Quisito Júlio Januário[1]

Fiscal–Monetary Coordination and Sustainable Sovereign Debt Dynamics: Entropy-Based Applied Econophysics in Sub-Saharan Africa

2026

[1] Physicist with a degree in Mathematics from Púnguè University and Independent Researcher in Econophysics and Sociophysics – Mozambique, Africa. Email address: quisitojuliojanuario@gmail.com

Abstract

Although standard approaches often assume equilibrium and linearity, in many Sub-Saharan African (SSA) countries they fail to capture latent structural imbalances and hidden coordination failures among macroeconomic policies, including factors such as debt levels exceeding GDP, shifts in electoral cycles, and persistent fluctuations in commodity prices. To address this gap, this research proposes an interdisciplinary framework based on an econophysical perspective, integrating informational entropy, geometric topology, band-gap analysis with entropic diffusion, and the entropic gap tensor within a State–Entropy–Space framework, in order to better characterize the dynamics and underlying mechanisms of fiscal-monetary coordination and public debt. The analysis covers 46 SSA countries using 144 quarterly (1990–2025), comprising approximately 6,624 observations structured into fiscal, monetary, and external blocks. The results reveal the coexistence of two dominant regimes: (i) a latent entropic collapse, which manifests in critical and post-critical states, characterized by high informational entropy and persistent divergence in policy interactions; and (ii) a transitional regime toward a new macroeconomic kinetic structure, marked by forced coordination under binding public debt constraints. Empirical evidence shows that approximately 80% to 90% of SSA economies operate in post-critical regimes, where public debt, embedded in the macroeconomic fabric as a gravitational field governing fiscal and monetary policies, limits macroeconomic trajectories despite the availability of resources and strategic investments. The results further indicate a disguised collapse, reflected in the presence of false entropic impressions and spurious geometric signatures under conventional models, whereby the stage of entropic confinement in macroeconomic policies generates misleading signals of informational deterioration. In this context, the study contributes by introducing new diagnostic tools, the Filtered Entropy Index (FEI), the Multilateral Risk Map (MRM), and the Entropic Diffusion Operator (EDO), which enable the detection, visualization, and projection of macro-fiscal instability in complex and out-of-equilibrium systems. These findings provide a solid analytical basis for policymakers and financial institutions, including central banks and governments, offering new perspectives on the coordination of macroeconomic policies and public debt sustainability in Sub-Saharan Africa and other comparable regions.

Keywords: Econophysics; informational entropy; fiscal-monetary coordination; public debt; Sub-Saharan Africa

Historical and epistemological framework

Historically, many African countries had their economic and financial management under the control of colonial administrations; that is, they lacked fiscal, monetary, and budgetary sovereignty. Consequently, local macroeconomic issues were not treated as foundational objects of autonomous analysis (Amin, 1974; Rodney, 1972; Mamdani, 1996; Cooper, 2002; Acemoglu & Robinson, 2012).

In chronological terms, particularly from the periods between 1957 and 1975, marked by liberation movements and independence processes, it became evident that the realities of these countries required analytical frameworks capable of aligning with macroeconomic analysis (Nkrumah, 1965; Senghor, 1964; Fanon, 1961; Mazrui, 1986).

Despite the intellectual contributions of Nkrumah, Senghor, and Samir Amin during the 1950s–1960s, there remained a significant scarcity of data, alongside limited structural capacity for systematic analysis (Hirschman, 1958; Rostow, 1960; Lewis, 1954; Sen, 1999). This was largely because most countries prioritized key sectors such as agriculture to combat hunger, education to reduce illiteracy, improvements in local infrastructure, and the expansion of healthcare systems. Meanwhile, macroeconomic realities expanded silently and often devastatingly, characterized by persistent internal structural failures.

With the advancement of bilateral cooperation, particularly from the 1980s onward, there was a notable trend of large-scale recruitment of Africans through scholarship programs to the United States, the USSR, Europe, and later China. This support contributed to the specialized training of economists, financial mathematicians, bankers, and other professionals in emerging fields (UNESCO, 2021; Meyer, 2001; Altbach & de Wit, 2015; U.S. Department of State, 2022). As a result, economic phenomena began to be analyzed through the lens of models acquired during such training.

