REVIEW ON SYSTEM DYNAMICS MODELING APPROACH TO MACROECONOMIC VARIABLES IN NIGERIA

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Abstract

The application of system dynamics to national economics modelling is becoming more acceptable, particularly for refining economic policies and forecasting. This study is focused on the targeted application of system dynamics modeling to the macroeconomic policy scenarios of Nigeria, spinning toward a transformative paradigm shift that harness this methodology for effective modelling of macroeconomic variables. The article understudies an innovative approach to reviewing economic variables within the framework of national economies, showing the innate potentials of system dynamics to unravel the complexities inherent in dynamics and nonlinear macroeconomics systems. A fundamental focus is placed on the important interplay between constituent elements within the system structure, with particular attention accorded to the pivoted stages of model conceptualization. Through this systematic review, the article serves to provide and enrich the comprehension of macroeconomic system bahaviour in Nigeria, with the ultimate aim of steering the design of more adept impactful macroeconomic policies.

Keywords: System Dynamics (SD), System Dynamic Modelling (SDM), Stocks, Feedback, Macroeconomic variables

Introduction

In policy evaluation, system dynamic modelling is a potential modelling paradigm that addresses the dynamics of complexity through stock-and-flow structure, feedback, non-linear and time lags in economic system (Wei, *et al.*, 2020). Developed to describe the structure and dynamics of complex systems, system dynamics utilises flows, stocks and feedbacks, translated into differential equations for formal representation (Kurennoy and Golembiovsky, 2021). This approach, prevalent in literature and emerging national economic studies, requires dynamic simulation analysis to comprehend economic system behaviour and formulate policies (Senaras, 2017). System dynamics (SD) is a system thinking methodology that analyse the behavior of complex systems over time. It has been used to model a wide range of phenomena, including social problem, technological, political, and economic systems. Researchers use various tools such as causal loop diagrams, stock and flow diagrams, and computer simulations to study complex systems and their nonlinear behaviour, delays and interactions among system components (Sterman, 2000; Bala *et al.*, 2017). Through the use of loop, stock and flow diagram to set up mental models for simulations, SD aid in policy analysis by identifying key variables and relationships for effective decision-making.

Studies on economic components are proposing a paradigm shift that will incorporate the application of system dynamic theory and modelling toward understanding the complexity and nonlinearity of macroeconomic variables (Lawler, *et al.* 2019). The authors assert that the field of economics science, particularly within the sub-field of macroeconomics, needs reset and upgrade of methodology. They emphasis the necessity of embracing the available systemic and cybernetic tools. This paper promotes a new paradigm and presents review that illustrate how a judicious application of systems theory can help to better understand the problem and offers an approach (System Dynamics) as a means for understanding economic problems. In the work of Moscardini and Lawler (2000), a comparative analysis was conducted between system dynamics and other conventional economic modelling approaches. Their findings position system dynamics as offering a more comprehensive pedagogical advantage, especially in the context of learning economic modelling related to macroeconomics variables. More so, the process of modelling system behaviour entails identifying the system's underlying structure, through the interactions among system elements.

Kennedy (2011) emphasizes that the fundamental feature of system dynamics is the concept of feedback, manifesting as interconnected variables within a loop. Further asserted that SD can be approached from two perspectives: quantitative and qualitative paradigms. The quantitative paradigm necessities simulation software, exemplified by the one developed by Richardson and Pugh (1981) and subsequently refined by Richmond (1999), which incorporate a user-friendly graphical interface. Research reveals varying outcomes for different countries stemming from impacts of complexity, uncertainties, shocks on the real sectors of their economies. Macroeconomic variables undergo heightened uncertainties due to both external and internal shocks. In recognising the significance of employing system dynamics for solution-oriented economic modeling. Moscardini and Lawler (2000) analyse the limitation of traditional teaching methods and proposed that system dynamics serves as a valuable complement to standard economic modelling. The system dynamics model methodology has been extensively applied to model complex systems. This methodology includes analysis of the models' components, development of dynamic hypothesis in the causality analysis, computational modelling in the flow and level diagram, model validation, scenarios runs and analysis of results. Several applications are developed for making decisions under controlled simulation scenarios in supply chain management, energy, environment, society, finance, and public policies (Becerra-Fernandez, *et al.,* 2022).

