + \frac{1}{1+h}E_t c_{t+1} - \frac{1-h}{\sigma(1+h)}(r_t - E_t \pi_{t+1}) \quad (2.14)$$

where π_{t+1} is next period's overall inflation in the economy defined as $p_{t+1} - p_t$. These equations (i.e., (2.13) and (2.14)) are the marginal rate of substitution between consumption and labour and the consumption Euler equation of the household in log-linearized form, respectively.

The real exchange rate, the terms of trade, and incomplete pass-through

Though not part of the basic model, one of the developments in open economy New Keynesian DSGE models is the incorporation of the deviation of prices from the Law of One Price referred to as the Law of One Price Gap (Monacelli, 2005: 1051). The claim is that the domestic market for imported goods is characterized by monopolistic competition where firms have some power on the prices of goods they import and distribute. This market power creates a distortion resulting into a difference between the domestic and foreign prices of imported goods when expressed in terms of the same currency. It is assumed that the Law of One Price holds at the border and the distortion comes in as the importing firms try to exercise their monopoly power to derive their optimal price, as will be discussed in the section below⁷. It is this distortion that is referred to as the Law

⁶Note that all lower-cases indicate log-deviation from steady state, i.e., $x_t = \ln X_t - \ln \bar{X}$ where \bar{X} is the steady state value of X .

⁷There are also other arguments for the deviation of the prices from the Law of One Price. For example, Mkrtchyan et al. (2009) discuss how the inefficiencies of domestic retail firms that distribute imported goods results into the distortion and hence deviation of prices from LOP.

of One Price Gap - the tendency of prices to deviate from the Law of One Price. This Law of one price gap is given by the ratio of the foreign price index in terms of domestic currency to the domestic currency price of imports

$$\Psi_t = \frac{\varepsilon_t P_t^*}{P_{F,t}} \quad (2.15)$$

where ε_t and P_t^* are the nominal exchange rate and the price index of the rest of the world, respectively. The nominal exchange rate is defined as the domestic currency price of a unit of foreign currency. $P_{F,t}$ is the average price of imported goods in terms of domestic currency. Expression (2.15) shows that if the law of one price holds Ψ_t is identically equal to unity. It is also worth mentioning that, throughout this paper, we assume that the Law of One Price holds for exports.

The real exchange rate is given as the ratio of the price index of the rest of the world (in terms of domestic currency) to the domestic price index:

$$Q_t = \frac{\varepsilon_t P_t^*}{P_t} \quad (2.16)$$

Another important relationship is the terms of trade of the domestic economy which measures its competitiveness in international markets. The terms of trade of the domestic economy is defined as the export price (price of domestically produced tradable goods) relative to the domestic currency price of imports.

$$V_t = \frac{P_{H,t}}{P_{F,t}} \quad (2.17)$$

We can derive some links between these quantities that are of use in the following sections. Log-linearizing (2.15) around symmetric steady-state (simultaneous steady-state at both domestic economy and the economy of the rest of the world) and subtracting one period lag we obtain the equation of the evolution of the Law of One Price Gap

$$\psi_t - \psi_{t-1} = e_t - e_{t-1} + \pi_t^* - \pi_{F,t} \quad (2.18)$$

Similarly, log-linearizing (2.16) yields

$$q_t = e_t + p_t^* - p_t \quad (2.19)$$

Since, from (2.6) above,

$$p_t = (1 - \gamma_1) p_{H,t} + \gamma_1 p_{F,t} \quad (2.20)$$

and using the Law of One Price Gap (in log-linearized form) to replace $e_t + p_t^*$, the log-linearized equation of the real exchange rate can be written as

$$q_t = \psi_t + (1 - \gamma_1)(p_{F,t} - p_{H,t}) \quad (2.21)$$

Replacing the last term in the right hand side of (2.21) by the log-linearized terms-trade equation, we obtain

$$q_t = \psi_t - (1 - \gamma_1)v_t \quad (2.22)$$

International risk sharing and the uncovered interest parity condition One of the assumptions made in the open economy New Keynesian models is that economic agents have access to the complete set of internationally traded securities. This implies the existence of international risk sharing. This assumption plays an important role in linking domestic consumption with that of the rest of the world and is a necessary condition to establish the stationarity of the model⁸. This link between domestic consumption and that of the rest of the world can be derived using the first order conditions (2.10) and (2.12) which can be combined to give the following consumption Euler equation of the domestic households

$$\beta E_t \frac{\lambda_{t+1}}{\lambda_t} = \frac{1}{R_t} \text{ implies that } \beta E_t \frac{(C_{t+1} - hC_t)^{-\sigma}}{(C_t - hC_{t-1})^{-\sigma}} \frac{P_t}{P_{t+1}} = \frac{1}{R_t}$$

Since agents in the rest of the world have access to the same set of bonds, their Euler equation can also be given by the following equation (assuming that agents in the domestic economy and the rest of the world have the same preferences)

$$\beta E_t \frac{(C_{t+1}^* - hC_t^*)^{-\sigma}}{(C_t^* - hC_{t-1}^*)^{-\sigma}} \frac{\varepsilon_t P_t^*}{\varepsilon_{t+1} P_{t+1}^*} = \frac{1}{R_t}$$

This implies that

$$(C_t - hC_{t-1}) = E_t \frac{(C_{t+1} - hC_t)}{Q_{t+1}^{\frac{1}{\sigma}} (C_{t+1}^* - hC_t^*)} Q_t^{\frac{1}{\sigma}} (C_t^* - hC_{t-1}^*)$$

In equilibrium, according to Galí and Monacelli (2005: 713), the following holds

$$(C_t - hC_{t-1}) = \chi Q_t^{\frac{1}{\sigma}} (C_t^* - hC_{t-1}^*) \quad (2.23)$$

for all t . χ is a constant that depends on the relative initial conditions in asset holdings. For future reference, log-linearizing (2.23) around a symmetric steady-state, and assuming

⁸Unless there are bond trades in the model, this assumption is innocuous and only serves the purpose of stationarizing (closing) the model.

that $c_t^* = y_t^*$ (because the rest of the world is large economy relative to the domestic economy, import or export of the domestic economy is negligible and, therefore, one can safely assume the rest of the world as a closed economy when modeling the small open economy), we obtain

$$c_t - hc_{t-1} = c_t^* - hc_{t-1}^* + \frac{(1-h)}{\sigma} q_t = y_t^* - hy_{t-1}^* + \frac{(1-h)}{\sigma} q_t \quad (2.24)$$

Furthermore, the assumption of complete asset markets allows to derive the link between the domestic and foreign interest rates through the uncovered interest parity condition. Assuming, as before, that domestic and foreign economic agents have the same preferences, the consumption Euler equation of the rest of the world can be given by

$$\beta E_t \frac{(C_{t+1}^* - hC_t^*)^{-\sigma} P_t^*}{(C_t^* - hC_{t-1}^*)^{-\sigma} P_{t+1}^*} = \frac{1}{R_t^*}$$

Log-linearizing around a steady-state gives

$$\frac{\sigma}{1-h} [(E_t c_{t+1}^* - hc_t^*) - (c_t^* - hc_{t-1}^*)] = (r^* - E_t \pi_{t+1}^*) \quad (2.25)$$

The same relationship can be derived for domestic households

$$\frac{\sigma}{1-h} [(E_t c_{t+1} - hc_t) - (c_t - hc_{t-1})] = (r - E_t \pi_{t+1}) \quad (2.26)$$

Subtracting (2.25) from (2.26) and using (2.24) and the definition of real exchange rate gives

$$\begin{aligned} & (r - E_t \pi_{t+1}) - (r^* - E_t \pi_{t+1}^*) \\ &= \frac{\sigma}{(1-h)} [(E_t c_{t+1} - hc_t) - (c_t - hc_{t-1}) - (E_t c_{t+1}^* - hc_t^*) + (c_t^* - hc_{t-1}^*)] \\ &= (E_t q_{t+1} - q_t) \end{aligned}$$

$$r - r^* = E_t q_{t+1} - q_t + E_t \pi_{t+1} - E_t \pi_{t+1}^*$$

$$r_t - r_t^* = E_t e_{t+1} + E_t p_{t+1}^* - E_t p_{t+1} - (e_t + p_t^* - p_t) - E_t \pi_{t+1}^* + E_t \pi_{t+1}$$

or

$$E_t e_{t+1} = e_t + r - r^* \quad (2.27)$$

This equation shows that the expected rate of appreciation/depreciation of the domestic currency is determined by the difference between the nominal interest rates of domestic economy and that of the rest of the world. With this we turn to the production side of the economy.

2.2.2 Firms

The production side of the domestic economy is given by monopolistically competitive firms that produce tradable goods using labour and capital. The basic New Keynesian model abstracts from capital. This tradition of ignoring capital when dealing with short-run fluctuations is based on empirical evidence. That is, studies show that the endogenous variation of the capital stock has little relationship with output variations at business cycle frequencies (McCallum and Nelson, 1999 cited in Walsh, 2010).

Hence, assuming a linear technology, the firms in the domestic economy have the following production function

$$Y_{H,t} = Z_{H,t}L_{H,t} \quad (2.28)$$

$Z_{H,t}$ represents total factor productivity; the logarithm of which is assumed to follow a first-order autoregressive process as follows:

$$\ln Z_{H,t} = \rho_H \ln Z_{H,t-1} + \epsilon_{H,t}, \quad 0 < \rho_H < 1. \quad (2.29)$$

where $\epsilon_{H,t}$ is an i.i.d normal error term with zero mean and a standard deviation of σ_{ϵ_H} .

