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AGENT-BASED COMPUTATIONAL ECONOMICS (ACE) AND  
AFRICAN MODELLING: PERSPECTIVES AND CHALLENGES

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## **ABSTRACT**

In recent years, the government, of African Countries has assumed major responsibilities for economic reforms and growth. In attempting to describe their economies, economists (policymakers) in many African Countries have applied certain models that are by now widely known: Linear programming models, input-output models, macro-econometric models, vector auto regression models and computable general equilibrium models. Unfortunately, economies are complicated systems encompassing micro behaviors, interaction patterns and global regularities. Whether partial or general in scope, studies of economic systems must consider how to handle difficult real-world aspects such as asymmetric information, imperfect competition, strategic interaction, collective learning and multiple equilibria possibility. This paper therefore argues for the adoption of alternative modeling (bottom-up culture-dish) approach known as AGENT-BASED Computational Economics (ACE), which is the computational study of African economies modeled as evolving systems of autonomous interacting agents. However, the software bottleneck (what rules to write for our agents) remains the primary challenge ahead.

**KEY WORDS:** artificial intelligence, computational laboratory, complex networks, multi-agent systems, agent-base computational economics, social networks, macro-econometric model, linear programming; input-output, vector auto regression ace models, var models, neural networks, gene networks, derivatives, financial contagion, Africa economies, aceges models, energy,

Tel No: B40, B41,B23,C10,C20,C30,C40,C50,C60,C80,C90

## **1.0 INTRODUCTION**

Obviously, the real world is quite complex and economic relationships are intertwined making it difficult to properly gauge the direct and indirect effects of economic policies. Consequently, the construction of economic models provides a logical basis for making inferences about the objective reality and directional impacts of policy interventions. However, no matter its complexity, economic model provides only as approximation of the real world. Thus, the relevance of a model may be judged by the extent to which it fulfills a set of conditions. These conditions include the extent to which it replicates the essential features of the real world; the extent to which it is able to explain the observed labyrinth of interactions among economic agents; the extent to which it is able to accommodate the indirect effects of policy interventions and its ability to provide alternative policy directions through sensitivity analyses.

However, a common criticism of empirical economics is that it pays insufficient attention to discriminating between competing explanations of the same phenomena. Yet interaction and heterogeneity of agents are pervasive characteristics of economic processes. Unfortunately, economics theory has neglected these features to a large extent. Instead, the paradigm of modeling representative agents has emerged (which by its very construction has eliminated any consideration of interaction and heterogeneity). Essentially, the representative agent's methodology originated from the need of developing micro-foundations of assumed macro-economic behavior. That is, by tracing back the market behavior of firms or households to their underlying objectives of profit and utility maximization. Overtime, this looked possible with our extremely limited number of agents entering economic models.

Consequently, the governments of African Countries have assured major responsibilities for economic reforms and growth. Along with these responsibilities, has come an increased awareness of the interrelatedness of different sectors of a national economy and of the need for coordination of policies that had previously been debated

in terms of their direct impacts on individual sectors. In attempting to describe their economies, economists in many African countries have applied certain models that are by now widely known. Thus, with the rapid progress in formal modeling techniques and the growing accessibility of electronic computers, it would not be out of place to expect every African country within the next decade, to have an operational formal model of the economy to use as an instrument for economic policy formulation and implementation. In general, these African economies are complicated systems encompassing micro behaviors, interaction patterns and global regularities. Whether partial or general in scope, studies of economic systems must consider how to handle difficult real-world aspects such as asymmetric information, imperfect competition, strategic interaction, collective learning and the possibility of multiple equilibria. Fortunately, recent advances in analytical and computational tools are permitting new approaches to the quantitative study of these aspects. Here, one such approach is AGENT-BASED COMPUTATIONAL ECONOMICS (ACE), which is the computational study of economic processes modeled as dynamic systems of interacting agents. This paper therefore explores the potential advantages and disadvantages of ACE model for the study of economic systems. Here, various approaches used in Agent-based computational Economics (ACE) to model endogenously determined interactions between agents are discussed; and this concerns models in which agents not only (learn how to) play some (market or other) game, but also learn to decide with whom to do that (or not).