Most researchers are using system dynamics to study the behaviours of macroeconomic variables (Khan, 2020; Sovilj, *et al.*, 2021; Sovilj, *et al.*, 2023; Kozytskyy *et al.*, 2023). Lawler (2019) in his paper, using system dynamics in macroeconomics advocated for a paradigm shift to system of dynamic thinking to better understand macroeconomic behaviours. The approach has been applied to model energy planning and carbon dioxide estimation of the Nigerian power sector (Sheri & Moumoure, (2020). Odoemena *et al.* (2020) conducted a study that examines the Nigerian beef supply-side using a dynamic system approach. Sanga, *et al.*, (2018) used a system dynamics simulation model to analyses the maize production under future scenarios in Kaduna State, Nigeria. Nigeria's economic performance is of great significance both regionally and globally. Previous researches on the Nigerian economy have emphasized the need for enhanced macroeconomic modeling to support policy analysis and decision-making. This is due to the fact that the economic performance over the years had not been impressive due to volatility and low performance of macroeconomic variables (Usmana, and Osagie, 2023).

Economic variables are highly interrelated, as posited by Olaniran *et al.*, (2017), there is dynamic relationship among macroeconomic variables and economic growth in Nigeria. The economy is complex and without causal and structural insight it become difficult to understand and formulate sustainable economic policies. To promote sustainable economic growth, it is crucial to develop effective approaches(model) for comprehending the complexity of this volatility (Okafor, 2020). Policymakers, investors, and other stakeholders (including academia) have to understand the behaviour of the economy in the face of uncertainty and random shocks in order make informed decisions (Eze, 2017). The high volatility, complex and nonlinearity of macroeconomic variables in Nigeria calls for a paradigm and new approach to policy design and methodology. Papageorgiou and Hadjis (2011) posited that the primary assumptions of the SD paradigm is that the persistent dynamic tendencies of any complex social system arise from its internal casual structure.

There are limited researches in Nigeria that applied System Dynamics Modelling (SDM), most especially on macroeconomic variables. The intention of this paper is to offer a new paradigm shift to the conceptual insight on the study of macroeconomic variables in Nigeria and spur researches in relation to bridging the gap on applying the aforementioned methodology. More so, examine the relevant research from the global perspective on complexity science with the application of system thinking. The systematic review of literature focused on the empirical application of system dynamic modeling to analyse macroeconomic variable in Nigeria drawing lessons from other countries. The comprehensive analysis of the selected studies shed light on the extent of utilisation, methodologies applied, and implication of employing system dynamics in understanding and improving macroeconomic policies within the Nigerian context. Several studies have laid emphasised on the application of system dynamic modeling for policy-making. By simulating different policy scenarios, researchers can assess the potential impact of various intervention on the economy. This approach enhances policymakers' ability to formulate informed decisions that will mitigate risks, reduce uncertainties, and promote sustainable economic growth. The finding of the systematics review, underscore the policy relevance of utilising system dynamic modeling in macroeconomic analysis for Nigeria. The ability to capture complex interactions and feedback loops aligns with the need for evidence-based policy-making that addresses the intricate dynamics of the Nigerian economy.

Applications of System Dynamics in Economics

The study of system dynamics on national economic has generated large volume of empirical studies, the studies cut across some components of the economic to include inflation, interest rate, and the entire system. Few of those studies were selected to be included in the review for this study. Sovilj, *et al.,* (2021), the authors evaluated the national economic model using system dynamic approach. Using a set of macroeconomic data for a transition economy to validate the model behavior in the past, and then simulated the future paths of key macroeconomic. They argued that economic systems are dynamic, complex, nonlinear, and composed of many interacting agents, that studies should take a holistic approach to modelling a complete national economy. Systems dynamics models consider the system as a whole, focusing on its structure and the relationships between different elements. Applying reinforcement learning to complex simulations in this field present a wealth of opportunities, offering insights that could shape economic policies, investment strategies, and broader understanding of complex macroeconomics components.