The objective of a representative firm in this sector can be given as minimizing the cost of production given the production level:

$$\mathbf{Min}_{L_{H,t}} \left(\frac{W_t L_{H,t}}{P_{H,t}} \right) \quad \text{s.t. } Y_{H,t} = Z_{H,t}L_{H,t} \quad (2.30)$$

The first order condition of the problem yields the expression for the marginal cost of firms producing domestic goods:

$$MC_{H,t} = \frac{W_t}{P_{H,t}Z_{H,t}}$$

which can be log-linearized to give

$$mc_{H,t} = w_t - p_{H,t} - z_{H,t} \quad (2.31)$$

Subtracting and adding p_t to the right hand side of (2.34) above and using (2.13) we obtain

$$mc_{H,t} = \varphi l_t + \frac{\sigma}{1-h}(c_t - hc_{t-1}) - z_{H,t} + p_t - p_{H,t}$$

and substituting for p_t we have

$$mc_{H,t} = \varphi l_t + \frac{\sigma}{1-h}(c_t - hc_{t-1}) - z_{H,t} - \gamma_1 v_t \quad (2.32)$$

This implies that in an open economy the marginal cost is influenced by more factors than in the closed economy. In addition to the cost of inputs and level of productivity, the marginal cost of the domestic firms is determined by the terms of trade of the economy.

2.2.3 Price setting

Price setting by domestic producers One of the basic tenets of New Keynesian economics is that prices are not perfectly flexible in the short-run. There are a plethora of reasons, highlighted in section 2.1, for the firm to charge a price level different from the optimal price level usually derived as a constant markup over the marginal cost. One way of modeling this price rigidity is the staggered pricing *à la* Calvo (1983). According to Calvo, at a given point in time a random fraction ϵ_H of firms cannot adjust their prices while the remaining $1 - \epsilon_H$ can do. However, we also assume that those firms who can reset their prices are of two types - in the literature referred to as “forward-looking” and “backward - looking” firms. The forward-looking firms are those firms that re-set their prices according to the Calvo (1983) model. These firms tend to take into account that their prices will remain fixed at the price level they are going to set now for some time to come. Hence, they consider all future losses that they incur as a result of this inability to adjust their prices when setting their prices at a given point in time. The backward-looking firms, on the other hand, set their prices based on rules of thumb using information about the historical development of the price level. Suppose random fractions ς_H of domestic firms set their prices based on rules of thumb using their knowledge of the historical development of price levels (hence, backward looking). This implies that fractions $(1 - \varsigma_H)$ of firms set their prices according to the Calvo price setting. This process will give the hybrid New Keynesian Phillips Curve developed by Gali and Gertler (1999)⁹. For domestically produced goods, this equation is given by

$$\pi_{H,t} = \kappa_{b,H}\pi_{H,t-1} + \kappa_{f,H}E_t\pi_{H,t+1} + \lambda_H m_{CH,t} \quad (2.33)$$

where

$$\begin{aligned} \kappa_{b,H} &= \frac{\varsigma_H}{\epsilon_H + \varsigma_H(1 - \epsilon_H(1 - \beta))}, \\ \kappa_{f,H} &= \frac{\beta\epsilon_H}{\epsilon_H + \varsigma_H(1 - \epsilon_H(1 - \beta))}, \\ \lambda_H &= \frac{(1 - \varsigma_H)(1 - \epsilon_H)(1 - \beta\epsilon_H)}{\epsilon_H + \varsigma_H(1 - \epsilon_H(1 - \beta))}. \end{aligned}$$

Price setting by import firms The law of one price gap is an important element in deriving the inflation dynamics of imported goods. As a result of this law the domestic

⁹For detailed derivations of the Hybrid New Keynesian Phillips Curve for small open economy, see Holmberg (2006).

currency price of imports is no longer equal to the product of the nominal exchange rate and the foreign price level. As with the domestic firms, we assume that the domestic market for imported goods is characterized by monopolistic competition. There are a continuum of firms importing and selling differentiated goods. Each firm in this market tries to maximize its profit by setting its optimal price, taking the demand for its product as given. Like the domestic producers, the importing firms also set their prices according to Calvo price adjustment. Accordingly, at a given point in time a random fraction ϵ_F of firms cannot adjust their prices while the remaining $1 - \epsilon_F$ can do. However, we also assume that of those firms who can reset their prices some are "forward-looking" and others are "backward-looking" firms. Suppose the fraction ς_F of firms set their prices based on rules of thumb using their knowledge of the historical development of import price levels (hence, backward-looking) while the fraction $(1 - \varsigma_F)$ of firms are "forward-looking" and set their prices according to the Calvo price setting. The rate of inflation in the average domestic currency price of imports will be given by the following equation:

$$\pi_{F,t} = \kappa_{b,F} \pi_{F,t-1} + \kappa_{f,F} E_t \pi_{F,t+1} + \lambda_F \psi_t \quad (2.34)$$

where

$$\begin{aligned} \kappa_{b,F} &= \frac{\varsigma_F}{\epsilon_F + \varsigma_F(1 - \epsilon_F(1 - \beta))}, \\ \kappa_{f,F} &= \frac{\beta \epsilon_F}{\epsilon_F + \varsigma_F(1 - \epsilon_F(1 - \beta))}, \\ \lambda_F &= \frac{(1 - \varsigma_F)(1 - \epsilon_F)(1 - \beta \epsilon_F)}{\epsilon_F + \varsigma_F(1 - \epsilon_F(1 - \beta))}. \end{aligned}$$

This implies that there are three factors that determine the inflation rate of the imported goods. The first two are the lagged and the expected future inflation rates - the magnitude of which depends on the fraction of the backward-looking (or the rule of thumb) and forward-looking firms in the import sector of the economy, respectively. The third factor is the law of one price gap.

Accordingly, the overall inflation rate of the economy can be given by subtracting the lags from both sides of (2.20) which is the average of the inflation in domestically produced and imported goods

$$\pi_t = (1 - \gamma_1) \pi_{H,t} + \gamma_1 \pi_{F,t} \quad (2.35)$$

2.2.4 Equilibrium Condition

The market clearing condition requires that the domestic product equals domestic consumption plus exports.

$$Y_{H,t} = C_{H,t} + C_{H,t}^*$$

Where $C_{H,t}^*$ is foreign consumption of domestically produced goods (export of the domestic economy). From (2.4) we know that

$$C_{H,t} = (1 - \gamma_1) \left(\frac{P_{H,t}}{P_t} \right)^{-\theta_1} C_t$$

which can be log-linearized to yield

$$c_{H,t} = -\theta_1(p_{H,t} - p_t) + c_t$$

Replacing for p_t we have

$$c_{H,t} = -\theta_1 p_{H,t} + \theta_1 (1 - \gamma_1) p_{H,t} + \theta_1 \gamma_1 p_{F,t} + c_t \quad (2.36)$$

Again, from (2.4)

$$C_{H,t} = (1 - \gamma_1) \left(\frac{P_{H,t}}{P_t} \right)^{-\theta_1} C_t \text{ which implies that } C_{H,t}^* = \gamma_1 \left(\frac{P_{H,t}}{\varepsilon_t P_t^*} \right)^{-\theta_1} C_t^*$$

Using the definition of the real exchange rate, the export can be rewritten as

$$C_{H,t}^* = \gamma_1 \left(\frac{P_{H,t}}{Q_t P_t} \right)^{-\theta_1} C_t^* \quad (2.37)$$

Log-linearizing (2.37) gives

$$c_{H,t}^* = -\theta_1 (p_{H,t} - q_t - p_t) + c_t^* \quad (2.38)$$

Replacing p_t by (2.20)

$$\begin{aligned} c_{H,t}^* &= -\theta_1 p_{H,t} + \theta_1 ((1 - \gamma_1) p_{H,t} + \gamma_1 p_{F,t}) + c_t^* + \theta_1 q_t \\ c_{H,t}^* &= -\theta_1 \gamma_1 v_t + c_t^* + \theta_1 q_t \end{aligned} \quad (2.39)$$

2.2.5 Monetary policy rules

The most commonly used monetary policy rule is the simple Taylor type rule where the monetary authority is assumed to act to stabilize inflation, output and exchange rate.

Hence, the monetary authority adjusts the nominal interest rate in response to deviations of inflation and output from their steady-state values and changes in nominal exchange rate:

$$r_t = \rho_r r_{t-1} + (1 - \rho_r)(\phi_\pi \pi_t + \phi_y y_t + \phi_e \Delta e_t) + \epsilon_{r,t} \quad (2.40)$$

where ϕ_π , ϕ_y , and ϕ_e are weights put by monetary authority, respectively, on inflation, GDP, and depreciation of the exchange rate. The lagged interest rate serves for interest rate smoothing while ρ_r denotes the extent of persistence of interest rate. The monetary policy shock is captured by $\epsilon_{r,t}$ which is i.i.d normal error term with zero mean and standard deviation σ_{ϵ_r} .

2.2.6 The External Sector

As discussed at the beginning of this section, in the small open economy model the domestic economy is small relative to the rest of the world and hence it cannot affect the foreign variables like income, inflation, interest rate, etc., that might significantly affect the performance of the macroeconomy of the home country. Therefore, the foreign economy can be modelled as exogenous. Following the literature in this area, we assume that the foreign variables follow first order autoregressive processes:

$$y_t^* = \rho_{y^*} y_{t-1}^* + \epsilon_{y^*,t}, 0 < \rho_{y^*} < 1 \quad (2.41)$$

$$\pi_t^* = \rho_{\pi^*} \pi_{t-1}^* + \epsilon_{\pi^*,t}, 0 < \rho_{\pi^*} < 1 \quad (2.42)$$

$$r_t^* = \rho_{R^*} r_{t-1}^* + \epsilon_{r^*,t}, 0 < \rho_{R^*} < 1 \quad (2.43)$$

where π_t^* , and r_t^* represent the foreign economy inflation and interest rate, respectively. y_t^* is the log-deviation of foreign GDP from its steady-state and $\epsilon_{i,t}$ is an i.i.d normal error term with zero mean and standard deviation of σ_i , where i stands for y_t^* , π_t^* and r_t^* .

2.2.7 Summary

The small open economy New Keynesian DSGE model is based on the representative household that maximizes utility from consumption of domestically produced and imported goods. The representative household can save in domestic bonds and also has access to international financial markets which implies the existence of international risk

sharing. The production side is also captured by representative monopolistically competitive firm that produces tradable goods. The model can now be solved and simulated, once the parameters are calibrated or estimated, to understand how the economy responds to different domestic and external shocks.