Again, we observe that agent-based models typically involve large numbers of interacting individuals with widely differing characteristics, rules of behavior and sources of information. Indeed, the dynamics of such systems can be extremely complex due to their high dimensionality. Similarly, emphasis on dynamic heterogeneous agent models (HAMS) in economics and finance is given to simple models that (at least to some extent) are tractable by analytic methods in combination with computational tools. Essentially, most of these models are behavioral models with boundedly rational agents using different heuristics or rule of thumb strategies that may not be perfect but perform reasonably well.

Typically, these models are highly nonlinear (due to evolutionary switching between strategies) and exhibit a wide range of dynamical behavior ranging from a unique stable steady state to complex, chaotic dynamics. Here, aggregation of simple interactions at the micro level may generate sophisticated structure at the macro level. Empirically, simple HAMS can explain important observed stylized facts in financial time series such as excess volatility, high trading volume, temporary bubbles and brood following, sudden crashes and mean reversion, clustered volatility and fat tails in the returns distribution. In other words, agent-based models used in finance concentrates on models where the use of computational tools is critical for the process of crafting models that give insights into the importance and dynamics of investor heterogeneity in many financial settings as well as allied settings of the 21<sup>st</sup> century based African economies.

## **2.0 MODELLING AFRICAN ECONOMIES**

Indeed, plan making and implementation in most African Countries have come to be accepted as necessities for the promotion of rapid economic growth. Perhaps, this would partly explain the growing number of formal macro models being developed for African economics (with the objective of serving as planning tool). In fact, there are already a sizable number of such models while only few of them are operational. Unfortunately, most attempts at building large scale macro models for African economies often proceed without an explicit recognition of the dualistic nature of these economies (Olofin, 1985). However, the areas in which macro models may find applications in the management of an economy can be classified into three categories: forecasting, policy analysis and long term planning. Generally, multisectoral macro models include the following model variants: input-output models (IOM) Linear programming models (LPM) Macro-econometric models (MEM) and computable General Equilibrium Model (CGEM). Figure 2A presents the basic features of different micro model types. Nationally, some of the empirical macro-econometric literature include Ojo (1972) Adamson (1974), Gosh and Kozi (1978), Olofin (1977), Uwujaren (1977), World Bank (1974), UNGAD (1973) and NISER (1983). However, the institutionally supported models include CEAR-FMNP-MODEL, MAC III, CEAR-MODEL-MACIV and the CEAR LINK model (see Olofin and Ekeoku, 1984b; Olofin, 1985; Olofin and Poloamina, 1984). Yet, the latter versions of Cear-Mac model including Cear Model MACV are well documented (see Olofin, et.al.1983a) Olofin, et.al. 1983b, Adeniyi et.al. 1983 and Raheem, Ogunkola and Olofin, 1991). Other recent macro-econometric models were that of Oshikoya (1990)

FIGURE 2A MACROMODEL VARIANTS

S/N	Model Characteristics	Linear Programming	Input Output	VAR	Macro Econometric	Computable General Equilibrium
I	Methodological Framework: Keynesian/Monetarist Neoclassical		X	X X	X	X
II	Time Horizon: Short term Medium/Long-term		X	X	X	X
III	Focus: Real Sector Monetary sector	X	X	X	X X	X
IV	Temporal Structure: Static Dynamic	X	X	X	X	X X
V	Data Nature: Time series (Data Intensive) Cross sectional (Data Extensive)	X	X	X	X	X
VI	Economic System type: Command Market	X	X	X	X	X
VII	Economic Aspects: Micro- economics Macroeconomics	X	X	X	X	X
VIII	Interest Ministries: Finance Ministry Planning Ministry	X	X	X	X	X
IX	Algorithm based solution	X	X	X	X	X