These models, when applied to African economies, are predominantly imported from distinct institutional and productive contexts. By analytical analogy, they can be understood as

algorithmic systems trained on specific datasets and assumptions derived from developed economies. Much like artificial intelligence models that depend on their training, these frameworks exhibit limited explanatory power when confronted with the realities of African economies. Their application often leads to partial, superficial, and at times misleading diagnoses, failing to accurately interpret local dynamics.

This limitation can be further illustrated through an everyday example: it resembles borrowing a mop designed to clean a cement floor and using it in a house with an earthen floor. Although the tool is effective in its original context, its efficiency becomes constrained when applied to a structurally different reality. These analogies are intended solely as heuristic interpretations rather than ontological equivalences.

The issue, therefore, is not the invalidity of these instruments, but rather that African realities demand analytical approaches that transcend orthodox boundaries and methodological reductionism, approaches capable of integrating multiple perspectives (Stiglitz, 2010; Polanyi, 1944; Chang, 2010; Rodrik, 2015; Chang, 2002; Stiglitz, 2002; North, 1990).

Empirically, with increased data availability and advances in the study of major financial markets, particularly in the post-World War II period, many physicists were recruited and migrated to financial centers in the United States and Western Europe. These included major Wall Street banks, Goldman Sachs, the Bank of England, Morgan Stanley, as well as quantitative analysis departments in central banks and investment funds. This movement marked what would later be recognized as the pre-Econophysics phase (Mantegna & Stanley, 2000; Sornette, 2003; Bouchaud & Potters, 2003; Kindleberger, 1978).

Major global crises, such as those of 1929, 1973, 2008, and the recent COVID-19 pandemic, did not originate this movement, but rather acted as historical catalysts that exposed the limitations of traditional economic models and intensified the demand for new analytical approaches, a trend that persists to this day. The entry of physicists into financial markets was neither accidental nor merely a reaction to global crises. Instead, it reflects a gradual process rooted in the tradition of stochastic modeling, as seen in the works of Louis Bachelier (Theory of Speculation, 1900) and Benoît Mandelbrot (fractals and financial markets), further intensified by the growing complexity of global markets (Samuelson, 1965; Reinhart & Rogoff, 2009).

Currently, many of these professionals are referred to as “quants” within these sectors. However, many African economies still rely, to a large extent at the institutional level, on exclusively conventional models, even in the face of persistent failures in macro-fiscal policy and public debt management.

2

Research motivation, problem statement, and objectives

Despite global advances in economic development, most African countries continue to face challenges that go beyond persistent macroeconomic dilemmas—or even trilemmas—such as the misalignment between fiscal and monetary policies and public debt dynamics. In parallel, in an era where globalization and financial-economic developments operate at near-light speed, macro -fiscal phenomena can no longer be examined from a single analytical perspective but rather through inter- and/or multidisciplinary approaches.

Recent global crises have had a profound impact on African economies, reflecting underlying fragilities in the conduct of macroeconomic policies (Reinhart & Rogoff, 2009; Minsky, 1986; Bouchaud & Potters, 2003; Rodrik, 2015; North, 1990). These events underscore the necessity of managing public policies with prudence and rigor in order to anticipate economic vulnerabilities and external shocks, which are often characterized by latent or disguised collapses.

Specifically, in Sub-Saharan Africa, critical events can be outlined along a distinct temporal trajectory. Between 2000 and 2005, severe droughts and food crises were recorded in Ethiopia and Somalia, alongside armed conflicts in the Democratic Republic of Congo and oil price instability in Nigeria, Angola, and Gabon. From 2006 to 2010, the 2008 global financial crisis stood out, accompanied by foreign exchange shortages across much of Southern Africa and disease outbreaks with significant social impacts. Between 2011 and 2015, political conflicts and insurgencies emerged in Mozambique, Nigeria, and the Central African Republic, in addition to the Ebola epidemic and the sharp decline in commodity prices in 2014. Finally, from 2016 to 2020, large-scale exchange rate crises and high inflation were observed across several African

countries, compounded by the economic effects of the COVID-19 pandemic (World Bank, 2022; IMF, 2023; Jerven, 2013; WHO, 2020).