3 Criticisms and recent developments in DSGE models

The enormously growing number of books, research papers, and commentaries, some of them by prominent macroeconomists who in one way or another contributed considerably to the development of the current conventional macroeconomic models, show the extent of dissatisfaction with the conventional economic models in general, and with the DSGE models in particular. While some of the criticisms are as old as the models themselves there are also those that are relatively new. The recent global financial crisis has also created considerable momentum for these criticisms as can be seen from the number of critical publications over the last couple of years. The critics argue that the DSGE models performed poorly both in predicting the crisis and in providing policy prescriptions on how to end the crisis¹⁰. At the same time, the last couple of years witnessed considerable advances in DSGE modeling, some of which addressed the concerns of the critics as a result of which some proponents argue that the recent economic crisis has contributed significantly to the improvement of these models (see Wickens, 2010). In this section we present both the criticisms against DSGE modeling and recent advances in these models, some of which are attempts to redress the caveats.

There is much work that challenges DSGE modeling. Perhaps one of the most exhaustive critical evaluations of the New Keynesian DSGE models is provided by Meeusen (2009 and 2011) who discusses a list of shortcomings that incapacitate these models from capturing the features of the real world economy and, therefore, leads to their incompetence in explaining and predicting economic events. According to Meeusen (2011: 60-66),

¹⁰It seems important to note that there are some who argue that the recent financial crisis is brought about by the failure to use modern macroeconomic models properly and not due to the failure of these models (Wickens, 2010). And others argue that the conventional macroeconomic models (DSGE models) should not be blamed for not predicting and explaining the recent financial crisis and the subsequent economic crisis since the institutional set up of the financial markets in the real world is completely different from what is assumed by all past and present macroeconomic models (Woodford, 2010). As will be discussed below, according to Woodford, the DSGE models are capable of performing their role given proper modeling of the features of the financial markets.

the most critical of these shortcomings are: their failure to capture heterogeneity of economic agents, the absence or ad hoc incorporation of the financial sector, the modeling of uncertainty, the absence of involuntary unemployment, the linearization and empirical validations of these models. We will try to discuss each of these criticisms together with recent advances in DSGE modeling so that we can have some view of the current state of these models. Our discussion shows that most of these criticisms are important challenges but not lethal. The most serious challenge to DSGE modeling (for that matter all conventional economic models) is the one casted by the behavioral school that rejects not only rational expectation hypothesis but also the assumption of rationality of economic agents in their decision making. We argue that this is lethal since all economic models are based on the central assumption that economic agents are rational, driven by economic motives, and make calculated decisions in an attempt to make the best out of what they have, given the circumstances under which they operate. The rejection of this central assumption, we believe, is the most disastrous criticism to economic models in general.

3.1 The Representative Agent

The representative agent assumption underlies all DSGE models; exceptions are few works that attempt to introduce heterogeneity of different forms most of which are responses to criticisms to the representative agent. In the representative agent models, as discussed in the previous section, the household sector of the economy is assumed to be homogeneous and hence represented by an infinitely lived representative household that maximizes life-time utility. Similarly, the production part of these models is represented by a representative firm that maximizes discounted profit. Recent criticisms revitalized the argument about the inappropriateness of this assumption (see, for example, Colander et al. (2008), Meeusen (2009 and 2011), Solow (2008)). However, this criticism is around for about two decades if not as old as the DSGE models themselves (see, Kirman (1992), Hartley (1996 and 1997)).

It is also worth mentioning that the assumption of a representative agent is not a new concept introduced into economics by DSGE models. Hartley (1996 and 1997) discussed how Marshall first used the representative firm to derive the industry supply curve for the first time in economics before it was challenged by economists of the time and abandoned. According to Hartley (1997), the assumption was reintroduced in New Classical Macroeconomics by Lucas and Rapping (1970). Then RBC versions of the DSGE models employed

it as a central assumption which is then inherited by the New Keynesian macroeconomics. Hartley (1997) organized the arguments in favour of the representative agent assumption in DSGE modeling into three: it helps address the Lucas Critique (discussed in the previous section), enable the development of general equilibrium models in the Walrasian tradition, and helps provide microeconomic foundations for macroeconomics.

As we indicated above, though the criticism against the representative agent assumption has been forwarded recently, some of the most profound criticisms are decades old. For example, Kirman (1992) argues that the attempt of recovering a stable and unique equilibrium of the aggregate economy through the representative agent assumption is impossible. He argues in favour of introducing heterogeneity in the means and ends of economic agents into economic models to generate a regular aggregate behaviour - stable and unique equilibrium. Likewise, Hartley (1997) provides a book length discussion on how the representative agent assumption is neither necessary nor sufficient to attain the three rationales forwarded for its justification, that is, the representative agent models “do not solve the Lucas critique, they are not a good basis for Walrasian models, and they do not provide for microfoundation” (Hartley, 1997: 30).

Recent critics also argue that the real economy is populated by economic agents of differing means and ends and hence cannot be represented by a representative agent. They assert that a model that does not account for this heterogeneity cannot explain the performance of the real economy. This view is more clearly and strongly put forward by Solow (2008: 243)¹¹ as follows:

After all, a modern economy is populated by consumers, workers, pensioners, owners, managers, investors, entrepreneurs, bankers, and others, with different and sometimes conflicting desires, information, expectations, capacities, beliefs, and rules of behavior. Their interactions in markets and elsewhere are studied in other branches of economics; mechanisms based on those interactions have been plausibly implicated in macroeconomic fluctuations.

Likewise, Colander et al. (2008) argue that attempts to make generalizations based on the assumption of representative economic agents for an economy that is populated by heterogeneous agents are erroneous as they suffer from the fallacy of composition.

¹¹It seems that the arguments in Solow (2008) lack logical consistency as discussed in Chari and Kehoe (2008) since he inclines towards very simple intuitive models and at the same time models that should capture many varieties of economic agents and the complex interactions among them.

The argument is that one cannot fully understand the aggregate behavior by studying the behavior of an agent since the interaction among the agents is what matters most. In their words, “Any meaningful model of the macro economy must analyze not only the characteristics of the individuals but also the structure of their interactions” (p. 237). This idea was launched two decades ago by Kirman (1992) who argues that macroeconomic models need to incorporate not only heterogeneity but also the interaction among these heterogeneous agents and the institutions that govern their interaction. He argues that

we should also consider the macroeconomic behavior of models in which heterogeneous individuals interact directly and consciously, through mechanisms like trading, the passage of information, the building of reputations, organizing into groups for purposes of bargaining, and more. The nature and extent of these contacts will, inevitably, be influenced by market considerations, but agents are much more than anonymous price-takers (Kirman, 1992: 131).

The argument in favor of introducing heterogeneity of economic agents is appealing. After all, in the real world, heterogeneity is the rule and homogeneity is an exception. The aggregate economy is the outcome of the interaction of a variety of economic agents in a variety of dimensions. It is also well documented (in the literature in the tradition of institutional economics) that these interactions among economic agents develop over time and are not spontaneous. Furthermore, these interactions, which are the reflections of the formal and informal institutions that govern them, play crucial role in determining the performance of the economy both at the micro and macro level. As suggested by Kirman (1992) and Colander et al. (2008) a model that captures these features could help in fully understanding the operation of the macroeconomy. However, the more one thinks about capturing more of the heterogeneity of economic agents and the interaction among them into a model, the more it becomes unmanageable and even meaningless. Models are abstractions and they are to provide guidelines about some basic features of the real world that can be combined with reasoning in order to understand the real world; they are not meant to represent the whole world.

The weakness of the representative agent paradigm and the importance of heterogeneous agents have been recognized in DSGE modeling. The problem was on the complexities that are introduced with heterogeneity and the difficulty to solve such models. There are many studies that have been trying to develop techniques to solve such models. These works

recognize and explicitly model the fact that agents differ in their endowments, experience different sequences of shocks, and have different abilities to insure themselves against risks (some of the early works are den Haan (1996), Krusell and Smith (1998 and 2006), and Rios-Rull (1997)). Recently, there are many works that are dealing with heterogeneous agents, aggregate and idiosyncratic shocks and incomplete markets (see Heathcote et al. (2009) for a review of works in this area). Indeed, recent works employing these models show that standard policy instruments generate different outcomes than what would have been expected in the representative agent models. For example, Algan and Ragot (2010) report that a monetary policy shock generates different results in heterogeneous agents models with binding borrowing constraint than in the standard representative agent models with complete markets. Likewise, the effects of fiscal policy have been found to be different in such models (see, Alonso-Ortiz and Rogerson, 2010 and Heathcote, 2005).

There is fast progress in models with heterogeneous agents and incomplete markets. This seems to continue at higher momentum as a result of flourishing techniques to solve models with heterogeneous agents in recent years. There is a growing number of studies that endeavor to solve and simulate DSGE models with heterogeneous agents and incomplete markets (see Maliar et al. (2010) and Reiter (2009) and the references in these papers).¹² These studies have developed different algorithms for solving, simulating and checking the accuracy of DSGE models with heterogeneous agents and incomplete markets.

3.2 Labour market frictions and involuntary unemployment

The early works in DSGE models did not incorporate labour market frictions and involuntary unemployment. This is understandable given the underlying tenets of the RBC economics. Their successors, the New Keynesian DSGE models, until recently have failed to address this issue of involuntary unemployment, a weakness that is acknowledged by prominent economists in this school (see, among others, Blanchard (2009), Blanchard and Gali (2010), Gali (2011), and Gali et al. (2011)). For instance, Blanchard (2009: 216) explains this weakness as a “striking (and unpleasant) characteristic” of the standard New Keynesian DSGE model. This is one of the inheritances that the New Keynesian DSGE models got from the RBC models since in the latter all markets, including the labour

¹²In addition to many separate works that attempt to develop techniques to solve models with heterogeneous agents, many recent works can be found in two dedicated issues of the *Journal of Economic Dynamics and Control* (Vol 34, No. 1 (2010) and Vo. 35, No. 2 (2011)).

market, always clear and therefore unemployment in the economy is only voluntary. Furthermore, according to the RBC models the change in employment is at the intensive margin as workers, based on their intertemporal preferences, decide to work more or less hours, or decide to participate in market activities or not.