and Soludo (1995). Indeed, efforts at building CGE models for Nigeria started with the study by Taylor, Yurukoglu and Chaudhry (1983) and PAD (1988). Other applications include Adenikinju (1994), Nwaobi (1996), Nwaobi (2004), Olayiwola (2000), Olaniyan (2000), Aminu (2006), Oyeranti (2006), Ajakaiye (1994), Ajakaiye (1995), Olofin and Adenikinju (2004), Nwafor, Ogujuba and Adenikinju (2006), Foluwewo and Udejaja (1999), Falokun (2009), Adenikinju and Falobi (2004). Unfortunately, most of studies borrowed coefficients from the literature and the role of money is relegated to the background. Again, most of the models did not explicitly address distributional issues and nearly all the models employ comparative static system except for the one that allow for limited dynamic adjustment. Again, most of the reviewed models are individual models constructed by researchers and thus institutional models are still not common. There, the major reason being that updating and revising models are quite time consuming and expensive at national levels.

Regionally, Harris (1985) found that about 190 models of various African economies have been constructed. However, it has been observed that Harris surveyed mainly the Anglophone African Countries and was also restricted to literature printed in English language. It is therefore estimated that probably over 250 macro-economic models of African economies may have existed as at 1985 and the number may have grown much higher since then (Soludo, 1994; 1998). Specifically, the United Nations Economic Commission for Africa (ECA) made one of the earliest and boldest attempts to develop and apply a regional macro econometric model to specific African countries. In fact, ECA (1980) envisaged extensive collaboration with individual planning ministries in each country as well as harmonizing its work with those of other agencies in the United Nations system involved in the studies of long term trends in Africa. Similarly, in the early 1990s, a CGE model was constructed and maintained at the ECA. However, a useful classification proposed by Montiel (1993) is to focus not only on the structure/closure rules embodied in African models; but more importantly to examine the extent to which they are contemporary in the sense of taking account of the post-Lucas critique innovations in macro-economic methodology. Thus, within this

framework, Montiel classifies existing models of African countries into two broad categories: traditional and contemporary. Here, some models incorporate rational expectations and budget constraints (Ligenor, 1990; Hague, Lahiri and Montiel, 1990; Hague, et.al, 1991, Agenor, et.al.1993; Soludo, 1993). On the other hand, some models incorporate optimizing agents (Montiel, 1993). And yet there are other models that were developed to evaluate policy and provide forecasts of African economies (Elbadawi and Schmidt-Hebbel, 1991; Pedersen, 1994; Kumar, et.al. 1993; Adams, 1990).

Several studies that have investigated African channels of transmission mechanism using vector Autoregressive models (VAR) include Nwafor (2006), Adebisi (2006), Central bank of Nigeria (2008) and Central bank of Nigeria (2010). Indeed, the VAR framework rests on its simplicity and high predictive power. However, within the VAR framework, small scale macro-econometric model can be estimated using dynamic stochastic general equilibrium methodology so as to address specific policy questions and issues of relevance in the African economy. Unfortunately, all the above reviewer models have the various limitations that demand for viable and sound alternative modeling framework for Africa.

### **3.0 AGENT-BASED COMPUTATIONAL ECONOMICS (ACE) MODEL**

#### **ALTERNATIVE**

Obviously, a complex system is any system featuring a large number of interacting components (agents, processes, etc) whose aggregate activity is nonlinear (non-derivable from the summations of the activity of individual component) and typically exhibits hierarchical self organization under selective pressures. In other words, a system is complex when it has so many variables and interacting forces that it cannot be understood in its entirety or optimized by traditional (top down) approaches. Typically, these system include gene networks that direct developmental process; immune networks that preserve the organisms identity; social insect colonies; neural brain networks producing intelligence and consciousness; ecological networks; social networks (transportation, utilities, telecommunication); and national (regional) economics. Notably, all social science research proceeds by building simplified representations of social phenomena. Perhaps, these representations are often verbal and the difficulty with such verbal presentations is that it is usually hard to determine precisely the implication of the ideas being put forward. However, in the economics profession, this representation is usually much more formal and often expressed in terms of statistical and mathematical equations. Compared to the verbal representation, the quantitative representation makes assessing consistency and generalisability much easier. However, in using statistical and mathematical models, many of the equations which one would like to use to represent real social phenomena are simply too complicated to be analytically tractable specifically, when the phenomena being modeled involve non-linear relationships, the advantages of mathematical formalization evaporate. Thus, a common solution is to make simplifying assumptions until the equations do become solvable. Unfortunately, these assumptions are often implausible and the resulting theories can be seriously misleading.