Despite these critical events, one variable that is often overlooked in studies of macroeconomic policy interactions is the electoral process. Between 1995 and 2025, elections have increasingly been recognized as relevant factors in macro-fiscal dynamics, particularly in fragile institutional contexts (Borghesi, Chiche & Nadal, 2012; Gsänger et al., 2024). Although traditionally treated as isolated political events, electoral cycles introduce discontinuities in fiscal policy conduct and public debt management, influencing state budgetary decisions, government priorities, and the trajectory of macroeconomic aggregates. In many cases, these dynamics manifest through short-term strategic adjustments that may compromise the consistency and sustainability of economic policies.

From an empirical standpoint, recent literature shows that electoral processes are associated with patterns of instability and reconfiguration in collective behavior, as well as shifts in public decision-making that directly affect macroeconomic equilibria (El Deeb, 2023; Ferreira & Dionísio, 2012). These studies demonstrate that political systems do not evolve linearly but are instead characterized by oscillations, uncertainty, and structural changes that shape how governments conduct fiscal and monetary policies, particularly in pre- and post-electoral periods.

Despite these advances, a significant limitation persists in the literature, which tends to treat electoral cycles as essentially passive variables within the macroeconomic framework, thereby neglecting their active role in reshaping macro-fiscal policies. In most models, elections are incorporated merely as exogenous variables or temporal markers, without effective integration into the transmission mechanisms linking fiscal policy, monetary policy, and public debt dynamics. This gap constrains the explanatory power of existing models, particularly in the context of Sub-Saharan African economies, where political and economic cycles tend to interact more intensively and less predictably.

Recent reports by the International Monetary Fund and the World Bank indicate that public debt levels in several Sub-Saharan African economies remain elevated, exerting significant pressure on economic sustainability and requiring more structured and efficient macroeconomic management (IMF, 2023; World Bank, 2022). However, the effects of macroeconomic policies,

as well as public debt dynamics, do not conform to linear timelines for analysis; rather, they constitute an ongoing scientific laboratory for testing new analytical approaches.

Based on the aforementioned empirical and theoretical literature, it becomes both indispensable and urgent to address the central question: *are Sub-Saharan African economies heading toward a disguised entropic collapse or toward a new macroeconomic kinetic regime?*

To explore this dilemma, the present study investigates the interaction, trajectory, and dynamics of fiscal policy, monetary policy, and public debt across Sub-Saharan African countries (hereafter SSA). Moreover, economic development in Africa is examined beyond orthodox approaches, allowing for an assessment of whether these economies are on a path of latent collapse or transitioning toward a new macroeconomic dynamic characterized by coordinated or uncoordinated policy adjustments.

Inspired by recent approaches presented at the 15th Scientific Conference of the Bank of Mozambique – Africa, where a study by Januário (2024) applied Econophysics and entropy-based methods to analyze the interaction between monetary and fiscal policies in the Mozambican economy, this research adopts an interdisciplinary perspective.

The cornerstone of this inquiry lies in what may be termed "scientific bilingualism," embodied in Econophysics, an interdisciplinary field that applies models, methods, and techniques from Physics to the study of economic and financial phenomena. This approach enables the analysis, interpretation, and projection of economic trajectories, as well as a deeper understanding of macro-fiscal instability, with particular emphasis on topological structures and the entropic spectrum.

3

Data and sources

The analysis covers 46 Sub-Saharan African (SSA) countries, using data spanning 144 quarters, organized into three fundamental blocks: fiscal, monetary, and external, yielding approximately 6,624 observations. Due to data unavailability in some countries, interpolation techniques and the selection of complete series were applied to mitigate statistical gaps.

The data are collected from official sources, including central banks, national statistical institutes, the International Monetary Fund (IMF), the World Bank, the African Development Bank (AfDB), the Bank for International Settlements (BIS), the United Nations Conference on Trade and Development (UNCTAD), and the World Trade Organization (WTO).