Recent works in DSGE modeling, in part in response to these criticisms, has come up with many ways of introducing labour market frictions and involuntary unemployment into these models. It is now common to see models with labour market frictions that incorporate different variants of the search and matching labour market models in the tradition of Diamond-Mortensen-Pissarides (see, for instance, Blanchard and Gali (2010), Christiano et al. (2010), Gertler and Trigari (2009), Gertler et al. (2008), Sala et al. (2008), and Trigari (2009)). The search and matching approach allows modeling an economy with involuntary unemployment at equilibrium. Some of this work answers the questions raised by others like Blanchard (2009) modeling both the adjustment of labour at the extensive margin and the existence of involuntary unemployment at equilibrium. The New Keynesian DSGE models that incorporate labour market frictions are significant developments as the estimated versions of these models are also promising in fitting the data (Christiano et al. (2010), Gali et al. (2011), and Gertler et al. (2008)).

3.3 The Financial market

The New Keynesian DSGE models are also criticized for their lack of a systematic treatment of frictions in the financial sector (Blanchard (2009), Meeusen (2009 and 2011), and Woodford (2010)). In most of the influential works so far, there are no commercial banks and other financial intermediaries. As indicated in the model we outlined in the previous section, there are simplistic and ad hoc assumptions where the households directly lend to the public sector and hold bonds, but in many instances there are no definitions of how the bonds themselves evolve. Meeusen (2009) emphasizes this issue of households operating as both savers and investors in the DSGE models and the implications of this assumption. He argues that “This implies frictionless financial markets, and also no hierarchy of interest rates. The single interest rate set by the central bank is at the same time the rate of return on capital, the rate of return earned by firms and households on savings, and the rate paid by borrowers. There is no place, and no need for a commercial bank sector that acts as intermediary” (Meeusen, 2009: 12).

Furthermore, even the studies that incorporated the financial intermediaries in their

models fall short of capturing the current state (institutional setup) of the sector in the developed world. This, in turn, makes the models impotent in explaining the effect of the shocks that emanate from the financial sector (see Woodford (2010)). There are many attempts made to incorporate the financial sector into the DSGE modeling in the past. But most of the works emphasized the effect of credit constraints faced by the non-financial firms and how that amplifies any shock that hits the economy - referred to as the financial accelerator. The work in this area is synthesized in the frequently cited work of Bernanke et al. (1999). The drawback with these models, according to Woodford (2010), is that the institutional framework of the financial market they assumed is completely different from the institutions that are at work currently in the real world. Financial intermediaries incorporated into macroeconomic models in the past are banks that collect short-term deposits and provide long-term loans and have to abide by regulatory frameworks. However, according to Woodford (2010), the financial institutions that were dominant during the time leading to the recent financial crisis were non-bank financial institutions that are completely different from the formal financial intermediaries or the banking systems (shadow banking/financial system). In the case of non-banking financial intermediaries, the firms generate funds by selling securities which implies that the regulatory systems designed for banks cannot affect them. In this respect, the problem seems that the macroeconomic models were lagging in capturing these innovations in the financial sector and hence it is not surprising that they could not explain or predict what was happening in the economy due to events in this crucial sector. Given the role that the financial sector plays, the place of the financial intermediaries in the policy transmission mechanism, and, most importantly, the place of the sector in the recent economic meltdown, it is imperative for macroeconomic models to capture how this sector works, and how it interacts with the real economy.

Recently there have emerged many studies, though following different approaches and emphasizing different issues, that attempt to fill this gap. These studies incorporate financial markets with various institutional setups and frictions into the DSGE models (see, for example, Christiano et al. (2010), Curdia and Woodford (2009), Gerali et al. (2010), Gertler and Karadi (2011), and Gertler and Kiyotaki (2011)).

For instance, Gertler and Kiyotaki (2011) introduce the financial frictions that affect the funds available to banks and analyze how this in turn affects the real economic activity. According to Gertler and Kiyotaki (2011), banks obtain funds from two sources; the

deposits from households and borrowings from banks in interbank loan market. Their model shows that, the disruption in financial intermediation due to the disruption in interbank markets leads to financial market segmentation and significant down turn in real economic activities. Gertler and Kiyotaki's (2011) model is a significant advance in an attempt to explain the effect of disruption of financial intermediation that is behind the recent global economic crisis and predicting the effects of credit policies that are undertaken to deal with the crisis.

3.4 The Solution methods

The standard DSGE models are not amenable to analytical solution. As a result researchers resort to approximating these models in a variety of ways. The common practice is linearization of the non-linear models. The most commonly used approach is Taylor expansion of the optimality conditions of the models around the steady-state values of the variables, referred to as log-linearization (the method we employed in section 2 above). This procedure and its importance are well stated in Fernandez-Villaverde (2010: 14) as follows:

The idea of perturbation methods is to substitute the original problem, which is difficult to solve, for a simpler one that we know how to handle and use the solution of the simpler model to approximate the solution of the problem we are interested in. In the case of DSGE models, we find an approximated solution by finding a Taylor expansion of the policy function describing the dynamics of the variables of the model around the deterministic steady state. Linearization, therefore, is just the first term of this Taylor expansion. But once we understand this, it is straightforward to get higher order expansions that are both analytically informative and more accurate.

That is, given the difficulty in solving the original nonlinear models, linearization method is the second best alternative to deal with these models.

The critics argue that this action amounts to stripping these models of their real world attributes (see, Lim and McNelis, 2008 and Meeusen, 2009 and 2011). It is also argued that this method can be helpful only when the deviations of the economy from the steady-state values are small. In other words, this method is local approximation (Lim and McNelis, 2008; Meeusen, 2011). Furthermore, according to Lim and McNelis (2008:

12), the solutions obtained through log-linearization “will overstate the volatility of the macroeconomic aggregates”.

It is worth noting, however, that there are many works that introduced alternative methods of solving the models without linearizing them. A method that is becoming popular in this regard is the projection method, which employs different approximating functions to the policy functions of the original model to solve these (see Lim and McNelis, 2008 for a textbook treatment of solving New Keynesian DSGE models by projection method, and Judd (1992), Judd et al. (2010), Pichler (2011) for application of projection method to RBC models). Pichler (2011) summarizes the three steps procedure of solving a DSGE model using a projection method as follows:

First, the model’s true equilibrium decision rules are replaced by parametric approximating functions which typically take the form of polynomials or spline functions. Second, a numerical integration method is used to approximate the conditional expectations in the model’s intertemporal equilibrium conditions. Third, a set of grid points in the state space is selected, and the approximation error (residual) in the model’s equilibrium conditions at each grid point is computed. Finally, the unknown parameters in the approximating functions are determined by minimizing the residuals subject to some loss criterion (Pichler, 2011: 240).

There are various approximating functions used in literature for the first step of the projection approach. The two most commonly employed approximating functions are the Neural network and the Chebychev orthogonal polynomial (see Lim and McNelis (2008) for advantages and disadvantages of these specifications).

Given the fast development in the techniques of solving these models, it seems that the criticism about application of linearized approximation will not be a serious challenge in the future.

3.5 Empirical Methods

The other practice of DSGE modeling that has been criticized is the empirical methods that are used to determine the values of the parameters of the models. The most commonly used method is the calibration method where parameter values are derived from the equilibrium conditions of the model by imposing the properties of a balanced growth path. This is a

tradition followed in DSGE modeling since the emergence of the early RBC models such as Kydland and Prescott (1982) and has been criticized since then (see, for example, Hansen and Heckman (1996), Hoover (1995), Sims (1996), Solow (2008), Meeusen (2011)). While some of the criticisms focus on the entire idea of calibration, others stress the testability of the results of such calibration exercises. There are also critics who argue that using the long-run properties of the economy (balanced growth path) to calibrate the model to analyze short-run fluctuations is not appropriate. However, the proponents of the calibration method argue that this exercise is correct since both short-run and long-run analysis deal with the same facts and hence need to be coherent (Kydland and Prescott (1996), Cooley (1997)). For example, Cooley (1997:57) defends this last criticism about using long-run property of the economy in calibration process as follows:

The reason for this is that we know most developed economies display the characteristics of balanced growth. Since both growth and fluctuations are features of the data for all economies, we would like any theory of the latter to be consistent with the former. This strongly suggests that we do not want to have separate models for growth and fluctuations.

Recent advances seem to partially overcome the problems associated with calibration as the estimation techniques are developed and many small and medium scale New Keynesian DSGE models are estimated from actual data. These models can be formally estimated now using either maximum likelihood or Bayesian methods. Many studies show that the Bayesian method, which has become popular in estimating DSGE models, is superior to maximum likelihood for various reasons (see Fernandez-Villaverde (2010)). One of the advantages of this method is its ability to help overcome the problem of small sample size (short time series) that is commonly faced in applied research. Applying the Bayesian method one can introduce non-sample information in the form of prior information and extract the maximum possible material from the small sample. According to Fernandez-Villaverde (2010), one can undertake Bayesian analysis with any level of sample available, and in effect even without a sample in which case our knowledge is just our prior information. However, the application of the Bayesian method though theoretically appreciated, is in practice criticized. According to Blanchard (2009), the Bayesian method can help to overcome the problem of near non-identification since the method allows the use of additional information in setting the priors of the parameters. He argues that, in practice,

priors of the parameters are passing from one work to another when there is no ground justifying their being borrowed.

3.6 Rationality and Rational Expectations

As we highlighted at the beginning of this section, the most organized criticism of the conventional macroeconomic models comes from the school of behavioral economics. The criticisms from this school are serious challenges not only to DSGE modeling but also to all conventional economic models that are based on the assumption of rational economic agents and rational expectations (see Akerlof (2007 and 2002), Akerlof and Shiller (2009) and De Grauwe (2010a, 2010b, 2010c, 2010d, 2010e)). The literature in this emerging field has one unifying element: the rejection of the rational expectations hypothesis. Most of the works by prominent proponents of this school also question the rationality of economic agents that underlie most modern economic models.

