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Şuay Nilhan Açıkalın
Luís Tomé *Editors*

Chaos, Complexity, and Leadership 2023

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Preface

The first quarter of the twenty-first century has been a period of experiencing great challenges for humanity. In addition to the problems brought about by economic crises and protracted wars, migration movements from the Middle East to the West have forced societies to transform. In addition to these, the global COVID-19 pandemic caused us to gain experiences that are not included in the short-term memory of humanity. A new normal was defined in many areas of life, from working life to education, from the entertainment sector to health. This chaotic period we are experiencing is a harbinger of the potential problems that await us for the rest of the twenty-first century. We have not yet experienced a problem caused by artificial intelligence, nor have the possible migration movements caused by global climate change started yet. But these problems seem to be waiting at the doorstep.

These chaotic situations we are experiencing and will experience in the near future require us to make discussions on complexity, leadership, and crisis management more visible in challenging times.

Our now traditional conference brought together leading researchers on the themes of chaos, complexity, and leadership this year. The 8th International Symposium on Chaos Complexity and Leadership was held in Istanbul on 4 May 2023. The hot topics like leadership, motivation, job satisfaction and challenges of security were discussed.

This book contains discussions on the above-mentioned themes from different perspectives. Readers will find valuable content on interesting areas such as leadership types, energy security, work motivation, economics and health management, and their future implications. In this respect, once more we would like to thank Leandro from the University of Macau, José Pedro Teixeira Fernandes from the Portuguese Institute of Internacional Relations, Ribeiro and Morais from Universidade Autónoma de Lisboa, Erkan Doner and Efe Efeoglu from Adana Alparslan Türkes Science and Technology University, Kaan Batı from Hacettepe University, Aditama from YARSI University, and Godinho and Santos from Universidade Autónoma de Lisboa, Özge Gürer and Birdal Şenoğlu from Ankara University, Gamze Güven from Eskisehir Osmangazi University, Adil Kılıç from Kırıkkale University, Unozkan from Haliç University, Potas from Ankara Hacı Bayram Veli

University, Yilmaz from Ankara University, Yılmaz from Koç University, Akıllı from Istanbul Arel University, and finally Akdeniz from Disordered Systems Working Group.

Aware that our world has to learn to live with chaos, we would like to re-emphasize our belief that the chapters in this book will shed light on the future. We hope that the chapters in this book, which have the potential to inspire future academic research and intellectual discussions, will be a good guide for managing chaos, complexity, and leadership.

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Governing Complexity: Resolving the Woes at the United Nations Security Council

Francisco José B. S. Leandro

Abstract For practitioners of international relations, the challenge is to on one hand strike a balance between establishing a (more) predictable international system and attaining some consensus on the need to extend participation and to innovate, and on the other hand recognize, as complexity theory in social sciences suggests, the need to rationalize the behavior. Therefore, we need to seek mechanisms to ensure efficiency, predictability and mitigation failures of the international security system (ISS), which is not only sizable, but has immense inertia and often operates at the edge of chaos. The ISS is therefore challenging for any plural leadership to govern with adequate legitimacy, as it must deal with sovereign actors possessing two distinctive features: (1) They all have, in principle, equal sovereign and legal status, and (2) they are perceived to have different geopolitical power statuses. To further complicate the system, there is an additional third characteristic—each sovereign actor's political culture is significantly different from its peers'; some are prone to exclusion, conflict and war and are less inclined to mutual restraint and cooperation, while others may like to avert conflict (and its escalation) as well as disorder, be sympathetic to attaining mutual benefits and be willing to be accommodating, though often through playing political games that still stem from ploys to advance their own collations of interests. Consequently, the ISS as a large system can be chaotic, wherein chaos is "conceptualized as extremely complex information, rather than as an absence of order" (Hayles, 1991). To reform the ISS implies a substantial redesign of the United Nations Security Council (UNSC). In 1992, the UNGA put forward an open-ended working group to review the equity of representation on the UNSC. In 2008, recognizing the importance of this matter and the lack of apparent progress, the UNGA began intergovernmental negotiations (IGNs) revolving around equitable representation and increasing the UNSC's membership. In 2022 (GA/12435, 12 July), the UNGA adopted the Oral Decision to Continue Intergovernmental Negotiations on Security

Disclaimer: The views, thoughts, and opinions expressed in the text belong solely to the author, and not necessarily to represent the official position of any organization that the author may be associated with.

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Council Reforms, in which statements from different states revealed a scenario of division, sectarianism and fragility. These concerns have prompted this research to adopt social sciences' complexity theory to study how the ISS as a higher-level system makes global decisions in a framework of chaos. Complexity theory therefore lends "a new lens… for understanding the international system and its change, given that it fits quite well into the features of complex adaptive systems" (Tomé et. al., 2019, p. 13). This study also combines structural realism (which considers the power status of agents), post-structuralism (which considers the formation of meaning producing structures (Campbell, 2013)) and the Copenhagen School's theory on securitization. Consequently, the study will be driven by an inquiry to understand if the ISS can be (re)designed in order to ensure legitimacy and effectiveness, and to make sure if one or a few elements fail, the impact on its overall performance can still be mitigated. In this vein of reasoning, the main focus of this research is to reform the UNSC as the institution that governs the ISS, which is currently one of the most significant topics on the international agenda. This chapter is organized as follows: Sect. 1 introduces and discusses some possible takeaway from complexity theory; Sect. 2 advances a possible definition of the international order, and outlines current discussions on reforming the UNSC; Sect. 3 formulates a framework for redesigning the UNSC based on complexity theory; and Sect. 4 draws conclusions as well as offers avenues for further research.

Keywords Theory of complexity · United Nations Security Council (UNSC) reform · International security system (ISS)

1 Introduction: Close to Equilibrium and Learning from Complexity Theory

To redesign the composition of the United Nations Security Council (UNSC) and establish a new pattern of relations with the United Nations General Assembly (UNGA) is perhaps the most pressing and critical topic on the current international agenda. In addition, the five UNSC permanent members (P5)—China, France, Russia (following the termination of the Soviet Union), the United Kingdom, and the United States—are particularly vested with a responsibility to lead the transformation of the United Nations Charter in close articulation with the UNGA. What is at the center of the problem is the legitimacy of the UNSC, and its efficiency as it often faces blockage. Indeed, since 1945, new major players have emerged (such as India and Brazil), and the world has witnessed a number of colonial self-determination processes as well as dissolution of multiethnic states (such as the Soviet Union, Yugoslavia and South Sudan), leading to the creation of new sovereign states, putting the number of UNGA full membership at 193, with two observer entities, namely, Vatican City and Palestine (2023). Moreover, and probably more importantly, the role of the UNSC has become more complex, and some of its permanent members

have been directly involved in using force that has not been backed by lawful UNSC resolutions: the U.S.-led invasion of Iraq, the NATO-led intervention in Libya, the breakdown of UN diplomacy over the war in Syria, the fallout from Russia's seizure of Crimea in 2014, and the invasion of Ukraine in 2022 are among the major events undermining the UNSC's credibility, legitimacy and authority. On September 20, 2023, speaking at the UNSC, Ukrainian president Volodymyr Zelensky delivered a strident statement in which he declared: "Ukrainian soldiers are doing with their blood what the UN Security Council should do by its voting", arguing that "veto power in the hands of the aggressor is what has pushed the UN into deadlock" (New York Times, 2023), categorically linking current global security troubles to the present configuration of the UNSC. Nevertheless, all is not lost; as Patrick observes: "The health of the Security Council is poor but not yet terminal" (Patrick, 2023, p. 3). Obstacles to reforming the Council may loom large, but there is hope that a less hostile ISS can be engineered.