Kurennoy and Golembiovsky (2021) demonstrates combined approach used to assess the probability of a company's bankruptcy, using system dynamics model. The authors used multivariate ARIMA-GARCH and system dynamics model incorporating the Monte Carlo simulation. They described modelling of macroeconomic parameters by ARIMA-GARCH models and the input parameters for the system dynamics model of an oil producing and refining. The simulation of the system dynamics model with macro parameters on its inputs allows estimating the probability of company default. A comparative analysis of the results and data from Moody's and Fitch demonstrates the closeness of the simulated probability of the default of the enterprise, and the corresponding estimations from rating agencies, which makes it possible to conclude that the described approach is acceptable for estimating the probability of default of a borrower. Lawler *et al.,* (2019) promotes a new paradigm shift and presents three examples that illustrates how a judicious application of systems dynamic theory can help to better understand macroeconomics problems and offers a tool as a means of obtaining meaningful solutions to complex and nonlinear problems. The authors posited the need to synthesize economic thinking, system thinking and cybernetic thinking and suggest ways of doing so through both quantitative and qualitative system dynamics modelling.

Sovilj, *et al.,* (2023) evaluated a national economic model of Croatia economy using system dynamic approach. The model behaviour was validated using macroeconomic data from a transition economic in the past, and then alternative paths of key macroeconomic variables are simulated. Instead of studying only a fraction of the economy or simple model, the authors built a large-scale national economic model. The study provides additional insights about the macroeconomic effects of economic policies through system dynamics information feedback, making it valuable tool for economic policy analysis. Scrieciu *et al.,* (2021) argued that the connection between complexity in economics and system thinking can be established by examining their shared commonalities and differences. Exploring complexity in economic variables, primarily focuses on the quantitative exploration of interactions among diverse agents at the micro-level. Conversely, systems thinking adopts a macroscopic approach to comprehending the intricate dynamics of systems and incorporates an inter-subjective interpretivist dimension in the study of complex social-economic order. Complexity economies relaxes the assumptions of neoclassical economics and considers agents with imperfect information who constantly change their actions and strategies in response to the outcome they mutually create. It also links to complexity science more broadly, further expanding its scope.

Hryhoriev, (2021) presented a system dynamic modeling of sovereign debt using the path dependence concept and simulation modelling. The aim was to find a fixed point in the motion of national sovereign debt towards its equilibrium and to change the existing mental model perception towards sovereign debt by changing the structure of the system. The research reveals the idea of the "debt snowball concept" using recursive dynamic approach. The fixed point as an equilibrium value for a country's sovereign debt stock to GDP ratio with a linear dependence has been built. The stock and flows SD modelling and simulation analysis of the sovereign debt in Ukrainian economy allows to make the conclusion of the inevitability of the sovereign debt existence even on the stable level and with the balanced national budget. Lindeman (2023) applied agent-based and system dynamics modeling to analysed the flow in the values of an economic system. These models provided insight into the behaviour of individuals and the overall dynamics of the system. Agent-based models simulated how individuals act, react, and interact in different societies, taking-into-account macro structures that influence their behaviour. System dynamics models, on the other hand, capture the stock and flow behaviour of the system, allowing for the identification of critical steps and bottlenecks. By combing these two modelling approaches, researchers can overcome challenges of representing the multidimensional nature of complex system and gain better understanding of the interactions and dynamics within the system. This integrated approach can provide valuable insights into economic development trajectories, decision-making process, and the impact of individual agency on the overall system.