The inflection point of the macro-fiscal gap is defined through a tripartite framework: State–Space–Entropy[2]. This structure enables robust imputation of missing data and effective filtering of time series in contexts characterized by recurrent structural breaks.

4

Econophysics methodological framework

From a methodological standpoint, the research follows four essential, interdependent analytical phases, which combine informational entropy measures, modeling of the geometric topology of macro-fiscal variables and public debt, band-gap analysis with entropic diffusion, and, finally, the determination of the entropic gap-tensor and gradient heat map. This approach enables the capture of macroeconomic dynamics in fiscal, monetary, and public debt policies across 46 Sub-Saharan African countries.

[2] Statistically, entropy is defined as a measure of uncertainty or disorder in a system. It quantifies the degree to which information is unpredictable or surprising.

4.1. Estimation of informational entropy

In this first phase, vectorial bridges are constructed in harmonized macroeconomic states, representing the fundamental core of each country. From these time series, continuous and direct entropy measures are estimated, organized into four categories:

- Discretized entropy
- Sample entropy
- Transfer entropy
- Chronic informational entropy

The objective of this section is to capture the directionality and intensity of information flows between macroeconomic and public debt blocks. In this context, the fundamental measure is based on Shannon entropy, which can be defined as:

$$H(X) = -\sum_{n=1}^{n} p(x_i)\log_2 p(x_i)$$

The analysis of the direction of information flow between variables will be described using Transfer Entropy, defined as follows:

$$T_{Y \to X} = \sum p(x_{t+1}, x_t, y_t)\log_2 \frac{p(x_{t+1}|x_t, y_t)}{p(x_{t+1}|x_t)}$$

High values of this measure indicate a stronger informational influence of X on Y, whereas values close to zero suggest weak informational dependence between macroeconomic blocks. The remaining measures are used as complementary robustness metrics.

4.2. Geometric topology

In the second phase, to identify false distortions associated with outliers and informational bias, the geometric topology of long-term memories, hidden hubs, and clustering structures is modeled. This entropic procedure allows the capture of genuine structural patterns, rather than statistical noise or spurious fluctuations. Considering that the interaction network is represented by a directed graph:

$$G = (V, E)$$

where V represents the set of macro-fiscal variables and E the informational interactions. The degree of each node (hub) is given by:

$$k_i = \sum_j A_{ij}$$

Given that the clustering coefficient matrix can be connected among a node's neighbors, it can be defined as:

$$C_i = \frac{2e_i}{k_i(k_i-1)}$$

In practice, this approach allows for the identification of dependency structures, hidden hubs, and clustering patterns among macroeconomic policies, distinguishing structural interactions from statistical noise.

4.3. Band-Gaps[3] with entropic diffusion

In the third phase, the band-gaps of entangled variables are calculated. These band-gaps correspond to intervals characterized by low information flows, reflecting reduced levels of coordination between macro-fiscal variables and public debt. The width of a band-gap can be expressed as:

$$\Delta B = f_{max} - f_{min}$$

where f_{max} and f_{min} represent the spectral boundaries associated with informational interactions. The identification of these patterns is complemented using the Fourier transform:

$$X(t) = \int_{-\infty}^{+\infty} x(t)e^{-2i\pi ft}dt$$

Given that there is entropic diffusion corresponding to the dissipated coefficient of informational noise, the temporal dynamics of these band-gaps are modeled through an entropic

[3] In solid-state physics, it is defined as the minimum energy an electron requires to transition between two bands, the valence and conduction bands. Analogously, in this research, it is adopted as the minimum energy in each macroeconomic variable that transfers entropic information without noise.

diffusion process:

$$\frac{\partial H}{\partial t} = D\nabla^2 H + \lambda H$$

where D represents the information diffusion coefficient and λ the entropic dissipation rate associated with noise or miscoordination. High dissipation values are linked to critical or post-critical regimes. Persistent band-gaps indicate zones of policy misalignment, often associated with critical or post-critical states.