Currently, the ISS is in near equilibrium, but controversies have arisen as some members have overstepped their veto privilege, using that power to advance their own interest rather than as a means to safeguard peace and the principles of the UN Charter. As the UNSC itself reports, "Permanent members use the veto to defend their national interests, to uphold a tenet of their foreign policy or, in some cases, to promote a single issue of particular importance to a state. Since February 16, 1946—when the Union of Soviet Socialist Republics (USSR) cast the first veto on a draft resolution regarding the withdrawal of foreign troops from Lebanon and Syria (S/PV.23)—the veto has been recorded 293 times" (UNSC, 2020). Presently, the exercise of veto power is unmatched (i.e., highly selectively granted), unscrutinized by peers, and uncontrolled by the UNGA, the most legitimate body of the United Nations system. The veto power is an exceptional legal measure granted to particular states to prevent any bills from producing their intended legal effects, but there should also be a (tacit) recognition that those states should opt to assume such a dominant power position to protect the ISS (as opposed to advancing individual national interests). The unmatched veto power made sense in the post–WW II order, but, currently, that it has been systematically utilized to block the UNSC has diminished global perception of its legitimate use. According to the United Nations Security Council (UNSC, 2020), "The veto affects the work of the Council in ways that transcend its actual use during voting. It is not unusual for a draft resolution not to be formally tabled because of the threat of a veto by one or more permanent members. This is difficult to document: a paper trail exists only if a draft is circulated as a Council document, which in most cases occurs only when there is a reasonable expectation of adoption. On some occasions, however, the sponsor of a draft resolution may put it to the vote in the full knowledge that it will be vetoed to demonstrate symbolic support for an issue and to create a historical record of positions within the Council". To overcome this vulnerability, the solution must be to create a collective mechanism of equilibrium, but not to outright abolish that veto power.

The waning of the UNSC's credibility and the recent armed conflict and deadlock in Ukraine have combined to prompt the UNGA to reassess its role in the area of international security, and, recalling the Uniting for Peace Resolution first employed

during the Korean War, to request an emergency assembly session: on March 2, 2022, the UNGA overwhelmingly approved a resolution deploring the Russian invasion, demanding Russia's immediate withdrawal, and reaffirming Ukraine's sovereignty and territorial integrity; then, on April 26, 2022, it passed another resolution to demand that any use of the veto must be followed by a special assembly debate within ten days, and must include justification from the permanent member that has wielded it. This was not only a plea for inclusiveness and fairness, but also a demonstration of the UNGA's potential. Furthermore, these two decisions were perceived as anticipatory of the future: if the P5 members do not take lead in reforming the UNSC, as explained by the theory of complexity in social sciences, the ISS, as a complex system, will progress and evolve in such a way that, over a number of life cycles of cooperation and competition, alternative leadership outside the UNSC will emerge from the bottom up, while the UNSC itself risks undergoing a process of isolation and/or, worse, irrelevance. Large complex systems that fail to adapt tend to risk experiencing dramatic changes and fading from the global continuity, and such is, indeed, a worrying outcome for the UNSC.

The UNGA has already acknowledged that the focus of redesigning the UNSC is "the question of equitable representation on [increasing] the membership of the UNSC (…) seeking a solution that could garner the widest possible political acceptance by Member States" (UNGA, Decision 62/557, 2008). In this line of reasoning, the UNGA Decision 62/557 (2008) has identified five issues: (1) membership categories; (2) the question of veto; (3) regional representation; (4) degree and method to expand the UNSC; and (5) relationship between the UNSG and UNGA. In this research, we adopt these five issues as our drivers.

Since its creation, the UN has seen its total number of member states quadruple, initially from 51 to 117, as a result of decolonization and dissolution of multiethnic states. Consequently, we acknowledge that the UNSC's composition has expanded from 11 members in 1965 to the current 15, but the additional seats are all elected and are non-permanent. In 2023, 193 + 2 (the latter two being observers) sovereign states are represented at the UNGA, and a growing number of them do not see the current P5 + NP10 as the legitimate configuration representing the interests of the international community.

Moreover, this enlargement falls short of today's new international security challenges—the United Nations Secretary-General has repeatedly called for a seat at the UNSC to be awarded to Africa (Africa Report, 2023). As such, there is a general mood to reform the representation at the UNSC as well as the Council's relations with the UNGA, but there is substantial disagreement on how to advance the process. According to Patrick (2023, p. 4), the "three blocs continue to hold irreconcilable positions on reform". Figure 1 summarizes the key positions of the most important political contenders.

In this study, we are seeking to anticipate possible transformations of the UNSC through referencing the theory of complexity while considering the power status of agents who are deeply influenced by individual cultural perceptions, but together form a meaning-producing structure. The theory of complexity lends to our study an inter- and post-disciplinarity (which was formerly unavailable as it was guarded as

Reforming the UNSC – The P5 and the Existing Blocks (2023)				
	P5 & UN Secretary-General	G4	Uniting for Consensus (UfC)	African Union (AU)
	China, U.S., France, UK and Russia	Brazil, Germany, India, and Japan	Argentina, Mexico, Italy, Poland, Pakistan, South Korea, and Turkey	
General Idea	Generally unwilling to expand the number of permanent members and dilute their veto power	Seeking the same status as the P5; proposed in 2004 to expand the Security Council to 25 members, with two additional seats for Africa	Advocate expanding the Council's elected membership from ten to 20	Its 54 members remain committed to the 2005 Ezulwini Consensus — three additional non-permanent seats*
Veto Power	Not willing to give up their veto power	Flexibility to negotiate	Flexibility to negotiate	Two additional permanent seats, with full veto rights
Number of seats	2005's Annan plan aimed for 24	Agree to increase	Agree to increase to around 25	

*The Ezulwini Consensus has been followed by Assembly/AU/Decl. 2 (V) Sirte Declaration on the Reform of the United Nations (July 2005), which reiterates the plea for two permanent and five non-permanent seats for African states at the UNSC. China has expressed support to African representation, and in particular, correct "historical injustices" to Africa: (MFA/PRC (2023).

Fig. 1 Reforming the UNSC—The P5 and the Existing Blocks (2023). *Source* Author

the turf of natural or social science), supplying a new science and a new ontology that support coexistence rather than opposition (Byrne & Callaghan, 2022, p. 18).

The theory of complexity is a composite of four main theories within a framework of complex systems. The four theories are:

(1) The theory of self-organization (also designated as spontaneous order theory) studies the formation patterns of interactions arising from the interaction between parts in an initially disordered system: order emerges out of initially disordered sub-units as they interact with each other to form an identifiable pattern of exchanges;

(2) The theory of non-linear dynamical systems (chaos theory) looks at the fact that change is not linear and small changes can have large consequences (e.g., butterfly effect) (Lorenz, 1963). In addition, there is an intrinsic unpredictability akin to a pinball machine. In non-linear systems, small changes in causal elements over time do not necessarily produce small changes in other aspects of the system or in the characteristics of the system as a whole; these changes are "evolutionary" and not time reversible (Byrne, 1998, p. 14). Small steps can have non-linear impact on a complex system; therefore, the outputs are not always directly proportional to the inputs. In other words, in non-linear relationships, changes in effects are disproportionate to the changes in the causal element(s) (Byrne & Callaghan, 2014, p. 18);

(3) Network theory seeks to understand connectivity, real-time flows and formal and informal interactions within a space of influence. Networks create status (differentiation) and legitimacy (Podolny, 1993), and a network is a form of organization with a number of distinct efficiency advantages not possessed by pure hierarchies (Bradach & Eccles, 1989). "(…) 'specific evolution' identifies the creation of evolutionary stages by adaptive responses leading to new forms of differentiation. 'General evolution' describes a grand movement in a particular direction and reflects a tendency for differentiation to create successively higher evolutionary forms" (Byrne & Callaghan, 2022, pp. 48–49). At this point, we emphasize that technologies help to visualize real-time flows of interconnectedness;
(4) The theory of adaptive systems studies the evolutionary adaptation of complex systems in response to their environment as they strive to achieve a common objective. As their sub-units act on and react to each other's behavior, complex systems have a tendency to adapt and progress; evolution is an adaptation over a number of life cycles of cooperation and competition.