Consequently, the breakthrough is computational modeling in the social sciences (economic sciences) came with the development of multi-agents systems (MAS).

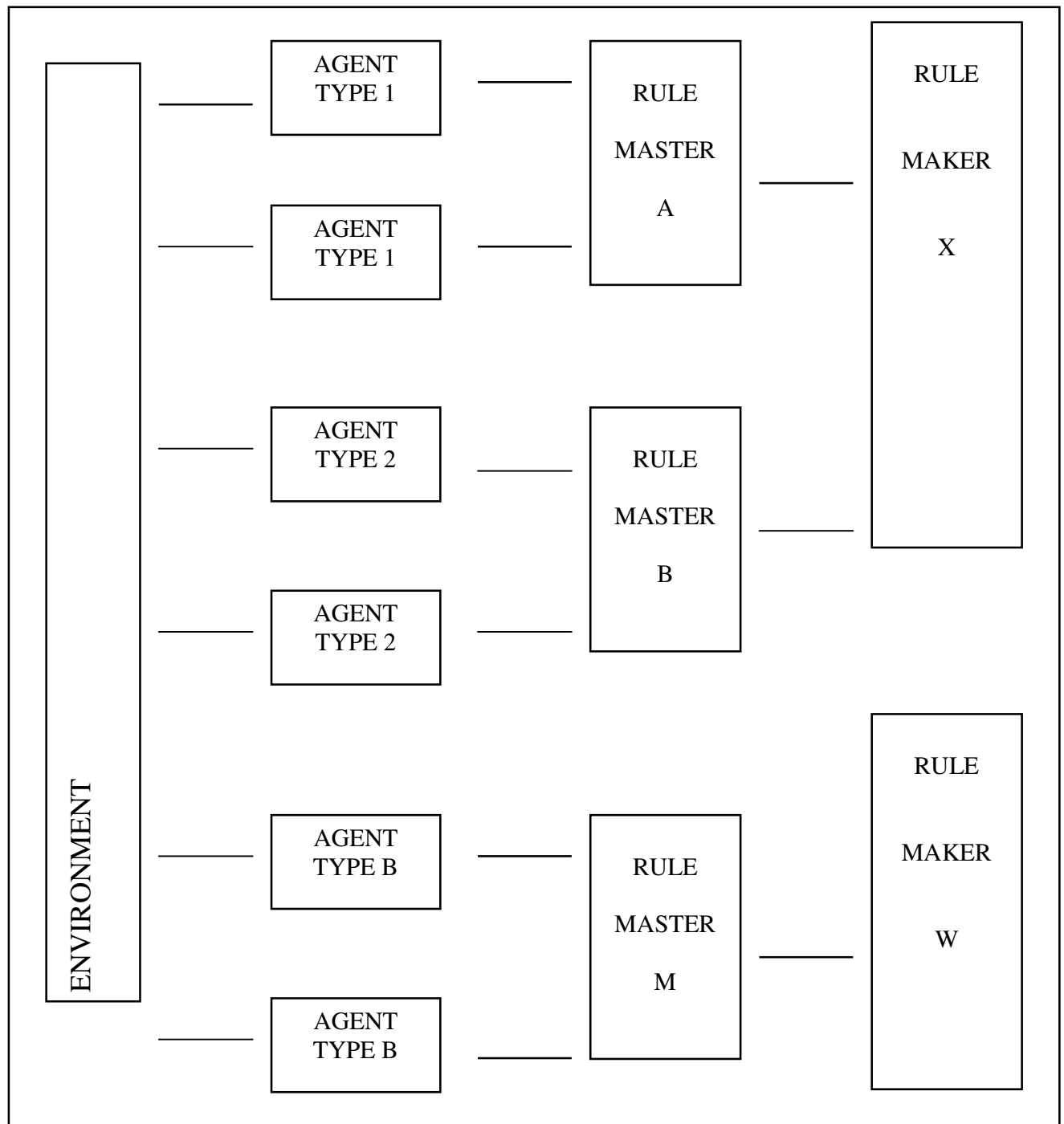
Essentially, these models were derived from work in the sub-area of artificial intelligence or distributed artificial intelligence (DAI). Basically, DAI wined to solve problems by dividing them amongst a number of programs or agents (each with its own particular type of knowledge or expertise). While DAI is primarily concerned with engineering effective solutions to real world problems; it was soon noticed that the technology of interacting intelligent agents could be applied to modeling social phenomena (with each agent representing an individual or organizational actor). Using MAS perspective, agents are processes implemented on a computer that have autonomy (control their own actions); social ability (interact with other agents through some kind of language); reactivity (can perceive their environment and respond to it); and pro-activity (are able to undertake goal directed actions). Here, the task of the modeler is to define the cognitive and sensory capabilities of the agents; the actions they can carry out and characteristics of the environment in which they are located to setup the initial configuration of the system; and then to observe what happens when the simulation is run. Scientifically, one is looking for emergent phenomena, that is, some patterns arising at the level of the system as a whole that are not self-evident from consideration of the capabilities of the individual agents. For example, institutions such as the legal system and government that are recognizable at the macro-level from the micro-level' actions of individual members society. Understanding this feature of human society variously known as second order emergence, reflexivity and double hermeneutic, is an area where computational modeling shows promise.