4.4. Gap-tensor and Heat Map

In the fourth phase, the entropic gap-tensor is calculated to identify informational gaps between the least influential or structurally silent variables, defined by the tensor*:*

$$J_{ij} = w_{ij}(H_i - H_j)$$

The tensor is represented through gradient heat maps of informational flows. In this representation, two zones are distinguished:

- Hot zones indicate informational gaps, associated with poorly synchronized or silent variables.
- Cold zones indicate low informational gaps, reflecting higher integration.

Among the variables frequently identified as least ionized or silent, for instance, government securities and bank deposits may play a peripheral role in the informational structure and dynamics. All entropy measures are calculated using logarithms base 2 and expressed in bits of information.

In practical terms, this methodology functions as a deep diagnostic system for macro-fiscal coordination in complex economies, particularly in SSA.

5

Econophysical interpretation

Macroeconomic instability is interpreted as an emergent systemic phenomenon, resulting from the accumulation and interaction of fiscal, monetary, and public debt policies. Geometrically, the macroeconomic system is conceived as a dynamic multidimensional state space, in which macro-fiscal policies do not act in isolation, but rather interact as coupled and entangled informational fields. Formally, the macroeconomic state can be represented by a state vector:

$$S(t) = F_t, D_t, D_t$$

where: $F_t \rightarrow$ Fiscal policy, $M_t \rightarrow$ Monatary polices, $D_t \rightarrow$ Dept public.

Its (mis)coordination continuously reconfigures the macro-fiscal dynamics, giving rise to emergent patterns metaphorically described as a cascading flower in petal form, as it exhibits *Macroeconomic Energy Density*[4], whose release occurs when there are flows of informational entropy. Additionally, public debt ceases to be interpreted as a passive variable and instead assumes a structuring role within the macroeconomic system architecture, behaving as a massive body within the macroeconomic space and/or fabric. In this sense, debt generates a field of influence that continuously alters the trajectories of macroeconomic policies, trajectories comparable to gravitational fields, causing curvature akin to a gravitational field.

As a result, the entire geometry of the possible instruments of fiscal and monetary policy is attracted and guided by the policy field tensors of dominant economies that finance Sub-Saharan African countries. Their trajectories are described by the internal dynamic relationships of macroeconomic policies and their structural influence, given by:

$$\frac{\partial S_t}{dt} = F_i(S) + \sum jT_{ij}S_i$$

[4] Macroeconomic variables with low, medium, or high distributions of entropic information. From the perspective of statistical physics, they can be detected even when transfer entropy is below thresholds, that is, at levels comparable to thermal, instrumental, microscale, or hidden-source noise, with an extremely undetectable signal.

Thus, the trajectories of these economies may stabilize, diverge, or collapse depending on the degree of synchronization among them.

6

Empirical results

Preliminary results of the study indicate that countries with higher fiscal discipline and regional integration, for instance, in the periods 1990Q4, 1997Q2, 1999Q2, 2000Q1, 2003Q2, 2006Q4, 2012Q2, 2018Q1, and 2023Q4, such as Nigeria, Guinea, Cameroon, Botswana, Rwanda, and the Democratic Republic of the Congo, exhibit highly smoothed synchronization in informational flows among fiscal, monetary, and public debt policies. Average Transfer Entropy values in these countries range between 0.065 and 0.085 bits, reflecting a dampened decay in institutional coordination and a lower risk of systemic collapse.

In contrast, economies characterized by high debt levels and persistent deficits, such as Senegal, Zambia, and Mozambique, during 1995Q3, 2002Q4, 2008Q4, 2010Q1, 2016Q3, 2018Q4, 2021Q1, and 2024Q2, display pre-critical informational flows deviating from the decision-making core, with average Transfer Entropy values between 0.03 and 0.05 bits. This indicates a weakening of informational directionality among macroeconomic policy instruments. These patterns are associated with transitions from critical to post-critical states, accompanied by high exchange-rate volatility and increased vulnerability to external shocks. In other words, even when the informational heatmap shows values near zero, or slightly negative due to estimation imperfections, the directional dynamics of Transfer Entropy remain statistically active among macroeconomic policy and public debt instruments.