Two notions are fundamental to the theory of complexity—complex system, and equilibrium:

(1) Firstly, the notion of a system has been one of the focal points in international relations theories and has varied meanings—"either as a regularly interacting or interdependent group of units forming a unified whole or as a form of social, economic or political organization" (Tomé et. al., 2019, p. 4). A system refers to a multi-level network and/or multi-actor structure (variety or heterogeneity), interacting with patterns of regularity, displaying different levels of complementarity and interdependency, but forming a whole with certain characteristics. The international system combines forms of social, economic and political associations to advance materialist interests in the context of a competitive power game between great powers (realists), to empower institutions capable of encouraging rational actors to cooperate and to avoid conflict (neorealists), or to facilitate the distribution of ideas in a context of social construction (constructivists) (Wendt, 1999). We understand system complexity as intertwined and intricate levels of bilateral, multilateral, formal and informal interactions between different system units and at different levels, as well as between the system and the environment. "Non-linearity is a fundamental characteristic of complex-system, which would otherwise be defined as complicated (…) in non-linear systems, non-linear connections can determine the structure and the organization of the system" (Piscitelli, 2016, p. 84). Put simply, "A complex one can't be analyzed and integrated either in reality or in mathematical representation" (Byrne & Callaghan, 2022, p. 12). As explained by Tomé, researchers became increasingly interested in the notions of "systems of systems" or "a complex of systems" (Tomé, 2010, 2016), "each involving various components/units that interact with each other to influence the various systems and the system of systems as a whole in a manner that could not be discerned by observing only the elements/units by themselves or the system as the simple sum of the parts/units" (Tomé et. al.,

2019, p. 5). In the same vein, Tomé explains that to understand complex systems involves five fundamental, competing notions—system, pattern, network, scale and non-linearity. Pattern essentially corresponds to the idea of repetition of structures, idea, behaviors and interactions, and networks are the sum of the connections, interactions and influences among units and sub-systems. Scale refers to the size and magnitude of the object of study and the scope of influence of the units. Non-linearity refers to the direct absence of a cause-and-effect nexus (Tomé, 2016, p. 22);

(2) Secondly, complex systems are often described as being "far from equilibric". As Byrne and Callaghan explain, "Systems can be equilibric, close to equilibric or far from equilibric. An equilibric system stays as it is. A close to equilibric system should move back towards a stable condition if disturbed from it (…). Far from equilibric systems can change radically" (Byrne & Callaghan, 2014, p. 25).

> *"In the absence of significant perturbations, a dissipative system will usually follow a 'normal' linear trajectory. Of course, there will be the usual boundary testing, but in the absence of any sustained increase in environmental energy, the system will return to its original point of reference. At some point, however, this stable regimen is disrupted, and, if the internal movement of the system is propitious, the system's stable behaviour gives way to random fluctuations (…) Abandoning its original trajectory, the system destabilizes and exhibits a so-called 'pitchfork bifurcation' pattern (…) That is, once destabilized, the system begins to fluctuate between two or more new points. The oscillation continues until it abandons its original path and takes one or more of the alternative points as its path of development" (Reed & Harvey 1996, p. 385).*

As we have argued, currently, the ISS is near equilibrium and, as such, it is possible to move back to a stable condition. Perceptions that the UNSC lacks legitimacy may cause instability within the system to snowball; while the decisive action to push the ISS back toward equilibrium is to reform the UNSC.

Figure 2 is a synthesis of the lessons to be drawn from the complexity theory which may help drive the reform of the UNSC.

From these lessons, a number of important arguments can be derived: (1) Firstly, as a complex system, the ISS evolves in a way that does not depend exclusively on singular actors but on the dynamics and interactions between them and within their networks, e.g., between the UNGA and the UNSC; (2) Secondly, actors that are perceived as small or informal may produce significant impact on the system, therefore compelling the UNGA to function as a second chamber to review the exercise of veto power; (3) Thirdly, failure to substantially reform the UNSC may cause the decision-making process to be transferred to the UNGA, consequently bringing back the problems of the League of Nations and bringing about other radical changes, all potentially coming at a great cost to humankind; (4) Fourthly, as complex systems form natural patterns of relations and naturally transform themselves, the UNSC needs to have full representation of all continents, and the power of veto must be diluted and be sanctioned by the endorsement from one or more members; (5) Fifthly, bottom-up channels of real-time information, originating from relevant UN bodies need to be put in place.

Lessons from Theory of Complexity				
	❶	❷	❸	❹
Lessons	Emergence of **spontaneous, irreversible patterns** of interactions observable in complex systems	Complex systems' changes are **non-linear** and **unpredictable**; possibility of small states to contribute with large effects	Complex systems' networking is a **space of influence** and **differentiation**; real-time flows need to be identified	Complex systems' tendency to **adapt and transform** over cycles of progress as a result of cooperation and competition
Implications for UNSC reform	UNGA as leading institution, in case of reform failure or incomplete transformation (but this can also be the cause of a major collapse/radical change)	All continents are represented; all states, acting as a whole must be involved in critical decision-making	Increase differentiation, awarding more seat with veto power, allowing for dilution of unmatched powers	UNSC reform is unavoidable
	Increase number of states vested with system governance responsibilities	Africa representation with veto power Asia representation	Increase NP rotational representation to improve influence; allow UNSC to receive real-time information from appropriate UN bodies	Failure to substantially reform the UNSC leads to natural radical change
	UNGA as second referee to promulgate individual veto by qualified majority	Veto power must exist. However, the dilution of veto power is beneficial	UNGA as a second referee to promulgate individual veto by qualified majority to increase legitimacy	

Fig. 2 Lessons from theory of complexity. *Source* Author

2 Current Discussion: How Should Governance in the International Security Order Be Understood?

The international society is governed by a number of orders, and the international security order is the order of orders. Bull (2002, pp. 8–9) defined the international order as "a pattern of activity that sustains the elementary or primary goals of the society of states, or international society". The World Economic Forum (WEF) (2017) defines it as the body of rules, norms and institutions that govern relations between key players on the international stage. Today, the international order includes a nexus of global institutions such as the United Nations and the World Trade Organization, bilateral and regional security organizations, as well as what can be described as "liberal political norms". As such, we understand the international order as a set of relationships, and is defined by a body of rules and principles, traditions, perceptions and expectations, circumstances, procedures, power networks and institutions that govern the relations between international actors, in a stable and predictable manner.

The international order is a contingent structure of power dynamics based on patterns of prepositive transformational interactions and convergent interests. The construction of the international order rests with all sovereign and non-sovereign

actors with an international presence, but its governance is a special responsibility bestowed on some, namely, the great powers. Moreover, we can pluralize the use of the term (i.e., "international orders"), as the "international order" itself encompasses different dimensions, and the governance of these different dimensions varies, such as is the case of the international economic order, the international security order and the international eco-sustainability order. These different architectures are all governed by the interests and power assumptions of diverse actors at different moments in time.

Therefore, as we see it, the international order ought to be defined as a constellation of networks and webs of material and immaterial relational systems (web of structures), multiple domains and actors capable of generating political and juridical expectedness (i.e., are stable but adaptable), as well as predicable patterns of interactions (e.g., competition and coexistence) between sovereign and transnational non-sovereign actors. Furthermore, as a constellation of networks of relational structures, it must be stable, predicable, principled, interdependent, governable, adaptable and capable of acting as a whole. In this context, the international security order is dissimilar from all others, as it deals with the securitization of international matters.

There is a substantial body of academic research in the area of securitization, among which are the works of Wæver (1995, 1998), Buzan et. al. (1998), Huysmans (1998), Williams (2003), Emmers (2007), McDonald (2008), Peoples & Vaughan-Williams (2010), Balzacq (2010), Deudney (2020), as well as several schools of thought (e.g., Paris and Copenhagen). For the UNSC, as it is a governing body of the ISS, security matters are a paramount concern in addition to other decision-making on global affairs. Here, securitization is the intersubjective establishment of an existential threat that demands immediate attention to develop countermeasures for (Buzan et. al., 1998, pp. 24–25; Wæver, 1989, 1995, p. 51). Eriksson (1999, p. 312) asserts that securitization (or security politicization (säkerhetspolitisering), as labeled by Kjell Goldmann (1978)) is the act of classifying an issue as a matter of security, but, contrary to "normal politics", it is a politics of exception or "abnormal politicization" (Alker, 2005, p. 197), in addition to being an attention-grabbing model that opens the door to politics of pure realism (and extremism), as well as "a kind of mobilization of conflictual or threatening relations, often through emergency mobilization of the state" (Buzan et. al., 1998, p. 8). Security is the move that takes politics beyond the established rules of the game and frames the issue either as a special kind of politics or as something beyond politics. Securitization can thus be seen as a more extreme version of politicization where the issue "is presented as an existential threat, requiring emergency procedures and justifying actions outside the normal bounds of political procedure" (Buzan et. al., 1998, pp. 23–24). It is therefore topical and sensible to evaluate security under a specific set of threats, circumstances, as well as states, groups and/or individuals. Consequently, security is diverse, and the nature of security as a problem differs substantially from state to state (Leandro, 2018, p. 147).

Based on this idea of securitization, we view the international security order as part of the international order governed by multipolarities and power-status interactions, with the United Nations Charter as its common legal threshold. As such, the design

of the UNSC must reflect this multipolarity as well as the fact that it deals with securitized matters in a relevant manner that ensures the system's stability, predictability and effectiveness. In fact, as the ISS's governing body, the UNSC is best defined as a normative participatory body driven by the aforementioned politics of exception (measures outside democratic decision-making but under limited democratic control) and reflects the dynamics and interactions being leading powers. Consequently, the international security order, as a power-relational system dealing with securitized matters (triggering perceptions of survival, urgency and threat), exhibits two important characteristics: (1) it sets narratives at the existential threat level, requiring measures outside the normal bounds of political equalitarian procedures; (2) it is governed by power relations, and its configuration is dynamic with ongoing oscillations between uni-, bi- and multi-polar powers.