According to the rational expectations hypothesis, economic agents make the best use of the pieces of information available to them, they do not make systematic errors and, therefore, on average their expectation is consistent with that of the economic model. Reliance on this hypothesis together with the assumption of rationality of economic agents, according to Akerlof and Shiller (2009), is the most important reason why macroeconomic models that are in use so far have not been in a position to help understanding the causes of recessions and depressions. In their setup economic agents could be non-rational and are driven by “animal spirits” than forming rational expectations in their decision making process. Hence, they argue that the failure of modern macroeconomic models emanates from the fact that these models do not capture the “animal spirits” that drive the economy. No conventional economic model that is based on rational economic agents, forming rational expectations and acting out of purely economic motives, is immune to their criticisms. For them, most of the economic instabilities that economies experience are the results of human beings acting in ways that are inconsistent with the rational, and self-interest driven behaviors assumed in the conventional models. Akerlof (2002: 428) asserts this position more clearly when he argues that

reciprocity, fairness, identity, money illusion, loss aversion, herding, and procrastination help explain the significant departures of real world economies from the competitive, general equilibrium model. The implication, to my

mind, is that macroeconomics *must* be based on such behavioral considerations.(Emphasis in the original).

If non-economic factors are more important in explaining decisions by economic agents, then the assumption of rationality that underlies modern economic models does not make any sense. Likewise, in their recent work which is published in the middle of the recent financial crisis, Akerlof and Shiller (2009) argue that the current macroeconomic models can explain at best only one of the four possible scenarios of the performance of an economy. That is, since modern macroeconomic models are based on the assumption of rationality of economic agents they can explain “How does the economy behave if people only have economic motives, and if they respond to them rationally?” (Akerlof and Shiller, 2009: 168). But, they argue that this is only one of four possible scenarios. The other three are rational economic agents possessing non-economic motives, irrational economic agents who possess economic motives, and irrational economic agents driven by non-economic motives. They argue that the three scenarios that are not explained by modern macroeconomic models explain most of the instabilities in the real economy. If one concurs with these authors, then it is not surprising that the modern macroeconomic models failed to forestall the onset of the recent crisis and to provide policy makers with sound policy prescriptions to pull the economy out of the crisis. Hence, unless we model these non-rational behaviors and non-economic motives, which characterize the economic agents in the real world, we cannot be in a position to understand the performance of the real economy.

But the “animal spirits” is the catchall word as there are a variety of elements in it. For example, Akerlof and Shiller (2009) mention confidence, fairness, corruption money illusion and stories to be factors that influence the decisions of the real people and hence elements of the set “animal spirit”. Others, such as Schwartz (2010), define components of the animal spirits in terms of some general terms like cognitive, emotional, cultural, and visceral factors. This might explain why there is no unifying model of this school of macroeconomic thought, which as some argue is over due (Schwartz, 2010). Furthermore, given the fact that these factors are interdisciplinary by nature, it is not clear whether a unifying model that captures them can be generated and applied to empirical economic analysis.

There are attempts to build a model that captures part of the elements of the animal spirit mentioned above. In a series of papers De Grauwe (2010a, 2010b, 2010c, 2010d; 2010e), for example, replaces the rational expectations assumption in the standard DSGE

model with simple rules that allow agents to learn from their experiences. The idea in De Grauwe is not a question of whether economic agents are rational or not. Instead, it is about rational economic agents that do not have foresight at the level presented in the weaker or stronger version of the rational expectations framework. In his set up economic agents have limitations in processing the pieces of information available and hence can possibly commit systematic errors. Furthermore, these agents are assumed to learn from their experiences and choose expectations that worked well for them. This selection mechanism through which economic agents choose to switch or stick to a rule depending on the performance of the rule is the indication of the rationality of economic agents, according to De Grauwe. Hence, the rejection of rational expectations does not necessarily mean embracing irrationality. According to De Grauwe, agents use simple rules that guide their decisions, learn from experience and this is the rational thing that economic agents can do. “They do this not because they are irrational, but rather because the complexity of the world is overwhelming. In a way it can be said that using heuristics is a rational response of agents who are aware of their limited capacity to understand the world” De Grauwe (2010b: 415).

De Grauwe compares the performance of this behavioral model with its basic New Keynesian counterpart and his results show that the models provide different explanations to a business cycle. Specifically, in the New Keynesian model the variations in key macroeconomic variables are the result of random exogenous shocks. Whereas, in the behavioral model the variations are endogenous. According to De Grauwe (2010a), this endogeneity of business cycle is the result of heterogeneity of rules used by economic agents; that is, different economic agents use different rules. Here the business cycle is the outcome of selffulfilling optimism and pessimism of economic agents.

The behavioural model creates correlations in beliefs, which in turn generate waves of optimism and pessimism. The latter produce endogenous cycles, which are akin to the Keynesian animal spirits. Occasionally this correlation of beliefs leads to extreme optimism (explaining booms) followed by extreme pessimism (explaining busts). Thus the behavioral model provides for an endogenous explanation of business cycle movements.(De Grauwe, 2010a: 31).

Hence, according to the behavioral model of De Grauwe, the booms and busts that the economies experience are the results of unpredictable changes of the confidence of

economic agents similar to the "Animal Spirits" discussed in the previous paragraphs. This model is a promising step as it provides an interesting approach of modeling non-rational expectations. The explanations that this model offers of business cycle is also persuasive. However, as highlighted by De Grauwe, the modeling approach is ad hoc in the sense that the introduction of the rules that economic agents use in their decision making process lack microfoundation. Notwithstanding this limitation, the approach seems promising as it is based on the accumulated knowledge in the DSGE modeling that makes the transition smooth.

3.7 Summary

The dissatisfaction with mainstream macroeconomic models has been growing at a considerable rate over the last few years. The last few years also witnessed the largest proportion of the criticisms mainly due to the failures of the mainstream models to predict and explain the recent global financial crisis. On the other hand, the proponents of these models do not seem to be convinced and shaken by the criticisms posed which can be seen from the following quote by Chari (2010: 2) "A useful aphorism in macroeconomics is: 'If you have an interesting and coherent story to tell, you can tell it in a DSGE model. If you cannot, your story is incoherent'". This tone of satisfaction in the progress of modern macroeconomics as a result of advances in DSGE modeling is shared by many (see, for example, Chari et al. (2009), Chari and Kehoe (2006 and 2008), Fernandez-Villaverde (2010), Wickens (2010), and Woodford (2009)).

Our assessment of the DSGE models shows that though there are many weaknesses that have been pointed out by the critics, there have also been considerable improvements in modeling them. Furthermore, some of the criticisms are weaknesses that apply to the whole of economics as a discipline and not unique to DSGE models. For instance, the issues raised by behavioral economics require restructuring of economics and not only to macroeconomics. A glance at the history of macroeconomic thought shows that one could reasonably be optimistic that the poor performance of the mainstream macroeconomic models in predicting and explaining the recent economic crisis, which is reflected in the dissatisfactions that we discussed above, might lead to the evolution of new paradigms in the near future. But for the time being, the New Keynesian version of the DSGE model seems the only well organized method for applied research for short-run economic fluctuations.

Given this background, we now turn to assess the implications of the assumptions that underlie the component parts of the basic open economy New Keynesian DSGE model, outlined in section 2, within the context of the macroeconomic environment of a typical SSA economy in order to enhance our understanding about whether these models can be directly applicable to such an economy or whether they need modifications. To that effect, we examine each of the characterizations of the economic agents and the environment in which they operate.¹³

4 Component parts of a New Keynesian DSGE model in the context of SSA economy

We now assess the assumptions that underlie the component parts of the open economy New Keynesian DSGE model closely and see their implications to a typical SSA economy. This requires discussion of the macroeconomic environments of these countries. Agenor and Montiel (2008, ch 3) provide exhaustive discussion of the features of the components of macroeconomic model in developing countries. In this section we rely on their discussions but organize our assessment within the DSGE framework.

4.1 Households: Consumption

In the standard DSGE models, the objective function of the households is captured by a utility maximization subject to sequence of budget constraints. Utility is derived from consumption of goods and services as well as leisure (see equations 2.1-2.8). This preference specification in most of the models is based on the assumption of intertemporal consumption smoothing as in the life cycle/permanent income hypothesis. That is, households smooth consumption through transferring resources across periods which requires access to financial markets so that households save/lend when they produce or earn above and over their current consumption and dissave/borrow when their current income falls short of their consumption expenditure. This amounts to saying that households have a smooth consumption path irrespective of the variability of their income flow.

¹³As highlighted in section 1, Agenor and Montiel (2008) make list of more than a dozen of characteristic features of developing countries that make them different from developed countries. They also provide an exhaustive survey of empirical studies on the behavior of economic agents in developing countries that support this difference between economic agents and environments in the two worlds. See also Frankel (2011) and Stiglitz et al. (2006).

This assumption is contestable for households in a typical low-income country like those in most of SSA since these households might not be able to smooth consumption even if they want to do so for various reasons. First, most of the population in the region lives in rural areas, participate in primary production, be it agriculture or mining, and earns subsistence income. Second, even when their income is higher than their current consumption expenditure they save in the form of non-financial assets or what De Soto (2000) refers to as “dead capital”; that is, assets that cannot easily be converted into liquid assets for consumption when they needed to do so due to institutional hurdles or absence of market institutions. Furthermore, these households, due to the nature of their livelihood and the economic environment, face credit constraints. This implies that low income (mainly close to sufficient for bare subsistence) reinforced by the absence of well functioning financial markets (leading to unavailability of different financial assets) make intertemporal resource transfer very difficult in a typical low-income economy.

Contrary to these stylized facts, many empirical studies on the consumption behavior of households in developing and low income countries report the existence of consumption smoothing (see Schmidt-Hebel et al. (1992), Morduch (1995), Rosenzweig and Wolpin (1993), and Rosenzweig (2001) among others). According to these studies, low income households smooth consumption even when they live in a world of liquidity constraints via accumulation and decumulation of non-financial assets. These studies are conducted in different countries using different methodologies but their overall findings show that households in developing countries, indeed, smooth their consumption which is in line with the assumption of the intertemporal optimization models. Given the stylized facts we raised with respect to the nature of income and the credit market characteristics faced by households in SSA countries, the evidence reported raises questions. One of such questions is: given the covariate nature of fluctuations in income of households in primary production, that constitutes the majority of the population in low-income countries, is it possible to smooth consumption by saving and dissaving non-financial assets? In other words, since most of these households face aggregate risk of income fluctuation it seems difficult to argue that the markets for non-financial assets exist or function well.