Kozytskyy *et al.,* (2023) examines the dynamic properties of output and inflation fluctuations that occur in response to economic shocks. They used a system dynamic approach and constructs two system dynamic models to examine the dynamics of output, prices, wage and inflation. Unemployment is a major challenge in many developing economies, including Nigeria. High unemployment rates can lead to social unrest and political instability. Stochastic and system-dynamic models have been used to study the determinants of unemployment and its impact on the economy. Numerous empirical studies on system dynamics and national economics highlight its application to various economic aspects, such as inflation and interest rates (Sovilj *et al.,* 2021). Sovilj *et al.* (2021) developed a complete national economic model to evaluate economy-wide effects of economic policies. Kurennoy and Golembiovsky (2021) assessed company bankruptcy using a combined approach of multivariate ARIMA-GARCH and system dynamics models. Lawler et al. (2019) advocated for using system dynamics in macroeconomics to better understand complex problems and offer meaningful solutions. Scrieciu *et al*. (2021) explored the link between complexity in economics and systems thinking, suggesting a hybrid approach. Hryhoriev (2021) models sovereign debt using system dynamics to identify equilibrium points. Lindeman (2023) combines agent-based and system dynamics modeling for a comprehensive economic analysis.

The study of this methodological approach concludes by summarising the systematic review process, key finding, and implications. The review aims to contribute valuable insight into the application of system dynamics modelling in analysing macroeconomics variables in Nigeria, shedding light on the strengths and limitations of existing approaches and suggesting opportunities for the future

Search Strategy and Model Building

The article applies a methodology designed to systematically review and analysed the application of system dynamics modelling to macroeconomics variable from broader literatures. The reviewed focused on gathering relevant literature, critically evaluating its content, and synthesizing key concepts. By employing a structured and comprehensive methodology, the study aims to provide a comprehensive overview of the subject matter. Papers were searched from multiple databases to ensure large coverage of relevant studies. Key words such as "economic policy," "macroeconomic variables," "system dynamic modelling," "system dynamic modelling of macroeconomic variables" guided the search. A set of inclusion and exclusion criteria was established to ensure selection of relevant literature was properly done. Including studies focused on the application of system dynamics modelling to analysis macroeconomic variables within the Nigerian context. The synthesised data was analysed thematically to identified patterns, trend, relevance, gaps, future studies, potentials in the literatures. Themed include the discipline, types of

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macroeconomic variables, model techniques employed, simulation techniques, policy implications derived and future suggestions. The analysis highlights recurring insights and potential areas for further research.

Design and Implementation of System Dynamics Modelling framework

Sterman, (2000), stated the requisite procedures for generating a dynamic system model, involve initial comprehension of the system employed to generate problem articulations. Subsequent to this, the dynamics hypothesis is created. Formulation of simulation models constitutes the third step, followed by testing of the simulation model. The design and evaluation of policies represents the penultimate step. The current representation of the system feedback structure is in the form of causal loop diagram, which is utilised to illustrate the interaction and correlation between variables in the model. Positive (+) and negative (-) arrows are employed in the model to indicate causal links. The causal loop diagram model, is usually created to investigate the relationships (Forrester & Albin1997: Sterman, 2000: Maani & Cavana, 2007).

It is significant to mention that system dynamic simulation is founded on three major principles or blocks, namely, stocks, flows and feedback loops. This stock portrays the state of the system and are also refers to as level variables. While flows variables are rates of change that determine the speed at which flows into or out of a stock variable (Martins et al., 2023). Mathematically, stocks are integrations, representing the change in a system over time, while Flows alter the quantity of stocks (Radzicki, 2021, Nakaji, 2006). Flows determine the statements that signify the degree to which a stock is governed. Furthermore, flows are rates or derivatives of both concrete and abstract entities measured per unit time. Thus, the three quantities, stocks, flows, and feedback loops characterise the most fundamental accuracy of the model systems (Shari, & Moumouni, 2020). Shari and Moumouni further posited that the inflow of resources into the stock was represented as the rate of change of the stock. The stock itself, being the cumulative sum of the net flows added to the initial stock value, was denoted as a level variable. Similarly, the inflow refers to the value of resources entering the stock at any given time (t) within the time interval from the initial time to the current time (t). The stock is expressed as an integral equation, as depicted in the equation below.