Therefore, the international security system presents, as we see it, a major challenge for any sort of collective leadership to exercise governance, as it deals with sovereign actors possessing two distinctive features: (1) they are all vested with the same legal international status under the principle of equality, and (2) they are all perceived with different assumptions of their relative power status. There is perhaps a third characteristic, which makes the system even more complex—each sovereign actor is significantly different compared to its peers, both in their geopolitical readings and in their political culture; some are prone to exclusion, conflict and war and are less inclined to mutual restraint and cooperation, while others, being averse to conflict escalation and chaos, are willing to play games to accommodate and work within their collations of interests with a view to attaining mutual benefit. In this vein, the reform of the UNSC faces another ultimate challenge: reforming the aforementioned five issues requires approval from not only a UNGA majority (i.e., two-thirds of its members) but also the UNSC itself (at the very least, all P5 need to abstain, as required by article 108 (Charter of United Nations (CUN)). However, despite all these hurdles and slow progress in inter-governmental negotiations, the vast majority of the UN member states are in support of reforming the UNSC (Patrick, 2023).

The ISS is composed of a number of formal and informal actors acting at the national, regional and global levels. "The state-centrism of [international relations] means that IR theories do not say much about other important international players. However, in the last decades, we have seen the empowering of international actors other than states, from individuals to transnational social movements, international/regional organizations, NGOs, transnational organized crime networks and terrorist groups or multinational corporations. Especially, globalization has triggered opportunities for non-state actors to be more effective in the international system and in decision-making processes" (Tomé et. al., 2019, p. 3). As such, the system should reflect a compromise between the interests and relative power statuses of its units, and should include other forms of representation other than states. Because it is a security system dealing mainly with sovereign states (and perhaps international organizations), and only a limited number of states possess the ability to influence or even coerce while still maintaining acceptable levels of legitimacy, there is a need to equip the governing body of the ISS with not only the ability to make swift, effective decisions but also the legitimacy to compel other members of the ISS to

adhere to those decisions. Further, there is a need for balance: one the one hand, a large expansion could well increase the UNSC's authority and legitimacy; one the other hand, a large number of members, as much as it more broadly represents different types of international entities, would decrease its efficiency and effectiveness. Nevertheless, regardless of the possible combinations, the UNSC has to adopt different power configurations to reflect a balance of powers, as embodied in the international security order, and, as such, the solutions must be dynamic. As the leading security governance body, the UNSC must be as multilateral as possible, have a representative power status to exercise collective might, and be adaptable to new reconfigurations of power. These three characteristics will form the basis for the analysis presented in the next section.

3 Analysis: Redesigning the UNSC Lest It Becomes Irrelevant

In this section, we apply what we have learned from the complexity theory as well as structural realism and post-structuralism to address the five lines of reform identified by the UNGA's Decision 62/557, (2008).

(1) Membership categories—The categories of UNSC membership are not consensual. However, the theory of complexity clearly advances solutions that induce the highest level of participation which is inclusive of different types of actors, to advance patterns of decision-making. In addition, realism and post-structuralism suggest that states and their power status as well as other forms of non-state representations should be considered, thus to accommodate different participatory capacities. In our model (Fig. 3), we have two types of membership, legacy (historical) membership and elected membership, and three types of terms—permanent (with and without veto), four-year and two-year terms. Moreover, in addition to state memberships, we also envisage membership for international organizations, namely, the G20 and the AU, the former representing the bulk of the world's economic power, while the latter symbolizes a continent with growing political leverage. The inclusion of permanent seats for the G20 and the AU (each electing a delegate state) will help the UNSC to adopt different power configurations and reflect the balance of powers represented by the international security order at a certain juncture. The rationale for granting seats to only the G20 and the AU is as follows: the G20 (2023) comprises 19 states: Argentina, Australia, Brazil, Canada, China, France, Germany, India, Indonesia, Italy, Japan, the Republic of Korea, Mexico, Russia, Saudi Arabia, South Africa, Türkiye, the United Kingdom and the United States, plus the European Union. Together, the G20 represents approximately 85% of the global GDP (2022), more than 75% of global trade, and about two-thirds of the world's population. More importantly, no other international organization possesses the level of political and economic concertation on a par with either the AU or the G20.

Nevertheless, the two permanent seats allocated to G20 and AU must be elected/designated by these organizations for a period of time no shorter than four years, and the designated state should represent the interests of the states that make up these organizations, as opposed to interests of its own. Scholars such as Sachs (2015) have argued that ASEAN countries should also be represented as a single constituency, as the Asia–Pacific region accounts for roughly 55% of the world's population and 44% of its annual income. However, in this study, we do not endorse this position, as it would open up a Pandora's box and invite similar questions regarding the representation of a number of other international organizations, i.e., the BRICS, European Union, MERCOSUR, and Euro Asian Economic Union (EAEU).

(2) The question of veto—This is probably the most challenging aspect of reforming the UNSC, as there is no consensus on its reforming principles. Regarding this aspect, what the complexity theory in combination with structural realism and post-structuralism has shown us can be summarized in three important principles: (1) to keep the P5's veto power as a legacy of the current international order and a result of their current international power status; (2) to dilute this veto power, extending it to one of the two additional seats, while keeping the total number odd. These seats will be elected by the members of two international organizations (G20 and AU), allowing for an adaptation to the new international relations reality; (3) to ensure that the usage of veto power is in accordance with the United Nations Charter. According to UNSC records, France advocated a voluntary restraint on the veto and, joined by Mexico, organized a ministerial-level event on this issue. In a summary of that event, the co-chairs called on the P5 to "voluntarily and collectively pledge not to use the veto in case of genocide, crimes against humanity and war crimes on a large scale." However, from among the permanent members, only the UK has supported the initiative (UNSC, 2020). These arguments clearly show that rules must be introduced to regulate the use of veto. These rules can be:

A. To require that all exercise of veto must be done in written form, with direct reference to either a specific provision of the Charter of the United Nations as ground, or a principle of the UN system that the veto intends to protect;
B. Single veto use must be confirmed by a UNGA qualified-majority;
C. Double veto use must be confirmed by a UNGA simple-majority;
D. Triple veto use is automatically validated (it does not require UNGA confirmation);
E. The use of veto is banned when the UNGA qualifies the matter subjected to UNSC decision as either genocide or a crime against humanity, as these represent large scale commission of international crimes; and, finally
F. Constructive abstention from all seats with veto power is allowed.

(3) Regional representation—This is another aspect where there has been general consensus among the UNGA member states. First, it is agreed that all continents should hold at least one seat at the UNSC. Second, it is largely recognized that

Africa and Asia are underrepresented (particularly considering that their representations are disproportionally low compared to their population and contribution to global GDP). To maximize representation, we let regions elect their own representation at the UNGA in two- or four-year terms. These regions are: (1) the Western Europe and Other Group (WEOG), (2) the Eastern European Group (EEG), (3) the Asia–Pacific Group (APG), (4) the Africa Group (AG), and (5) the Latin American and Caribbean Group (LACG). Each state can only have a singular representation at the UNSC regardless of the type of representation, but all regions are each granted at least one four-year seat to ensure continuity, as well as rotating seats, with the exception of Africa, who has been granted permanent representation via the AU.

(4) Degree and method to expand the UNSC—This aspect seems to have garnered large consensus among the P5 and the UNGA. A significant number of states view that expanding the UNSC would broaden representation, and 25 is often accepted as the maximum number of members for the UNSC to still function effectively. Similar consensus has also been obtained as regards the need to allocate either two or three seats to the African continent. All permanent and non-permanent members of the UNSC should rotate duties through a trio-time scheme: six months before taking up office, a future member should (begin to) follow closely the work of the UNSC in close consultation with the incumbent members. Upon assuming office and duties, the new incumbent member will continue to work in close consultation with the past, current and future members. Likewise, within six months of concluding its incumbency, the now past member continues to work in consultation with other incumbent members. Furthermore, as suggested by the theory of complexity, any member of the UNSC has the ability to request a release of real-time information from relevant UN bodies.