However, even if one subscribes to the assertion that low-income households smooth their consumption via transferring their assets across periods, one needs to check the role of interest rates in the process of saving and dissaving. The intertemporal optimization assumption that underlies the DSGE models implies that households accumulate more

when the rate of return is higher than their rate of time preference which at the optimal of the consumer gives the well known consumption Euler equation. This has very important implications for the applicability of DSGE models to these economies.

The aggregate demand part of the DSGE models, which is given by equation 2.14 in the case of a basic closed economy, is the consumption Euler equation derived from the first order conditions of the optimality of households' consumption and saving decisions. This equation links current consumption and future expected consumption via the real interest rate. This link breaks down if there is no relationship between the interest rate and intertemporal substitution in consumption. The literature on the saving behavior of households in low income countries shows that the elasticity of saving to changes in interest rates is very low (see Ogaki et al. (1996)). This low responsiveness of private savings to changes in the real rate of interest in low income countries forces one to question the argument that saving in these countries is induced by the intertemporal optimization motive. One convincing explanation, instead, is what Carroll (1997) refers to as "buffer-stock" saving behaviour. In this case, households save because they face high income uncertainty and prefer to consume more had they known their future income with certainty. One thing seems clear: the intertemporal optimization assumption that is based on consumption smoothing does not apply to the majority of households in SSA.

Economists recognized that this assumption of symmetry of preferences or an economy populated by identical households that smooth consumption intertemporally and representing them by infinitely lived representative household is problematic even for developed economies. As discussed above, it is a more problematic assumption to make for a typical SSA economy. One way that this problem is addressed is through introduction of two types of households in to the model economy. That is, to assume an economy composed of two types of households: optimizing and non-optimizing households (Campbell and Mankiw, (1989 and 1991), Mankiw (2000), Gali et al. (2004), Ratto et al. (2009), Bosca (2011), and Calciago (2011)). In this characterization, some households behave as the representative household commonly used in the standard models. These households have access to financial markets, do not face credit constraints, behave rationally, have longer planning horizon and, therefore, smooth their consumption by transferring resources across periods. The non-optimizing households (referred to as rules-of-thumb or non-Ricardian consumers or hand-to-mouth consumers) consume their current income generated in each period. Different reasons are given for households to deviate from the life-cycle/permanent

income hypothesis even in developed countries. Mankiw (2000) argues that the rule-of-thumb consumers exist due to naivety on the side of the households or rational households facing binding borrowing constraints or because households attach higher weight to their current income when forming their expectations about their future income.

Currently, the rule-of-thumb consumers are introduced in DSGE models that deal with specific questions (like effects of fiscal policy) rather than as a permanent part of the models. The introduction of rule-of-thumb consumers when modeling economies in SSA has clear advantage over the standard optimizing representative household model. This is justified by the fact that the proportions of households in SSA countries that exhaust their current income for current consumption is large due to either subsistence level of income or liquidity constraint.

4.2 Households: The labour market

Labour is the most valuable asset for the majority of households in most economies of the world. The performance of the market for this asset, therefore, is very important to understand how the whole economy operates. This is even more appealing in the case of low income countries where income from labour services represents the only source of livelihood for the largest proportion of their populations. The wellbeing for such households depends not only on whether they are employed (working) or not, but also on whether their labour earns a reasonable income. This argument makes much sense for SSA, one of the regions where the majority of working poor (people who are working but earn very low income) of the world lives. Hence, understanding the operation of the labour markets in these economies and incorporating their dynamics into the model of their economies seem crucial to understand how different shocks affect different households or social groups. It also helps to know how employment/unemployment responds to different global and domestic shocks.

However, until recently the DSGE models did not incorporate labour market dynamics. As discussed in section 3, most of the studies in the standard New Keynesian models assume that the labour market is perfectly competitive as a result of which any unemployment in the economy is voluntary. Recently we have been witnessing considerable improvement in this area. However, as we will show in what follows, none of the works that attempt to incorporate labour market into DSGE models deal with the problems and specificities of the labour markets in SSA.

The labour markets in SSA have their own peculiar characteristics that need to be noted and emphasized. For instance, the inflexibilities in these markets are of different types than those observed in the developed economies. Kingdon et al. (2006) identify and assess three attributes of labour market flexibility within the context of African economies, namely; downward flexibility of real wages overtime, the tendency for wages to respond to unemployment rates, and the extent of wage differentials across sectors and firms. Their findings show that African labour markets could be seen as flexible in terms of downward flexibility of wages and responsiveness of wage rates to unemployment rates. However, they report that there exists compelling evidence to conclude that labour markets in Africa are rigid in terms of wage differentials among sectors and/or firms. That is, there is a high paying sector (formal sector) with better working conditions, on the one hand, and a low paying sector (informal sector), on the other hand, in the same economy. It is worth mentioning that it is not the mere coexistence of labour markets with different attributes (the duality) that makes the labour markets in Sub Saharan Africa peculiar, but the fact that the informal sector (low paying sector) employs the largest proportion of the labour force in these countries. The share of this sector as a percent of non-agricultural employment in Sub Saharan Africa is, the largest of all regions in the world; about 80 percent on average and ranges from 40-97 % (Charmes (2000), Blunch et al. (2001) and OECD (2009)).

This duality – the formal sector with relatively higher wages and the informal sector with lower wages serving as employer of last resort - as argued by Kingdon et al. (2006), is the common characteristic feature of all labour markets in Africa. Hence, we believe that this duality observed in the labour market needs to be introduced into the open economy New Keynesian DSGE model in order to understand the effects of various domestic and external shocks on the macroeconomic performance of these countries.

To our knowledge, Castillo and Montoro (2010) and Mattesini and Rossi (2009) are the only studies that attempt to incorporate duality of labour markets into the New Keynesian DSGE model. However, the sources of duality assumed in these studies are different. In the work by Mattesini and Rossi (2009) duality arises from the coexistence of a Walrasian labour market characterized by perfectly flexible wages with a unionized labour market characterized by rigid real wages. In Castillo and Montoro (2010), by contrast, duality prevails due to the coexistence of formal and informal labour markets in an economy where both formal and informal labour markets are characterized by some frictions. The setup

in Castillo and Montoro (2010) implies that firms have the options of employing workers on the basis of formal contract and hence the benefits and obligations associated with it or employ workers on informal basis. Both of these studies deal with a closed economy New Keynesian DSGE model. To our knowledge, there is no work that addresses the duality of labour market in an open economy New Keynesian DSGE framework. However, as discussed in some detail in Agenor and Monteil (2008) openness is one of the features that differentiates the macroeconomy of low-income countries from that of developed countries. Therefore, to understand the effects of domestic and external shocks, it is imperative to rely on an open economy model that captures the segmentation of labour market that characterizes these economies.

Furthermore, the duality in the labour markets in SSA countries is different from the dualities discussed in the aforementioned two papers. Of the two works discussed above, the labour market in Castillo and Montoro (2010) is closer to the labour market segmentation in SSA. But unlike the assumption in Castillo and Montoro where the duality emanates only from coexistence of workers employed formally and informally in the same firm, the duality in the economies of SSA is economy wide - as is the case of the dual economy models of Lewis (1954) and the literature that followed this tradition. For instance, Fields (2009) provides an exhaustive discussion of the nature of labour market segmentation in developing countries that corresponds to those in SSA economies. In this context, there are firms that operate based on only informal labour and others that rely on formal labour market. Indeed, firms operating formally could have workers employed formally or informally as in Castillo and Montoro (2010). But a closer examination of the economic structures of the countries in the region and the literature on their labour markets show that Castillo and Montoro's setup represents only a small section of the economy, if any.

The other difference with respect to the labour market in these countries is the wage setting mechanism. The works that incorporated a labour market into New Keynesian DSGE models assume either competitive labour markets, where the real wage rate is the marginal product of labour, or a wage rate determined via Nash bargaining. Applying these mechanisms in modeling low income countries is bound to be beset by problem since the largest proportion of the labour force that is in the informal sector is self-employed, or works in family business or in businesses owned by relatives. As a result, as argued by Ranis (2006), there is some form of income sharing mechanism that applies to this setup where the wage or income share is between marginal and average product of labour. This

argument emanates from the fact that the marginal productivity of labour is small in some sectors of the economies in low income countries; and could even be closer to zero. The concept of wage is related to subsistence instead of productivity and here comes the idea of income sharing.

As discussed in Ranis (2006) the maximum that this income-share could attain is the average product. But an income share equal to average product implies that there will be no production next period since even for some primitive economic activities one needs to have working capital for next period. This implies that the wage rate or income share is between average and marginal product of labour. The challenge here is then on developing a model that captures this institutional setup of income sharing.

Hence, we argue that any macroeconomic model that is meant to investigate the effects of various domestic and external shocks should rectify these issues of labour market segmentation and wage setting mechanisms.

4.3 Firms: credit and foreign exchange constraints

The production side in the New Keynesian DSGE model is characterized by monopolistically competitive firms that produce goods and services using labour and capital, given the technology and the demand for their products. The standard model assumes that firms do not face credit constraint for investment and working capital and that capital is produced domestically. However, many studies show that firms in SSA operate in a completely different economic environment. For instance, Bigsten et al. (2003), using a panel data on the demand and supply of credit in a sample of SSA countries, show that of the total number of firms who applied for formal credit from banks only about 25 percent succeed in obtaining it. The same study also reports that larger firms are more successful in obtaining credit than small and micro enterprises. This is important given the fact that most of the firms in SSA are either small or microenterprises and the lack of access to credit may well be the fundamental reason behind their size. Fafchamps (2004) in an extensive study of market institutions in SSA documents how the underdeveloped financial markets lead to lack of credit for starting investment or for working capital by entrepreneurs. Fafchamps (2004) confirms the relationship between the size of firms and their access to credit, like Bigsten et al (2003). He documents that most firms in SSA countries are small and fail to grow to medium and large scale mainly due to the lack of formal credit for expansion. Therefore, it is important to consider this constraint while

modeling the macroeconomy of the countries in the region.