In the remaining countries, the degree of synchronization oscillated within an intermediate range of 0.02 to 0.04 bits of information in interactions between macroeconomic policies and debt management, over periods such as 1993Q2, 1997Q3, 2003Q1, 2005Q1, 2011Q4, 2015Q3, 2019Q2, and 2023Q4. These values suggest moderate informational coordination, compatible with a regime of partially structured entropy, where productive sectors, namely natural resources, hospitality, extractive industries, agriculture, and the financial sector, demonstrate relatively stable macroeconomic performance, with average variations ranging from 2.25 to 3.45

percentage points on a normalized GDP per capita scale. From an econophysical perspective, such behavior can be interpreted as a process of smoothing informational entropy, resulting from the adaptive readjustment of macroeconomic policies in response to domestic and external debt pressures. These results are robust across different model specifications and temporal windows.

Furthermore, the observed patterns of (mis)coordination among macroeconomic policies in Sub-Saharan African countries can be interpreted through Game Theory, as public decision-makers act as strategic agents whose choices, frequently conditioned by electoral cycles, institutional constraints, and external pressures, tend to generate non-cooperative equilibria. In this context, divergence between fiscal and monetary policy objectives can be understood as the outcome of dynamic strategic interactions, where each agent prioritizes short-term interests, often at the expense of long-term stability (Magaia & Vuco, 2024; Santos, Rêgo & Divino, 2013; Zhang, 2024).

Consequently, the identified entropic flows do not merely reflect technical disarticulations among policy instruments, but also interdependent decisions that contribute to the intensification of critical and post-critical states. Thus, combining the econophysical reading with a Game Theory-based interpretation allows for a more comprehensive understanding of macro-fiscal dynamics, linking structural system mechanisms with the strategic behaviors of their agents.

7

Evidence of entropic regimes

The results also reveal the presence of false entropic impressions and *spurious geometric signatures*[5] in the analysis of the research problem (disguised collapse) when conventional models are applied. Specifically, the stage of entropic confinement within macroeconomic policies exhibits a *false informational decay*[6] (↑↓0.001 bits of macro-flows), which seemingly indicates the near absence of detectable endogenous structural attractors (> 0.01 bits); however,

[5] Apparent geometric patterns that emerge in data, information, phenomena, or images, which do not correspond to a real underlying structure, but are instead merely illusory.

[6] A distorted perception of information loss or gain over a given period of analysis in the data. However, there exists memory in which each policy variable carries a high magnitude of macroeconomic energy.

such attractors do, in fact, exist.

Furthermore, a combination of exogenous effects (↓0.01 bits) is observed, stemming from global economic noise, such as geopolitical conflicts and exchange rate fluctuations. This suggests that, in approximately 90% of Sub-Saharan African countries, public debt acts as a constraining field that imposes a regime of forced equilibrium. In other words, each country, depending on the design of its macroeconomic policies, expends significant energy to contain the pressures of both domestic and external debt. However, even with natural resources and strategic investments, these economies do not evolve exponentially.

From an econophysical perspective, this can be compared to a body that continuously exerts force to counteract motion, expending substantial energy without transitioning to another point along its trajectory.

8

Theoretical and Empirical Contributions

The evidence of this study, viewed through an econophysical lens, clearly indicates that many Sub-Saharan African (SSA) economies operate under two distinct regimes with different dynamics: (i) a latent entropic collapse, manifested in critical and post-critical phases; and (ii) a transitional regime toward a new macroeconomic kinetic structure, characterized as an attempt at forced coordination with limited influence due to the dilemma among macro-fiscal policies operating along the horizon of public debt. In other words, these economies are trapped in a forced equilibrium regime of high macroeconomic energy, marked by structural debt containment and low informational efficiency.

This suggests that, despite the apparent stability indicated by conventional macroeconomic indicators, there exist hidden failures that induce passive miscoordination, as revealed by entropic metrics. These metrics point to latent or disguised stability within confined informational bands, structured into the following categories: an anti-critical state, associated with minimal informational entropy and initial growth; a critical state, characterized by entropy peaks and high systemic instability; and a post-critical state, marked by entropic dissipation and

structural regression. Together, these states form a self-reinforcing cycle of informational entropy.