$$Stock(t) = \int_{to}^{t} [inflow(s) - outflow(s) + stock(t_o)] \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

The net flow is therefore the derivative of the total stock with respect to time. This is defined as a differential equation represented in equation (2).

$$\frac{d(stock)}{d_t} = inflow(t) - outflow(t) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

(Shari, & Moumouni, 2020)

Implementing the Model (Stock-Flow diagram)

The use of Vensim special purposed software together with R software for dynamic system simulation to effectively execute the system dynamic model that is based on defined stocks, flows, feedback loops, equations, and stochastic elements. In particular, specific variables and parameters in the macroeconomic context that display stochastic properties (behaviour) or uncertainty are taken-into-account. The traditional dynamic model according to Sterman, (2000) is given by

$$\frac{d_{x_t}}{d_t} = f(x_t), \quad where, y_t = g(x_t)$$

Where x_t is the vector of state variables or stocks, y_t denotes a vector of measurement, both at time t. The introduction of measurements y_t allows for modeling of state variables that cannot be observed directly. The vector functions $f\ (\cdot)$ and $g(\cdot)$ are considered known at this stage. Note that the bulk of the system dynamics modeling work is hidden here in specification of the flow vector $f\ (\cdot)$ (Kulhavy**,** 2007)

$$\frac{d_{x_t}}{d_t} = f(x_t, u_t),$$
$$y_t = g(x_t, u_t)$$

Adding an unknow parameter, the functions $f\,(\cdot)$ and $g(\cdot)$ are not known precisely. The uncertainty about their exact forms can be expressed through a vector of unknown parameter θ.

$$\frac{d_{x_t}}{d_t} = f(x_t, u_t, \theta),$$
$$y_t = g(x_t, u_t, \theta)$$

the stochastic behavior can be modeled easily through introduction of vectors of random variables w_t and v_t into the functions $f\,(\cdot)$ and $g(\cdot)$, respectively. As a result, we obtain

$$\tau_s^{-1}(x_{t+1} - x_t) = f(x_t, u_t, w_t)$$
$$y_t = g(x_t, u_t, v_t),$$

Table 1: Summary of Relevant Articles

S/N	Authors Years	Aim and Methodology	Conclusion
1	Lawler, K., Vlasova, T., & Moscardini, A., (2019)	The paper promotes the use of system dynamics in macroeconomics to better understand problems and obtain meaningful solutions.	In this article, the authors argue that economic science in particular the sub-field of macroeconomics needed a profound reset and upgrade and that it should use the SD and cybernetic tools that are now available.
2	Sovilj, et al., (2021)	The paper develops a complete national economy model which can then be used for to evaluate economy-wide effects of the particular economic policy.	In this article, the authors evaluate a national economic model using a system dynamics approach, using a set of macroeconomic data for a transition economy to validate the model behavior in the past, and then simulate the future paths of key macroeconomic variables.
3	Kurennoy & Golembiovsky (2021	The paper discusses the use of system dynamics to assess the probability of company default and its relationship with macroeconomic factors.	A comparative analysis of the obtained results and data from Moody's and Fitch demonstrates the closeness of the probability of company defaults obtained by simulation and corresponding estimates of rating agencies, which makes it possible to conclude that the considered approach is acceptable for estimating the probabilities of default of a borrower.
4	Sovilj, et al., (2023)	Use system dynamic approach to build a large-scale national economic model.	This paper is focused on the modelling of the national economic system, using the system dynamics approach and the practical application of the model calibrated on the real historical data. The research identified the advantages and possible further practical applications of the model in forecasting paths of GDP, investment, consumption, government expenditure, inventory, interest rates, inflation, fiscal deficit, public debt,