Moreover, firms in SSA, like those in most of low income countries rely on imported intermediate inputs and physical capital. Therefore, the ability of the country to import these inputs is an important factor that determines the performance of the firms operating in these countries. This brings the availability and cost of foreign exchange to play indispensable role in the production process.

To our knowledge, there is only one study that applied the RBC version of small open economy DSGE model to explain business cycle in Africa (Kose and Reizman, 2001) which recognized the importance of imported intermediate inputs though failed to recognize the importance of the availability of foreign exchange and the exchange rate for production.

There are different studies, though not within the context of the DSGE framework, that show the crucial role that the availability and cost of foreign exchange play in the macroeconomic performance of developing and low income countries (Agenor and Monteil (2008), Lensink (1995), Moran (1989), Polterovich and Popov (2003), Porter and Ranney (1982), Stiglitz et al. (2006)). Porter and Ranney (1982: 753) argue that in a typical low income country, in the short run, expanding output without increasing cost of production could be possible “provided only that foreign exchange can be located to purchase the needed raw material imports”. This argument is based on the characteristic features of the low income economies that Porter and Ranney and many other authors share. One of these characteristic features is that shortage of foreign exchange forces firms to produce below their capacity. Porter and Ranney (1982) also illustrate the policy implications of this characteristic feature of low income economy in a simple but very instructive IS-LM framework. Agenor and Monteil (2008) and Stiglitz et al. (2006) also assert that the availability of foreign exchange is crucial supply determining factor in developing countries. For instance, Stiglitz et al. (2006: 56) argue that

... the problem for many developing countries is the deficiency of productive capacity and not the anomaly of its underutilization. And, ..., *the availability of foreign exchange may become, under many circumstances, the principal factor limiting economic activity.* Demand constraints do exist, ..., , but supply constraints—generated either by the availability of capital or by the availability of foreign exchange—are more important.(Emphasis added)

We argue that dependence of production on imported intermediate inputs and, there-

fore, on availability of foreign exchange is one of those circumstances to which Stiglitz and his co-authors refer.

The empirical literature on this issue, though few, also supports this argument. For instance, Moran (1989) studied the effect of the fall in inflow of foreign exchange in the early 1980s, due to declined foreign lending, rise in interest rates on debts, and fall in commodity prices, on volume and composition of imports of developing countries. His result shows that most of the countries considered were affected negatively. Sub Saharan African countries, according to Moran (1989), experienced significant fall in imports which, in turn, led to deterioration of investment and a fall or stagnant per capita output. Lensink (1995) also assessed the effect of the same phenomenon (fall in the foreign exchange inflows into low income countries in 1980s). But unlike Moran (1989), Lensink (1995) investigates the effect on overall macroeconomic performance with an emphasis on economic growth. His simulation analysis shows that SSA countries are among the hard-hit. He deduced that, other things being the same, improvement of economic growth in low income countries depends on availability of foreign exchange to import intermediate inputs. The results of these two studies (Moran, 1989 and Lensink, 1995) imply that the imports of low income countries are mainly intermediate inputs and capital. This concurs with the study by Kose and Reizman (2001) that shows that over the period 1970-1990 the proportion of intermediate inputs and capital in the total imports was more than 75 percent (approximately 48 and 28 percent, respectively) for African countries. Under such circumstances, it is not surprising that decreasing import results into decreasing investment and output. Likewise, Polterovich and Popov (2003) in their empirical study of the relationship between the accumulation of foreign exchange reserve, on the one hand, and investment and growth, on the other, using cross-country regression find strong positive links. That is, developing countries with growing stocks of foreign exchange tend to show higher growth of investment to GDP ratios and higher GDP growth rates. We expect this to be true for the economies of SSA given the economic structure of the countries in the region.

Hence, we argue in the line of Porter and Ranney (1982) and Stiglitz et al. (2006), that for low income countries like those in SSA, foreign exchange needs to be considered as an input of production just like labour and capital, since imported capital and intermediate inputs are all dependent mainly on the availability of foreign exchange and on its price, the exchange rate. The important question is how to capture the effect of exchange rate and

availability of foreign exchange on investment and production within the DSGE framework.

Introduction of foreign exchange will have considerable implications. It means the production in low-income countries directly depends on the performance of the external sector of the domestic economy and the health of the economy of the rest of the world. Accordingly, when the country's external sector performs well and there is inflow of foreign currency from export revenue, remittances, aid and foreign loan, domestic firms will have good access to foreign exchange for import of intermediate inputs and capital as a result of which output and investment increase. On the other hand, if the external sector performs poorly due to either problems that emanate domestically or poor economic situations in the rest of the world, then production and investment of the domestic economy will be affected negatively. This makes production in low income countries function of foreign income and the real exchange rate. In terms of the basic equations of the New Keynesian DSGE models discussed above, the income of the rest of the world and the real exchange rate enter the aggregate supply equation, (equation 2.32 above) which is not the case in the standard model.

We argue that introducing the availability and cost of foreign exchange constraint to firms can also capture the credit constraint discussed above. The reason is that firms need credit either for initial investment or capacity expansion which entails import of capital, or for working capital most of which is for imported intermediate inputs. In all the cases the demand for credit is indirectly a demand for foreign exchange.

4.4 Access of the economy to international financial/asset markets

The other basic assumption of the standard open economy DSGE model is the assumption about the access of economic agents to international financial markets. As discussed in section 2.2.1, most works in the standard models assume that households have access to a complete and perfectly competitive international capital markets and hence hold foreign assets. Even those modified versions of the standard model meant to explain business cycles in developing countries (Kose (2002) and Kose and Reizman (2001)) assumed that households have access to the world financial markets. These latter studies, however, assumed that these markets are incomplete and economic agents can hold only a single asset.

This assumption implies that households can use international capital markets to transfer income across periods and spaces to smooth consumption or it amounts to saying that

there exists international risk sharing through these markets. Many developing countries have capital controls which makes it difficult for households to hold foreign assets. Hence, this assumption of international risk sharing by households through international asset markets is untenable. This, even for developed countries, is not always true as can be seen from the current situation of Greece and other countries that are facing difficulty of accessing credit in international asset markets as they are facing ever increasing rate of interest.

In addition to the existence of capital controls, there is issue of attracting foreign investors in the case of low-income countries such as those in SSA. Stiglitz et al. (2006: 57), for instance, argue that African countries "...have not been able to attract the interest of foreign investors to begin with" let alone to talk about the nature of assets that households hold. In general, governments and firms in low-income countries have limited access to international asset markets. For example, a recent study by Hostland (2009) finds that low-income countries have less access to global private debt markets and heavily depend on official development assistance and concessional loans.

There are various explanations for this inability of low income countries to borrow in international markets. Eichengreen et al. (2003), for example, attributes it to what they call the "original sin" which is the inability of the countries to borrow in their own currencies. The fact that the loans are denominated in foreign currencies reduces the ability of the countries to access these markets. Because the ability of the countries to repay their debt is dependent on many factors most of which are beyond their control. Any event that reduces the ability of the outputs of these countries to command reasonable price in global market will influence their debt repayment abilities. Since lenders know this, they are reluctant to lend money to these countries. Eichengreen et al. (2003) further argue that the institutional strength, macroeconomic stability, and credibility of policies that are some times referred to as determining access to loan in own currency do not have strong evidence. Some countries with the same attributes might be discriminated in these markets: some borrowing in own currency others in foreign currency. Almost all macroeconomic models meant for developing countries do not mention the issues associated with the "original sin" and the currency mismatch¹⁴ problem that emanates from it.

¹⁴See Frankel (2011) for extensive discussion on the sources of currency mismatches that governments and firms in developing countries face and their potential effects on the performance of the aggregate economy.

The literature on this issue is enormous and factors mentioned to be determinants of a country's access to international credit markets are many. But one thing is clear: low income countries have imperfect access to these markets. As discussed in Eichengreen et al. (2003) in detail, this imperfect access to global financial and asset markets has important implications for the ability of these countries to smooth the effects of shocks.

We argue that macroeconomic modeling for low-income countries must take this imperfect access to international financial markets and the associated problems into account. It is only within such a model that the differential effects of shocks on these countries can be understood.

4.5 Monetary policy

The monetary policy rule that is followed by the monetary authorities in SSA is different from the simple and modified Taylor rule that are commonly used in the standard New Keynesian DSGE literature. This emanates mainly from the differences in the macroeconomic problems that the monetary authorities in these countries encounter compared to monetary authorities in developed countries. The monetary policy regimes are among the areas where the distinction between developed and less developed countries, like those in SSA, is vivid. In the past, as was the case in other developing and low income countries, monetary policy in SSA was characterized by financial repression. Financial repression, as discussed by McKinnon (1973) and Shaw (1973) cited in Agenor and Monteil (2008), is a term coined to express the condition where extensive government intervention in the financial market creates a small financial sector. That is, through direct and administrative controls on deposits and lending interest rates, as well as required reserve ratio, the government creates a situation of credit rationing that usually leads to the development of informal (parallel) credit markets. This was common in many countries where governments dictate the allocation of credits administratively instead of through the market forces. Recent years witnessed that many countries in the region, like other developing countries, introduced policies for financial sector liberalization.

The literature on the financial sector and monetary policies of developing countries reports that the financial sector in most developing countries is still not well developed and commercial banks are still dominant financial intermediaries (Frankel, 2011). The same is true of countries in SSA. Furthermore, in some countries there is a parallel operation of the formal and informal financial intermediaries. Since the monetary policy instruments

directly affect only the formal financial intermediaries, the effect of the policy depends on the size of these two sectors. As discussed in section 4.1, in low-income countries the consumption-saving decisions are not responsive to changes in interest rate which implies that using interest rate as a policy instrument does not make much sense to influence aggregate expenditure if it cannot influence credit expansion by financial intermediaries to non-financial firms. That is, since the effectiveness of the transmission of monetary policy depends on the performance of the financial intermediation, it is crucial to take these issues into consideration while modeling monetary policy in these economies.