(5) Relationship between UNSG and UNGA—This is a critical point of reforming the UNSC. Though there is large consensus to empower the UNGA, the common platform on how to do it is, unfortunately, narrow. In matters of international security, the UNSC should continue to have driving power, and its decisions should be binding to all states. That is why it is remarkably important that the UNSC and UNGA work together over the most sensitive cases, namely the exercise of veto power. Indeed, it is important to put in place a mechanism to review the juridical and political merit of any attempt to invoke the veto power. A double veto rule may be applied, or the UNGA should be allowed to revise the procedure for exercising single veto, and subject each veto's merit to a simple or qualified majority ruling. This can prevent the P5 from receiving harsh criticisms for using their veto power to protect their national interests as opposed to protecting the principles of the United Nations Charter.

Figure 3 shows the possible recomposition of the UNSC based on the aforementioned ideas. The solution comprises two types—legacy and elected—of membership of either permanent (with and without veto), four-year or two-year terms.

This proposed solution comprises three types of representation: (1) legacy (historical) representation, which ensures that all P5 will continue to enjoy their permanent

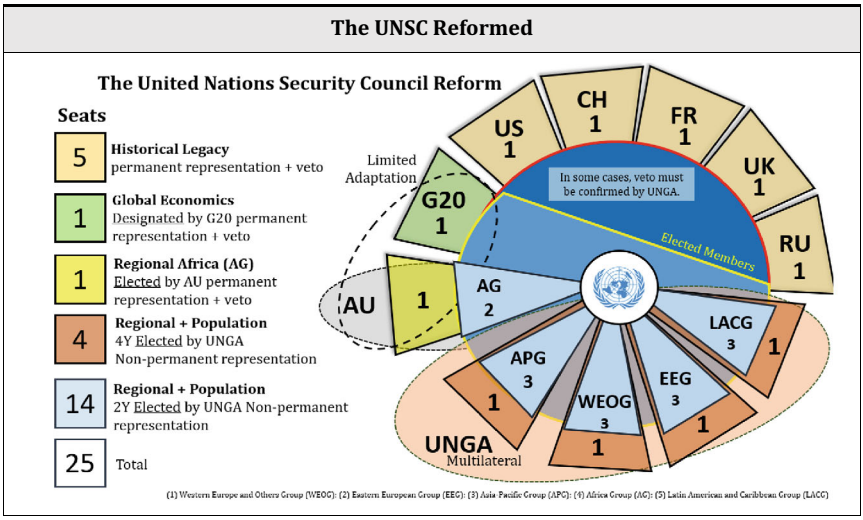

Fig. 3 The UNSC Reformed. *Source* Author

status and veto power; (2) global representation as represented by the G20, which not only ensures that the most economically robust states are represented, but also allows states such as Brazil, India, Germany and Japan to get a seat as long as their economies perform well. One thing to note here is that the P5 are all automatically excluded from the G20 representation as they already have their own seat; (3) a two-pronged regional representation: firstly, Africa, led by the AU, as it is a politically structured regional organization (i.e., the AU will hold and manage one permanent seat with veto power and two more seats on a two-year term), and, secondly, the remaining four regions are represented by one seat on a four-year term and three seats on 2-year terms, all elected by the UNGA.

Furthermore, this solution (Fig. 3) has five important merits. First, it keeps the legacy of permanent members but dilutes their veto power (though only slightly), forcing them to work with the UNGA. Second, it ensures supremacy of the most dominant states, drawing lessons from the failure of the League of Nations and from structural realism. Third, it opens the door to alternative types of representation, drawing lessons from post-structuralism, allowing a single, direct representation of the G20 and multiple, indirect representations of the African Union. Fourth, it enlarges the participation of states and their regional representation, which is in line with the theory of complexity and post-structuralism, as it reinforces the UNSC's legitimacy. Fifth, the two added permanent seats are elected, therefore leaving room for any necessary adjustments over time to reflect any changes in power status among the members.

4 Conclusion—Using Representative Pluralism and Relative Power-Status to Attain More Predictability, Stability and Functionality

The ISS must be governed normatively and efficiently by a body that has legitimacy to rule, and for the ISS to function properly, its members must also agree to participate normatively, and there must be a securitization of the relative power status. Currently the ISS has a near-equilibrium, but its governing body, the UNSC, can be defective at certain junctures and thus requires a structural overhaul. To do so is, however, difficult, as potential reform options often trigger feelings of insecurity, and a considerable number of member states may seize the opportunity to either increase their power or at least to protect what power and privilege they already hold.

However, what the theory of complexity tells us is that we should not allow stalemates to continue to dominate UNSC decisions. In fact, unresolved security challenges among the P5 states may cause the ISS to collapse and induce radical changes to the system, and humankind will pay dearly for it. In the interim, we see that the UNGA is being reinvigorated, and there has been an emphasis to encourage all sovereign states to participate in ISS-related decision-making. The alternative—an ISS not governed by a system based on representative pluralism and relative power status—would in fact be an anachronism.

Nevertheless, since 1998, the UNGA has put forth several initiatives to restructure the UNSC, but the road toward a reformed UNSC has proved to be full of obstacles. This is the direct result of securitization processes perceived by influential states as a dilution of their power. The point that needs to be emphasized, however, is that the main objective of a UNSC reform is to boost its power, legitimacy, effectiveness and resilience, and our research probes the feasibility of such a redesign.

Currently, two points seem to have gained significant consensus and support—to increase the number of UNSC members, and to include and increase African and Asian representation. It also seems to be generally agreed that the exercise of veto needs to be controlled and/or limited, as current practice has led to suspicions that the privilege has been abused for individual gains, casting a shadow of doubt over the legality of its utilization. On the other hand, there has been more controversy than agreement in regard to adding G4 (or sometimes designated as P4) (Brazil, Germany, India and Japan) and/or UfC representation to the UNSC, which may be mitigated by adding seats for G20 and AU, as doing so would also empower the G4 and UfC. In this vein, our model presents two types of membership: legacy membership and elected membership, of either permanent, four-year or two-year terms.

What the theory of complexity echoes in terms of reforming the UNSC is to increase the number of members and to dilute the privilege of veto power, as well as to involve the UNGA as a second referee over any exercise of veto. This measure will contribute significantly to increasing the normativity and legitimacy of the UNSC and the overall ISS's ability to adapt and adjust to changes in governance. On the other hand, the lessons that are drawn from structural realism and post-structuralism indicate that any possible redesigns of the UNSC must respect current perceptions of

power status, historical legacies, the inclusion of new non-state entities, and the formation of legitimate responses. In particular, post-structuralism suggests that improved UNSC-UNGA relations can be a source of added legitimacy for the UNSC.

Ultimately, the proposed model addresses historical, regional and dynamic representation, extends the composition to a number of member states while still allows the body itself to function effectively, and is an alternative to the current walking on thin ice with unacceptable stalemates, as it combines representative pluralism and ponders of relative power status. This topic presents several avenues for further research, the most pressing of which is perhaps to study how consensus may form on sovereign matter involving the theory of complexity and securitization.

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The Old and the New Geopolitics of Energy and Its Impact on Energy Security

José Pedro Teixeira Fernandes

Abstract The implementation of the Paris Agreement (2015) will force a shift from economies based on the intensive use of fossil energies to economies that will use renewable energies with neutral environmental impacts. Beyond the need to preserve the planet, this is a highly complex transformation with potentially huge repercussions on international political economy, i.e. wealth and power, as well on the energy security. In this exploratory approach, a brief literature review is provided, and the operational concepts used (geopolitics, energy transition and energy security) are also outlined. The main purpose is to identify the effects of the overlap of two geopolitics during energy transition (the old geopolitics of fossil fuels with the new geopolitics of renewable energy) and its impact on energy security. The possible consequences at the global level will be also taken into account, including a brief look at the specific case of the European Union.

Keywords Energy transition · Energy security · Geopolitics · Fossil fuels · Renewable energies

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1 Introduction

A far-reaching global energy transition driven by the Paris Agreement (2015)[1] is set to take place in the coming decades. Beyond the environmental sustainability, there are multiple consequences for the economy, employment, technology, wealth distribution, power and global politics that are difficult to grasp in the fullness of their effects. Thus, the main objective of this chapter is to identify the (inter)connections between the energy transition and geopolitics and trying to understand the potential consequences at the global level completed with a brief look at the case of the European Union. The starting point is the tracing of the main geopolitical repercussions of the energy transition from the current model based on the use of fossil fuels to a model based on renewable energies. Then, a second point will be about understanding the extent to which the countries that are not fossil fuel producers will be vulnerable to geopolitical and/or geo-economic shocks during the energy transition, with particular attention to the case of the European Union.