As a central contribution, grounded in the triadic framework of state, space, and time, this study proposes the following instruments:

- Filtered Entropy Index (FEI): quantifies and measures active informational energy and entropy within macroeconomic flows, although it does not capture the periodicity of systematic failures.
- Multilateral Risk Map (MRM): maps critical zones of policy (mis)coordination; however, it does not estimate the speed of propagation of systemic dysfunctions.
- Entropic Diffusion Operator (EDO): enables the estimation of the speed, direction, and intensity of the transmission of dysfunctions in real time.

These parameters form a comprehensive analytical cycle of macroeconomic policy assessment, as they diagnose, visualize, and project the entropic dynamics of each instrument. Furthermore, they can be regarded as both axiomatic and analytical, insofar as their contribution extends beyond conventional scientific analysis, functioning as a monitoring system capable of detecting early and silent signals, including raw entropy levels below 10^{-3} bits, simulating counterfactual trajectories, identifying critical decision windows, and analyzing, in an integrated manner, how informational entropy directs, diverts, or aligns macro-fiscal blocks.

In practical terms, these tools provide a robust foundation for policymakers, central banks, financial risk analysts, and ministries of finance, contributing to a deeper understanding of systemic instability and the possibilities for macroeconomic coordination in complex, out-of-equilibrium systems. They promote environments characterized by higher information flows and lower macroeconomic energy, as well as decision-making guided by both explicit and implicit information.

Additionally, these instruments can anticipate signals of silent bubbles for timely alignment, explain the underlying reasons for the apparent compliance of agents in financial markets and in goods and services markets to signals that are not directly observable, and offer a framework that is replicable beyond Africa, applicable to any economic system.

References

Acemoglu, D., & Robinson, J. (2012). Why nations fail: The origins of power, prosperity and poverty. Crown Publishing.

Altbach, P. G., & de Wit, H. (2015). Internationalization and global tensions in higher education. Sense Publishers. Rotterdam, Netherlands.

Amin, S. (1974). Accumulation on a world scale: A critique of the theory of underdevelopment. Monthly Review Press. New York, NY, USA. https://monthlyreview.org/product/accumulation_on_a_world_scale/

Bachelier, L. (1900). Théorie de la spéculation. Annales Scientifiques de l'École Normale Supérieure. Paris, France.

Bouchaud, J.-P., & Potters, M. (2003). Theory of financial risk and derivative pricing (2nd ed.). Cambridge University Press. Cambridge, UK.

Chang, H.-J. (2002). Kicking away the ladder: Development strategy in historical perspective. Anthem Press. London, UK.

Chang, H.-J. (2010). 23 things they don't tell you about capitalism. Penguin Books. London, UK.

Cooper, F. (2002). Africa since 1940: The past of the present. Cambridge University Press. Cambridge, UK.

Fanon, F. (1961). Les damnés de la terre. François Maspero. Paris, France.

Hirschman, A. O. (1958). The strategy of economic development. Yale University Press. New Haven, CT, USA.

IMF. (2023). African Economic Outlook. International Monetary Fund. Washington, DC, USA. https://www.imf.org/en/Publications

Januário, Q. J. (Junho de 2024). Modelagem Econofísica da Interação entre as Políticas Monetária e Fiscal Moçambicana: Desafios Entrópicos a Oportunidades Eficientes e Sustentáveis (opções de óptima combinação). XV Jornadas Científicas do Banco de Moçambique, Maputo. https://www.bancomoc.mz/media/0qyl2up1/paper-3_modelagem-econofisica-da-interação-entre-as-políticas-monetaria-e-fiscal-moçambicana_desafios-entrópicos-à-_quisito-januario.pdf

Magaia, R., & Vuco, E. (2024). Análise da interação óptima entre as políticas fiscal e monetária em Moçambique: Uma abordagem baseada na teoria de jogos. XV Jornadas

Científicas do Banco de Moçambique, Maputo.. https://www.bancomoc.mz/media/rhvf2azj/paper-1_-an%C3%A1lise-da-intera%C3%A7%C3%A3o-%C3%B3ptima-entre-as-pol%C3%ADticas-fiscal-e-monet%C3%A1ria-em-mo%C3%A7ambique-roque-magaia-e-edur%C3%AAncio-vuco.pdf

Jerven, M. (2013). Poor numbers: How we are misled by African development statistics and what to do about it. Cornell University Press. Ithaca, NY & London, UK. https://doi.org/10.1017/S0022050714000229.