Operationally, there are different architectures or designs used in building agents for a multi-agent system. Nevertheless, every agent design has to include mechanism for receiving input from the environment; for stoning a history of previous inputs and actions; for devising what to do next; for carrying out actions; and for distributing outputs. Again, Agent architectures can be divided into those that are rooted in the symbolic paradigm of AI and non-symbolic approaches such as those based on neural nets here, one effective design for an agent is to use a production system and this has three components set of rules, working memory and rule interpreter. These rules consist

of two parts: a condition which specifies when the rule are to be executed (fire) and an action part which determines what is to be the consequence of the rule firing. However, the problems arising when we go from simple to complex result suggest that a crucial role for the usefulness and the acceptability of experiments is played by the structure of the underlying models. Consequently, there exist general schemes that can be employed in building agent-based simulations. As shown in figure 3A, the main value of the environment- Rules-Agent (ERA) scheme, is that it keeps both the environment (which models the context by means of rules and general data) and the agents (with their private data) at different conceptual levels. To simplify the code, agents should communicate directly, but always through the environment. In other words, the environment allows each agent to know the list of its neighbors (which not mandatory) and if we admit direct communication between agents, the code becomes more complex. Again, with the aim of simplifying the code design, agent behavior is determined by external objects (RULE MASTERS) that can be interpreted as abstract representations of the cognition of the agents. Rule Master Objects are therefore linked to rule maker objects, whose role is to modify the rules mastering agent behaviors (such as by means of a simulated learning process). Similarly, rule makers interact with rule masters, which are responsible for getting data from agents to pass to Rule Makers. Although, this code structure appears to be complex, there is a benefit when we have to modify a simulation and the rigidity of the structure becoming a source of invaluable clarity ( Nwaobi, 2001).

Specifically, Agent- based computational Economics (ACE) is the computational study of economic processes

**FIGURE 3A BUILDING AGENT BASED COMPUTATIONAL MODELS:**  
**ENVIRONMENT-RULES-AGENTS FRAMEWORK**



modeled as dynamic systems of interacting agents. These agents refer to a bundle of data and behavioral methods representing an entity constituting part of a computationally constructed world. Here, examples of possible agents include individuals (consumers, producers), social groupings (families, firms, communities, government, and agencies), institutions (markets, regulatory systems), biological entities (crops, livestock, and forests) and physical entities (infrastructure weather and geographical regions). Thus, agents can range from active data-gathering decision makers with sophisticated embodied cognitive capabilities to passive world features with no cognitive function. Again, agents can be composed of other agents, thus permitting hierarchical constructions. Illustratively, a firm agent might be composed of worker agents, manager agents and shareholder agents. Essentially, one primary objective of ACE research is empirical understanding: why have particular observed regularities evolved and persisted despite the absence of top-down planning and control?