This analysis falls within the scientific area of International Relations. By its very nature, it is a multidisciplinary field marked by a diversity of approaches, which is reflected in the theoretical lenses, as well as in the choice of research methodologies used for the subjects studied. As for the theoretical lenses, a few considerations should be made here. In a subject as complex and multifaceted as the energy transition and geopolitics, the shortcomings of the usual theoretical lenses—realist, liberal, constructivist or others—, particularly in relation to change in the world, lead to explore alternative possibilities to overcome such deficiencies. Recently, there has been a growing tendency in the Social Sciences (Byrne & Callaghan, 2022; Kiel & Elliott, 1997), including the International Relations (IR) studies, to use the theories of chaos and complexity (Kantemnidis, 2016; Tomé, 2016; Tomé & Açıkalın, 2019). The later, in particular, brings with it a new set of tools—the complex systems analysis or, in its more conceptual variant, the complexity theory—which originate in the study of the natural world, in subjects such as Physics and Biology.

Of course, to use these tools in the IR research, which is still in its infancy, raises ontological and epistemological questions and criticisms (Glover, 2012). As happens with all imports from other scientific areas, of theories, models or concepts—a classical case is the concept of paradigms, transposed from the work of Thomas Kuhn (1962) in the field of the history of science and Physics to the International Relations—, the fit is never perfect. There is always the problem of adapting, without distortions, the original concepts and theories to a new field of study. Despite these undeniable difficulties, adding to the usual theoretical lenses of IR field new concepts and ideas from other areas of knowledge, like the theories of chaos and complexity,

[1] The Paris Agreement, which contains a global climate commitment, entered into force on 4 November 2016 when 55 States Parties ratified it, accounting for 55% or more of global greenhouse gas emissions. See United Nations Climate Change, Paris Agreement—Status of Ratification, https://unfccc.int/process/the-paris-agreement/status-of-ratification. Its main objective was to limit the increase in the global average temperature to below 2 °C above pre-industrial levels, with the aim of setting this limit at 1.5 °C.

can lead to a better understanding of the world. As Tomé & Açıkalın (2019, pp. 4–5) pointed out, "IR theories always have difficulty in explaining change more generally, especially because a large number of variables as well as the notion of change do not fit in their respective ontological postulates." This major limitation is increased by the fact that IR theories are also "associated with another problem: their typically linear perspective". Simply put, linearity means "that all physical phenomena are assumed to be based on a few core laws and thus difficult to change. In other words, the linear approach is mainly based on high levels of order and predictability, as well as on a cause-and-effect nexus. However, this creates an illusion of certainty "that evolution and change always follow a linear route, both in natural sciences and social sciences".

Thus, concerning the theoretical lens used, the starting point will be the neorealist worldview, which includes inter-state rivalries, competition, power struggles and (a certain degree of) anarchy as characteristics of the contemporary world. To overcome the limitations of a classical neorealist approach, the theoretical lens will be supplemented with ideas and concepts transposed from the theories of chaos and complexity, especially the aforementioned idea of non-linearity. As has already been noted, in a subject as complex and with so many ramifications as the energy transition and its relationship with geopolitics, this syncretic research model will allow to improve our understanding of the subject, albeit in an exploratory way. Lastly, relating the methodology, it will be a qualitative one (supplemented, occasionally, by the use quantitative data) based on the collection of documentary and bibliographic data and on an interpretative analysis of them through a deductive reasoning.

As for this chapter, the analysis is structured in several topics. Firstly, a literature review is carried out[2] with a brief overview of the energy transition and its connections with geopolitics. Then, a brief approach to the geopolitical issues linked to the old fossil fuel economy, including the use of fossil fuels as a geo-economic and geopolitical weapon. A third topic will focus on the new renewable energy economy and its geopolitical dimension. It will also analyse to what extent expectations of dramatic increases in energy security and energy independence are realistic. Finally, the intersection of the two geopolitics will be analysed with a brief overview of the case of the European Union.

2 Literature Review

By 2020, the literature on the energy transition produced by academics or experts in the field already exceeded two hundred publications (Vakulchuk et al., 2020). A good overview is given in The geopolitics of energy system transformation: A review (Blondeel et al., 2021). Of course, in a subject as wide-ranging and complex as this one there are multiple perspectives and quite different views. Part of the

[2] This includes publications from international organisations that are leading the way in the transition to renewable energy, such as the International Renewable Energy Agency (IRENA).

literature reviewed focus on the geopolitics of the global energy transition and the geopolitics of renewable energy (Hafner & Tagliapietra, 2020; Scholten & Bosman, 2016) as well as on how the energy transition will transform geopolitics. (Bordoff & O'Sullivan, 2022; Goldthau et al., 2019) and the energy map (Yergin, 2020). Another part of the literature draws attention on the ongoing competition for a new energy and economic model (Sanderson, 2022) also pointing to potential winners and losers in terms of power and geopolitics. (Vakulchuk et al., 2020) and a future troubled by new energy disputes (Yergin, 2020). (Salimi & Amidpour, 2022). Other works main subject of interest is the impact the energy transition will have on the power of the countries that traditionally produce fossil fuels. Finally, there are the works that underline the increasing need—and the increased competition—for the use of minerals, in particular the so-called critical minerals, which a renewable energy economy will entail (Bazilian, 2018; Gielen, 2022). As regards the specific case of the European Union, it has also been the subject of several investigations (Hernández, 2022; Leonard et al., 2021).

Given the limited purposes of this exploratory chapter it impossible to review in depth all the works and topics mentioned above. So, I decided to approach the works of the International Renewable Energy Agency (IRENA) about the geopolitical dimension of the energy transition. Although it is not strictly academic-scientific literature, it is the main international organisation in this area, and its reports and studies are important documents to take into account. The second topic I chose to delve into is the temporal duration of the energy transition. Whether this will be a (very) long transition, or whether it will be done in a (relatively) shorter period of time is something that divides the literature as we will see below (Grubler et al., 2016; Smil, 2010, 2016; Sovacool, 2016). Due to its importance for the subject analysed, let us now take a closer look at both topics.

Related with the first topic, IRENA recently published a study on the geopolitics of energy transformation. In the document the authors state: "First, renewable energy resources are available in one form or another in most countries, unlike fossil fuels which are concentrated in specific geo- graphic locations. This reduces the importance of current energy choke points, such as the narrow channels on widely used sea routes that are critical to the global supply of oil. Second, most renewables take the form of flows, whilst fossil fuels are stocks. Energy stocks can be stored, which is useful; but they can be used only once. In contrast, energy flows do not exhaust themselves and are harder to disrupt. Third, renewable energy sources can be deployed at almost any scale and lend themselves better to decentralized forms of energy production and consumption. This adds to the democratizing effects of renewable energy. Fourth, renewable energy sources have nearly zero marginal costs, and some of them, like solar and wind, enjoy cost reductions of nearly 20% for every doubling of capacity. This enhances their ability to drive change but requires regulatory solutions to ensure stability and profitability in the power sector (IRENA, 2019, p. 23).

Concerning the prospective power shift, the authors of the IRENA study make the following forward-looking assessment. The US "is close to energy self-sufficiency, largely due to the shale revolution. It became a net exporter of natural gas in 2017

and is projected to become a net oil exporter early in the 2020s. The US is well positioned in the clean energy race: US companies hold strong positions in new technologies, including robotics, artificial intelligence, and electric vehicles." In the case of China the country "will gain from the energy transformation in terms of energy security. It has a leading position in manufacturing, but also in innovation and deployment of renewable energy technologies. It is the biggest location for renewable energy investment, accounting for more than 45% of the global total in 2017. Currently, it remains highly dependent on oil imports which have been growing steadily." Regarding the cases of the European Union and Japan, it is noted that "are major economies which are very dependent on fossil fuel imports. They also hold strong positions in renewable technologies". Regarding the case of India, it is observed that it is "has been among the fastest-growing economies in the world in the last few years, lifting millions out of poverty. It is projected to have the world's largest population by 2024 and is poised to overtake China as the world's largest energy growth market by the end of the 2020s." As for Russia, it will have severe difficulties in the energy transition and will be a likely loser. As the world's largest exporter of gas and the second largest exporter of oil, it will face enormous adaptation challenges. "Even though Russia is stepping up renewable energy deployment and is investing in research and development, it still lags far behind China and the US in terms of patents for renewable energy technologies" (IRENA, 2019, pp. 28–29).