An other problem in designing monetary policy in these countries is the challenges that monetary authorities face from the external sector. Adam et al. (2009) elaborate these problems and their implications for the choice of monetary policy rule by most of African countries. According to Adam et al. (2009), the change in policy regimes from administrative controls in the financial markets happened at a time when both prices of export commodities and inflows of official aid and FDI into these countries were increasing. Furthermore, it is almost a stylized fact that the prices of exports of these countries, which are primary commodities, are highly erratic, and studies (e.g. Bulir and Hamann, 2003, and 2008) show that aid flows from developed to low-income countries are also highly volatile. These events are sources of problems for monetary authorities in deciding which monetary policy rule to choose.

First, the authorities are concerned with how to maintain the competitiveness of the economy by preventing the exchange rate from appreciation in the face of the inflows discussed above. Second, they need to decide whether the foreign exchange market intervention to maintain competitiveness should be sterilized to maintain the monetary base which in turn has ramifications on interest rates. Hence, Adam et al. (2009: 465) argue that monetary authorities face a trade-off between “nominal (and real) exchange rate volatility on the one hand and high and volatile interest rates on the other, where the latter, in turn, raise concerns about private investment, the lending behavior of the banking system, and the quasi-fiscal burden of increased domestic borrowing”. This trade-off between monetary policy rules in the region is also emphasized by Peiris and Saxegaard (2007).

In general, assessment of the structure of the economies in the region and the few works on this topic shows that the simple or modified Taylor rule employed in the DSGE literature - where there is a policy interest rate and where inflation and output gap are

targeted - does not seem appropriate for modeling of monetary policy rule in SSA.

A monetary policy rule that takes into account the problems faced by many of the SSA countries seems to be the one developed by Adam et al. (2009). Though this model is constructed to deal with the policy responses to manage aid inflows in these countries, it is a reasonable model in capturing the specificity of a typical SSA economy. Revisiting this model and introducing possible extensions in to it seems to be a relatively productive research avenue in the process of building New Keynesian DSGE model for a SSA economy.

It is also worth mentioning that there are those who question whether predetermined and publicly communicated monetary policy rule is appropriate to the economies of the region (see for example, Heintz and Ndikumana, 2011). The reason is that given the structure of the economies and the frequency of exogenous shocks that these economies face the monetary authorities (Central Banks) need to be empowered to act in a timely fashion. According to this view, the monetary policy regime that is appropriate to the economies in the region is discretionary monetary policy.

5 Literature on New Keynesian DSGE for SSA

There are few studies conducted within the framework of New Keynesian DSGE models for SSA countries (excluding South Africa for which there are many such studies). Though these models are developed to study various issues and therefore ought to be evaluated within the context of their objectives, we briefly discuss them with respect to the specificities of the SSA economies discussed above.

There are two studies that were estimated from actual data of countries (Peiris and Saxegaard (2007) and Houssa et al. (2009)). Peiris and Saxegaard (2007) estimate a New Keynesian DSGE model for monetary policy analysis using data from Mozambique. The study recognizes and incorporates in its model the credit frictions that firms face and a version of the monetary policy reaction function developed in Adam et al. (2009). According to this model, firms borrow to cover their working capital at a premium where the premium depends on their debt to asset ratio. They assume that the loan markets are perfectly competitive. However, as discussed previously, firms in SSA face imperfect loan markets. Unlike the traditional Taylor rule, Peiris and Saxegaard (2007) introduce a reaction function for monetary policy where the monetary authority influences the supply of money through foreign exchange and government bond transactions. Except for these

two modifications, i.e., the credit constraint faced by firms and the monetary policy rule, this is the standard closed economy New Keynesian DSGE model of Christiano et al. (2005) version. Moreover, given the importance of the external shocks in driving economic fluctuations in low income economies like Mozambique, the closed economy model of Peiris and Saxegaard (2007) does not seem of any use for policy analysis that they claim.

Houssa et al. (2009) is another study that estimates an open economy version of New Keynesian DSGE model using Ghanaian data. Though Houssa et al. (2009:2?) emphasize the need to develop the DSGE models “for the analysis of fiscal and monetary policies in Sub-Saharan Africa and then use the resulting model to develop policy rules tailored specifically to the issues facing these economies”, we do not concur with them that just estimating a model that does not capture the structural specificities of the economies will help that end. As we argued in the previous section, for any model to be helpful for policy analysis in countries of the region the model must incorporate salient specificities of the countries. The model in Houssa et al. (2009) is a version of Adolfson et al. (2007) which is itself an open economy version of Christiano et al. (2005). Hence, none of the modifications we discussed above or others are either discussed or incorporated in this paper.

Perhaps a serious work in attempting to model the specificities of African countries in a New Keynesian DSGE model, albeit in one direction, is a work by Adam et al. (2009) and Adam et al. (2008). These works, closely related, build a multi-sector DSGE model that incorporates the fiscal and monetary policy rules quite different from the standard literature. Their main contribution is that the central banks in Africa employ foreign exchange intervention and government bond transactions with the private sector as monetary policy instruments. They convincingly established, as discussed in section 4.5, that the interest rate rule that is embeded in the standard models is untenable in these countries. Furthermore, the government sector in these studies is also different from the exogenous process in many standard models. They model this sector in such a way that it captures the problem of volatility of foreign aid that many countries in the region encounter. However, the models in these studies do not incorporate labour market, the financial market, and the credit and foreign exchange constraints discussed in the previous section.

To our knowledge, the most comprehensive model built so far for a country in the region is Berg et al. (2010). These authors develop a multi-sector monetary DSGE model

to analyze the macroeconomic effects of a scaling-up of aid and examine the implications of different policy responses. This model captures many features that are important to the economies in SSA some of which we discussed in the previous section. For instance, they recognize and explicitly model the importance of public investment and the potential crowd in effect of such an investment. It is well known, at least since Barro (1990) that public capital (public sector expenditure on infrastructure and human capital) can generate an externality that increases the productivity of the private sector and hence have crowd in effect on private investment (unlike the crowd out effect assumed in most conventional models). Given the shortage of human capital and low level of development in infrastructure in the countries of the region, the role of the public capital and the externalities from public investment are expected to be very large. Berg et al. (2010) also recognize the inefficiency in conversion of public investment into useful capital. We believe that systematic modeling of these issues in a DSGE framework for countries in SSA is crucial. Furthermore, this study unlike the other studies we discussed in this section and in line with our discussion in 4.1 above, models the coexistence of Ricardian and non-Ricardian households (what they referred to as asset holders and hand-to-mouth households, respectively). The fiscal and monetary policy rules in this study are similar to that of Adam et al. (2009). The imperfect mobility of labour across sectors in this model can also help capturing wage difference across sectors but we believe that the labour market better modeled than through this assumption, as discussed in 4.2. There is no credit and foreign exchange constraint in this model and no financial sector (no financial intermediaries). Berg et al. (2010) calibrated their model for the economy of Uganda. Dagher et al. (2010) calibrated this same model to analyze the effect of oil windfalls on Ghanaian economy.

To sum up, there are few studies that try to construct and estimate a New Keynesian DSGE models for countries in SSA excluding South Africa. Though some of these studies attempted to introduce some specificities of the structure of the economies in the region into the standard model, they do not address the characteristic features we believe are crucial. For example, none of these papers discuss the labour market frictions and unemployment, which is the pressing problem of the region. Given that labour market frictions and unemployment are recent developments in the standard model, it is not surprising they are missed in the models developed for the region. Similarly, the foreign exchange constraint that firms face in the countries of the region is not modeled in these papers.

Hence, it is our belief that a fruitful model seems to combine the modifications that are already introduced and the modifications we indicated above.

6 Conclusion

In this paper we tried to review the developments of the New Keynesian DSGE models, the criticisms they have been facing, their recent progresses and their applicability to a typical low-income country such as those in SSA. Our assessment shows that critics of these models have identified many weaknesses some of which are addressed by recent progresses in the area. However, the criticism put forward by school of behavioural economics is a serious challenge. This is true not only to these specific models but to all conventional economic models that are based on rational economic agents that form rational expectations about future values of key macroeconomic variables. Whether the ideas promoted by this school will develop to a full fledged, empirically applicable framework that can be used to explain and predict the macroeconomy remains to be seen.

Our review also shows that there is enormous progress in DSGE modeling in recent years. From methodological aspect, the development of techniques to solve these models with their nonlinearity and the introduction of heterogeneity and incomplete markets are clearly significant strides forward. The same can be said about the advances in the techniques of estimating these models from actual data. Similarly, there are also considerable advances in substances. First, the incorporation of labour market frictions and involuntary unemployment fills one of the gaps for which these models have been criticized. Second, the introduction of financial market frictions that reflect the characteristic feature of these institutions in the real world and the capability of models with these elements in explaining the role of financial markets in economic crisis like the recent one is obviously a positive step.

On the other hand, though the New Keynesian DSGE models are registering much progress and have been able to redress many caveats, the current tendency of applying the same models to all types of economies is not justifiable. In this, we concur with Blanchard (2009:224) who argue that “...models are more similar in the structure than would seem desirable: Roughly the same models are used both in rich and in emerging economies, despite their different structures and shocks”. We argue that these models need modifications and changes to reflect the differences of the economies in their structure and

the nature of shocks they face to be of use to specific countries.

Accordingly, we identify that the foreign exchange constraint, labour market segmentation, imperfect or no access of the economies to international financial markets are among the modifications required to improve the applicability of these models to low-income countries. Similarly, monetary and fiscal policy rules that are usually incorporated in the standard models need modifications and/or changes for these models to be meaningfully applied to low-income countries in general and SSA in particular. Furthermore, sequential introduction of these modifications and changes seems to be more productive than simultaneous introduction of all of them. The merit of this step-by-step introduction of modifications or changes helps understanding the implications of each separately in order to get the insight about how they interact when they all combined and introduced in a single model. This is so since some of these modifications might have effects that are reinforcing or offsetting each other.

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