Here, such examples of regularities include interaction networks, financial market, stylized facts, protocols for market operation, and the common adoption of technological innovations. ACE researchers therefore seek causal explanations grounded in the repeated interactions of agents operating in realistically rendered worlds as well as trying to understand whether particular types of observed regularities can be reliably generated from particular types of agent-based worlds. Yet, another related primary objective is normative understanding: How can ACE models be used as laboratories for the discovery of good economic designs? ACE modelers pursuing this objective are interested in evaluating whether designs proposed for economic policies; institutions or processes will result in socially desirable system performance overtime. Here, as agent –based world is constructed that captures the salient aspects of an economic system operating under the design; and the world is then populated with privately motivated agents with learning capabilities (and allowed to develop over time). Yet, the key issue is the extent to which the resulting world outcomes are

efficient, fair and orderly despite attempts by agents to gain individual advantage through strategic behavior.

The next primary objective is qualitative insight and theory generation: How can ACE models be used to gain a better understanding of economic systems through a better understanding of their full range of potential behaviors over time (equilibria and attraction basins)? In fact, such understanding would help to clarify not only why certain types of regularities have evolved and persisted but also why others have not. Again, what are the self-organizing capabilities of decentralized market economies as well as the evolution of institutions and social norms? In other words, how do institutions and the behavioral dispositions of cognitive agents co-evolve over time, and what is the general likelihood that efficient social institutions will emerge without top down intervention? And the last primary objective is methodological advancement: how best to provide ACE modelers with the methods and tools they need to undertake theoretical studies of economic systems through systematic computational experiments, and to examine the compatibility of exponentially-generated theories with real-world data. Thus, ACE modelers are exploring a variety of ways to address this objective ranging from careful consideration of methodological principles to practical development of programming, visualization and validation. Indeed, one area where ACE methodology has frequently been applied is Asset pricing, where researchers have developed computational models in which many agents choose from a set of possible forecasting strategies in order to predict stock prices, which affects their asset demands and thus affects stock prices. Basically, these models assume that agents are more likely to choose forecasting strategies which have recently been successful; and the success of any strategy will depend on market conditions and also on the set of strategies that are currently being used frequently, these models find that large booms and busts in asset prices may occur as agents switch across forecasting strategies, and some have suggested that ACE might be a useful methodology for understanding the global financial crisis. Other related applications include Extreme Financial Events Modeling (closed form solution for equity options assuming a generalized extreme value risk



neutral density function) and regime switching models for portfolio management as well as digital modeling of financial contagion (derivatives). ACEGES is an agent-based model for exploratory energy policy by means of controlled computational experiments. It is operationally designed to be the foundation for large custom-purpose simulations of the global energy system that have direct relevance to the African economies.

#### **4.0 CONCLUSION**

Regrettably, it should be stressed that while the state of knowledge about the functioning of economies is incomplete, the state of ignorance about African economies are even much higher. However, given the rate of progress in the development and applications of information and communication technologies (ICTS) as tools for policy analysis, economic projections and the overall management of the economy on a short-run and longer term basis; it is difficult to envisage a situation whereby any country in the near future would prefer the primitive techniques of rule of thumb to formal modeling of the economy. This paper therefore recommend that policing modeling provides a unifying focus within which to study a very wide range of economic problems that have always been presented in isolation from one another. Yet these conventional macro models essentially at their present level of development are no more than the analytical framework or skeleton which still requires the flesh and blood of details and common sense to be useful instruments of policy. As an alternative modeling framework, the Agent-Based computational Economics (ACE) modeler provides the initial configuration of a computational economic system comprising multiple interacting agents. And the modeler steps back to observe the development of the system over time without further intervention.

Here, system events should be driven by agent interactions without external imposition of equilibrium conditions. However, constructive understanding of production, pricing and trade processes, essential primary of survival; strategic rivalry and market power; behavioral uncertainty and learning; role of conventions and organizations; and the complex interactions among structural attributes, institutional arrangements and behavioral dispositions, are valid concepts in the ACE framework for the modeling of African economics.

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