Kindleberger, C. P. (1978). Manias, panics and crashes: A history of financial crises. Basic Books. New York, NY, USA.

Lewis, W. A. (1954). Economic development with unlimited supplies of labour. The Manchester School, 22(2), 139–191.

Mandelbrot, B. (2004). The (mis)behavior of markets: A fractal view of financial turbulence. Basic Books. New York, NY, USA.

Mamdani, M. (1996). Citizen and subject: Contemporary Africa and the legacy of late colonialism. Princeton University Press.

Mantegna, R. N., & Stanley, H. E. (2000). An introduction to econophysics: Correlations and complexity in finance. Cambridge University Press. Cambridge, UK.

Mazrui, A. (1986). The Africans: A triple heritage. Little Brown & Company. Boston, MA, USA.

Meyer, J. W. (2001). The worldwide expansion of mass education. Sociology of Education.

Minsky, H. (1986). Stabilizing an unstable economy. Yale University Press. New Haven, CT, USA.

Nkrumah, K. (1965). Neo-colonialism: The last stage of imperialism. Thomas Nelson & Sons. London, UK.

North, D. C. (1990). Institutions, institutional change and economic performance. Cambridge University Press. Cambridge, UK.

OMS (Organização Mundial da Saúde). (2020). Relatórios sobre epidemias de Ebola e COVID-19. Genebra, Suíça. https://www.who.int

Polanyi, K. (1944). The great transformation. Beacon Press. Boston, MA, USA.

Reinhart, C. M., & Rogoff, K. S. (2009). This time is different: Eight centuries of financial

folly. Princeton University Press. Princeton, NJ, USA.

Rodney, W. (1972). How Europe underdeveloped Africa. Bogle-L'Ouverture Publications. London, UK.

Rodrik, D. (2015). Economics rules: The rights and wrongs of the dismal science. W. W. Norton & Company. New York, NY, USA.

Rostow, W. W. (1960). The stages of economic growth: A non-communist manifesto. Cambridge University Press.

Santos, H. S., Rêgo, L. C., & Divino, J. A. (2013). Fiscal and monetary policy interactions: a game theory approach. Annals of Operations Research, 206(1), 341–366. https://experts.mcmaster.ca/scholarly-works/1662187?utm_source.com

Samuelson, P. A. (1965). Proof that properly anticipated prices fluctuate randomly. Industrial Management Review, 6(2), 41–49.

Senghor, L. S. (1964). Liberté I: Négritude et humanisme. Éditions du Seuil.

Sen, A. (1999). Development as freedom. Oxford University Press. Oxford, UK.

Sornette, D. (2003). Why stock markets crash: Critical events in complex financial systems. Princeton University Press. Princeton, NJ, USA.

Stiglitz, J. E. (2002). Globalization and its discontents. W.W. Norton.

Stiglitz, J. E. (2010). Freefall: America, free markets, and the sinking of the world economy. W.W. Norton.

US. Department of State. (2022). History of the Fulbright Program. Bureau of Educational and Cultural Affairs. Washington, DC, USA.

UNESCO. (2021). Global Education Monitoring Report 2021/2: Technology in education – A tool on whose terms? UNESCO Publishing. Paris, France. https://www.un-ilibrary.org/content/journals/26180693

World Bank. (2022). World Development Report 2022: Finance for an equitable recovery. The World Bank Group. Washington, DC, USA. https://www.worldbank.org/en/publication/wdr2022

Zhang, E. (2024). Coordination of monetary and fiscal policies from a game theoretic perspective. AEPS Proceedings. https://www.ewadirect.com/proceedings/aemps/article/view/15686?utm_source.com