5	Scrieciu, et al., (2021)	The research explores the commonalities and differences between complexity economics and systems thinking, arguing for a hybrid approach.	The authors argue for a hybrid approach, in that agent-based complexity perspectives in economics could more closely connect to two main systems thinking attributes: a macroscopic approach to analytically capturing the complex dynamics of systems, and an inter-subjective interpretivist dimension, when investigating complex social-economic order.
6	Hryhoriev, (2021)	The article uses system dynamic modeling and simulation to find a fixed point in the motion of sovereign debt towards equilibrium and change perceptions about sovereign debt.	In this article, a system dynamic modelling of sovereign debt using the path dependence concept is presented. But, the main purpose of this part of the analysis was to show the more complicated oscillated behaviour of the system and the multiplicity of possible equilibrium points.
7	Lindeman (2023)	Applied agent-based and system dynamics modeling to analysed the flow in the values of an economic system.	System dynamics models, on the other hand, capture the stock and flow behaviour of the system, allowing for the identification of critical steps and bottlenecks

Discussion of Findings

From the in-depth review of this methodology, the systematics review provides a comprehensive and insightful overview of the role of system dynamics modeling in understanding and improving the studies of macroeconomic variables and policies. Several reviewed-on system dynamics modelling on the economics of other countries highlights its application on various economic aspects, such as inflation, and interest rates (Sovilj et al., 2021). The authors developed a complete national economic model to evaluate economic-wide effects of economic policies. Kurennoy & Golembiovsky (2021) assessed company bankruptcy using combined approach of multivariate ARIMA-GARCH and system dynamic models. Lawler et al. (2019) promoted the use of using system dynamics in macroeconomics to better understand complex and to offer meaningful solutions to economic problems. Scrieciu et al. (2021) explored the link between complexity in economics and system thinking, suggesting a hybrid approach to economic modelling. Hryhoriev (2021) models sovereign debts using system dynamics to identify equilibrium points. Lindeman, (2023) combines agent-based and system dynamics modelling for a comprehensive economic analysis. This review highlights the growing acceptance and wide application of system dynamics modelling, especially in understanding and enhancing macroeconomic variables. The reviewed emphasize the importance of feedback loop, understanding interaction between elements, and the need for a paradigm shift toward embracing and utilising system dynamics for robust policy analysis and forecasting of economic components on the Nigerian economy. This will paper contributes body of knowledge on the application of system dynamics to complex economic system and potential for Nigeria economic in particular.

The reviewed illuminated the widespread use of system dynamics modelling in macroeconomic analysis. The finding emphases the versatility of the methodology, its ability to provide holistic insights and implications for policy formulations. The study also pointed to areas for further research and methodology refinement, underscoring the importance of continues innovation in understanding and managing the complexity of macroeconomics variables within the Nigerian context.

Conclusion

The research problem addressed in this systematics review is the need to improve the accuracy of macroeconomic forecasting and policy analysis by integrating system dynamics modelling to macroeconomics variables analysis in the Nigerian context. System dynamics modelling can improve and add a new useful perspective macroeconomics forecasting and policy analysis in Nigeria, providing a more realistic dynamics of how economic variables are related (Cavana, *et al*., 2021). The use of system dynamics (SD) simulations provides comprehensive insight, visualization and analysis of complex system with dynamic feedback, model dynamic behaviour, and interaction between interrelated variables, especially macroeconomic factors, easily using scenarios or system change. System dynamics confers an advantage in studying complex system using diagrams and simulation models, as observed by Aprillya and Suryani (2023). The application of system dynamics method in simulation can effectively depict the interaction among the variables of interest, namely the interest rate, exchange rate, unemployment rate, inflationary rate and GDP to determine economic growth and development. Through this approach, various scenarios can be evaluated, and quantified results can be obtained to formulate a viable policy integration into the system. The study provides a comprehensive and insightful overview of the role of system dynamics in understanding and improving macroeconomics policies in Nigeria.

Suugestions for further studies

The systematic review identifies research gaps that indicate promising future directions in the study of national economic in Nigeria using this approach. There are limited studies specifically focused on the Nigerian economy context, suggesting opportunities for further empirical investigations. More so, there is a potential for the advancement of the application of a hybrid model that integrate system dynamics with other methodologies possessing similar properties. This integration would provide more comprehensive insight into the forecast and policy analysis of macroeconomic variables in Nigeria.

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