Still on the case of China, some remarks in the study are worth highlighting here: "China's concerted efforts to research, develop and invest in renewable energy and clean transport offer its industry the opportunity to overtake US and European companies, which have been dominant in sectors such as cars and energy machinery. This will give China a comparative advantage in trade and lend impetus to the country's economic growth" (IRENA, 2019, p. 40). A second relevant remark on the role that China could acquire in the new energy model is linked to the geopolitical dimension of the transformation. "By taking the lead on renewables, China has improved its geopolitical standing in several respects. By producing more of its own energy, China is reducing its reliance on fuel imports and the risks of energy disruption which could put a brake on its economic ambitions. Its technological expertise in renewables has established it as a leading exporter of clean energy technology, creating a balance of trade advantage. The clean energy technology race could result in a situation of technology dominance. In some respects, that outcome can already be seen in mobile technology where a few companies (Huawei, Samsung, Apple) compete for global leadership. If a small number of players were to dominate clean energy technology in a similar way, it would raise concerns that concentration could stifle competition, suppress innovation, and distort markets. Countries that do not control key energy technologies may become heavily dependent on the few countries and companies that do" (IRENA, 2019, p. 42).

Let us now turn to the second point, which is the temporal dimension of the energy transition. In his approach to this issue Sovacool (2016, p. 205) noted that the historical record suggests that previous energy transitions all occurred over a long period of time. The same idea was also explained in detail by Smil (2010): "In the US, it took crude oil half a century from its exploratory phases in the 1860s to capture

10% of the national market in the 1910s, then another 30 years to reach 25%. Natural gas took 70 years to go from 1 to 20% in the US. It took coal 103 years to represent just 5% of the total energy consumed in the US and another 26 years to reach 25%. Nuclear-powered electricity took 38 years to reach a 20% share in the US, which it did in 1995." In other words, what past energy transitions have shown is that, on average, it took between 50 and 70 years for a new energy resource to reach a high degree of penetration. The reasons for this long transition are linked to the size of the financial investment, the infrastructures that have to be created, technological innovation and regulatory needs. All this means that it takes many decades for a new energy source to have a great impact".

However, despite this historical record and the arguments explained above, it is also contested that the current energy transition process necessarily has to be (very) long. The counterarguments are based on the fact that some empirical data suggest that a transition, under certain favourable conditions, can also occur rapidly. Thus, as Sovacool points out in the aforementioned work, there are three types of arguments that suggest that we may have a (relatively) rapid transition to sustainable energy (Sovacool, 2016, p. 207). These arguments are as follows: (i) we have previously seen relatively rapid transitions in energy end-use devices (e.g. ethanol vehicles in Brazil or air conditioning in the US); (2) there are several cases of rapid national-scale transitions in energy supply (e.g. for oil and electricity in Kuwait, for natural gas in the Netherlands and for nuclear-based electricity in France); (3) the drivers of future transitions may differ substantially from the drivers of previous energy transitions—there is also learning from previous cases—which may allow for faster future transitions. But they are an (overly) optimistic view of the energy transition, underestimating geopolitical and geo-economic tensions in today's world. Furthermore, as Sovacool draws attention to, the qualification of an energy transition as fast or slow depends (and a lot) on how it is defined and measured. For example, what is a "significant" transition or who are we considering (the world, a specific country, developed countries…). In addition, the duration of the transition is not entirely objective, as various forms of time measurement can be used (Sovacool, 2016, p. 211).

Thus, before concluding this brief literature review, let us return to the aforementioned work by Blondeel et. al (2021) and to some of the reflections therein to retain key ideas. They underline that "the current geopolitical landscape reflects the continuation of many of the familiar tensions associated with fossil fuels". Thus, geopolitics will intervene to "ensure that the remaining demand for fossil fuels is not simply allocated to the lowest-cost producers." The energy transition will be complex and with multiple "winners and losers that are likely to cause tension and conflict, particularly as many of the world's producing economies are already politically fragile and in regions that are unstable" (Blondeel et al., 2021, p. 12). Blondeel et al. (2021) further add that "a low-carbon energy system based on renewables and electrification would not be free of the geopolitical tensions associated with fossil fuels." They exemplify with "geo-economic competition to control supply chains for critical materials associated with renewable energy". And yet with the "emergence of new patterns in the international trade of biofuels, biomass and potentially hydrogen", recalling the "types of problems associated with the production, trade and consumption of

fossil fuels." Finally, they note that "While it is true that the relative magnitude of international trade in energy commodities will fall, it will be replaced by global production networks that deliver low-carbon technologies to consumers. Already we see international rivalry between states and corporations over these perceived threats as they are determined to be the winners in the emerging zero-carbon global economy" (Blondeel et al., 2021, p. 12). In short, with great probability geo-economic and geopolitical tensions will continue both during the energy transition and once the new renewable energy model is in place, although these are expected to diminish.

3 The Long Continuity of Fossil Fuel Geopolitics

Despite its primacy over several decades, in 2020 the cartel of the Organisation of Petroleum Exporting Countries (OPEC)[3] seemed to be in a clear loss of power in 2020. By the end of the second decade of the twenty-first century, the US, once again, had the world's largest production—something that not happened since the 1970s—due to the discovery of new reserves of shale oil and the hydraulic fracturing (fracking). The surprising return of the US to the top of global production has substantially altered the energy map and markets (Aguilera & Radetzki, 2014; Yergin, 2020). Making matters worse for OPEC, a hitherto unknown virus caused a pandemic that semi-paralysed global economic activity. March–April 2020 seemed to be the twilight of the organisation, with an extraordinary drop in the price of a barrel of oil on world markets to near $20. In the midst of the spectacular drop due to drastically reduced demand, Saudi Arabia and Russia—the latter is not a member of OPEC, but is part of the OPEC + [4]agreement with other major producers outside the cartel (OPEC, 2021)— engaged in a price war which has further accentuated the decline of its power (Ma et al., 2021).

However, the story of the power of OPEC and the old geopolitics of fossil fuels did not end in 2020, nor with the European Union's efforts to drastically reduce fossil fuel use by 2050 under the European Green Deal (European Commission, 2019) and the subsequent plan REPowerEU (European Commission, 2022), neither with the Inflaction Reduction Act of 2022 of the United States (The White House, 2022). It is true that these are, admittedly, medium-term and long-term plans, and that they will take several years to implement, but that is not the critical point here. The critical point is that a smooth transition also depends on factors that the Western countries, and the European Union in particular, does not control. The first signs that OPEC would continue to have substantial economic and geopolitical power during the energy transition occurred in 2021. It is important to note that it was before Russia invaded Ukraine in early 2022 which provoked the prices on international markets

[3] OPEC was founded in 1960 by Saudi Arabia, Iraq, Kuwait, Iran and Venezuela.

[4] OPEC + is a broad alliance of non-OPEC member states seeking to extend, as far as possible, traditional energy dominance over developed countries' traditional markets, and to extend it to markets experiencing high growth in energy demand, particularly in Asia.

increased substantially. Before Russian invasion, there was clearly a rise in the prices of oil on and other fossil energy sources such as natural gas. It seems to have taken many of those most committed to a rapid energy transition to a renewable energy by surprise, not least European policymakers. It has contradicted the prevailing view, mainly propagated by the optimism that usually pervades official EU discourse, that an energy transition of this scale can be made (relatively) quickly, without incurring high economic costs, and also without geopolitical upheaval. The optimistic narrative implicitly assumes a global co-operative attitude that would help to keep energy prices reasonably low and without supply problems. But this has not been the case.

It is worth looking at the prospects for the development of fossil energies in OPEC's World Oil Outlook 2045. The outlook projected therein is very different from what we are used to in the West (and particularly in the European Union). At first glance, it would appear to be more a catalogue of wishes of oil producers and exporters than a consistent and realistic elaboration of scenarios. The study reads: "In 2020, oil accounted for 30 per cent of global energy needs. Together with the post-pandemic recovery in oil demand, the share of oil is expected to gradually increase to a level of more than 31% by 2025."

(OPEC, 2020, p. 7). The same forward-looking analysis also adds: "Non-OECD[5] energy demand grows over the forecast period as energy-intensive industries in the region flourish. This growth can be attributed to population increases and expanding economies, particularly in Asia, Africa and the Middle East. Declining energy use in OECD regions is offset by energy demand from developing regions. India's energy growth is expected to outpace China's" over a time horizon to 2045 (OPEC, 2020, p. 59).

However, OPEC's view seems based on factual solidity and prospective reasonability. It is corroborated by Daniel Yergin, an influential US energy executive and vice-president of S&P Global. He says that over the coming decades, "the world's energy supply will come from a mixed system of rivalry and competition among energy choices. In this system, oil will retain a pre-eminent position as a global commodity" and remain "the primary fuel that makes the world go round. Some will simply not want to hear that. But it is based on the reality of all the investment already made, the timescales for new investment and innovation, supply chains, its central role in transport, the need for plastics from the building blocks of the modern world to the operating theatres of hospitals, and the way the physical world is organised." As a result, oil, along with "natural gas, which is now also a global commodity" will continue to play "an important role in the world economy" (Yergin, 2020, pp. 384–385).

The arguments converge with those of Bordoff and O'Sullivan (2022, pp. 4–5), who argue that "traditional fossil fuel suppliers will benefit from volatile fossil fuel prices". They add that the "combination of pressure on investors to divest from fossil

[5] The OECD is the Organisation for Economic Co-operation and Development and comprises 38 states: Australia, Austria, Belgium, Canada, Czechia, Chile, Colombia, Costa Rica, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Israel, Italy, Japan, Korea, Latvia, Lithuania, Luxembourg, Mexico, New Zealand, Netherlands, Norway, Poland, Portugal, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey and the United Kingdom.

fuels and uncertainty about the future of oil is already raising concerns that investment levels could fall in coming years, leading oil supplies to decline faster than demand declines—or to decline even as demand continues to rise, as is happening today". The result tends to lead to "periodic shortages and therefore higher and more volatile oil prices". It also tends to increase the power, at least in the immediate years, of Middle Eastern oil producers who extract oil cheaply and are less dependent on Western financial institutions, which now avoid financing fossil fuel projects.

Therefore, the scenarios outlined by OPEC, Daniel Yergin and Bordoff & O'Sullivan deserve serious consideration. It is important to note that OPEC anticipates that the shift of the centre of the world economy to the Asia–Pacific—where the vast majority of the population is located and growing rapidly—will compensate its loss of market share in the traditional developed world, i.e., the European Union, the US and Japan, for more than two and a half decades. OPEC also anticipates that Western countries' divestment and withdrawal from fossil fuel production will strengthen their global share and power. The recent investments by Saudi Arabia and its state-owned oil company, Saudi Aramco, point in this direction (Wilson, 2023). The scenario is also (very) plausible for other reasons linked to the complexity and difficulties of the transition period in an extraordinarily heterogeneous world. The long-term trend for Western economies is to gradually lose influence and power, at least in relative terms. This also highlights a potential vulnerability, in terms of energy security, of those areas of the world most dependent on fossil fuel imports during the energy transition—such is the case with the European Union. In turn, for the major fossil fuel producers, the transition, despite the dangers for its economies, carries also an opportunity for maximisation of profits related with fossil fuels. This can probably be done for many years to come, either by artificially reducing supply, manipulating markets, or taking advantage of geopolitical conflicts that intersect with energy supply. In 2022, Russia's deliberate use of the energy weapon against the West—i.e., the European Union—and Saudi Arabia's clear lack of political will to increase its production to reduce high prices leave little doubt about that.

4 The Deception of Renewable Energy Without Geopolitics

The literature review has also showed several ways in which the new renewable energy economy and geopolitics are interlinked. Taking into account the main ideas that emerge from the literature review, the following geopolitical risk areas were identified: (i) the concentration in certain countries—accentuated by possible scarcity—of critical minerals and rare earths, including the possibility of the emergence of a new "resource curse"; (ii) the use of electricity grids as a geopolitical weapon in a kind of substitute for the use of fossil energy (oil and/or natural gas); (iii) the cyberattacks on electricity and/or communications grids in an economy based on renewable energy, but increasingly also digital and dependent on such grids. For the purposes of this analysis, the last two areas will be addressed together. Naturally, a varied set of perspectives is found here. There are also those who anticipate a "new

brave world" of renewable and clean energy, largely co-operative and on the fringes of significant geopolitical tensions, so they set out to "debunk four emerging myths" (Overland, 2019). However, without prejudice to some useful criticisms made by this researcher from the Norwegian Institute of International Affairs (e.g., on the lack of a rigorous use of the concepts of critical metals and rare earths, and a linear extrapolation of past geopolitical problems) there are solid facts and trends that point in a different direction: very probably, geopolitics will continue to raise troubles to the new renewable energy economy. What is unknown is the exact extent and degree of the impact of geopolitical factors on the different countries of the world.

4.1 The Geopolitics of Critical Minerals

Before turning to this point, it is important to clarify that the concept of critical minerals is used here as defined by the American Geosciences Institute—which is similar to the conceptualization made by the International Energy Agency—meaning that "critical minerals are mineral resources that are essential to the economy and whose supply can be disrupted". Thus, the criticality of a mineral "varies over time as the supply and needs of society change". Currently, many critical minerals are metals that "are central to high-tech sectors. They include the rare earth elements and other metals such as lithium, indium, tellurium, gallium, and platinum group elements" (AGI, 2023).

The International Energy Agency has produced a detailed study on the role of critical minerals in the transition to renewable energy (IEA, 2022). In that study it was observed that "an energy system fuelled by technologies that provide clean energy differs profoundly from one fuelled by the use of traditional hydrocarbons." On the new resources needed, several points were also emphasised: "Minerals are a case in point. A typical electric car requires six times more mineral components than a conventional car, and an onshore wind power plant requires nine times more mineral resources than a gas-fired plant of the same capacity. Since 2010, the average amount of minerals required for a new unit of power generation capacity has increased by 50% as renewables increase their share of total capacity additions. The transition to clean energy means a shift from a fuel-intensive to a material-intensive system" (IEA, 2022, p. 28). The types of mineral resources used vary according to the technology. "Lithium, cobalt and nickel play a central role in giving batteries higher performance, longevity and greater energy density. Rare earth elements are used to make powerful magnets that are vital for wind turbines and electric vehicles. Electricity grids need huge amounts of copper and aluminium. Hydrogen electrolysers and fuel cells require nickel or platinum metals, depending on the type of technology. Copper is an essential element for almost all electricity-related technologies. These characteristics of a clean energy system mean that demand for minerals will increase significantly as more batteries, solar panels, wind turbines and grids are deployed. It also means that the energy sector will emerge as a major driving force in the growth of demand

for many minerals, highlighting the strengthening links between minerals and clean energy technologies" (IEA, 2022, p. idem).

On the issue of minerals, Bazilian (2018, p. 93) noted that the technical challenges linked to the growing need for minerals and metals for the energy transition were now slowly emerging. The same was true, he observed, of its geopolitical ramifications: "while the direction of travel in the energy transition is beginning to become clear, its pace and contours remain elusive". The issue has also been addressed by the International Energy Agency, both from the perspective of technical and business challenges to mineral extraction, and from the perspective of public policy and geopolitics. It should be remembered here that a concern with critical metals and rare earth elements, including their geopolitical dimension, was also identified in the literature review. One key idea that emerged from the literature review was that the change of energy model alone will not lead to a new era of energy security without geopolitical risks. What is anticipated is a transformation of the geopolitical risks linked to energy supply, which will not be the same as what we were used to.

As also noted by the IEA (2022), beyond the environmental benefits of adopting clean and renewable energy, delicate questions "about the security and resilience of renewable energy supply chains" are also emerging—and increasingly clearly—to which policy makers must respond. Multiple facets thus need to be considered, not least because "supply chains for clean energy technologies can be even more complex" (and more opaque) than those for traditional oil and natural gas, for example. However, the most geopolitically sensitive issue is not even that, but the fact that the supply chains for many of the technologies used—and the raw materials needed in the new energy model—are "more geographically concentrated than oil or natural gas". Examples of this are lithium, cobalt and rare earth elements. For these mineral resources, the top three producers "control well over three-quarters of global production. In some cases, a single country is responsible for about half of world production. South Africa and the Democratic Republic of Congo account for around 70% of global platinum and cobalt production respectively, and China accounted for 60% of global rare earth element production in 2019." The degree of concentration "is even higher for processing and refining operations. China has gained a strong presence worldwide. China's share of refining is around 35% for nickel (the figure becomes higher when including the involvement of Chinese companies in Indonesian operations), 50–70% for lithium and cobalt, and up to 90% for rare earth element processing that converts mined production into oxides, metals and magnets." (IEA, 2022, p. 32).

Of course, there are also potential positive effects on energy security related with the transformation that must be taken into account, which have also been identified during the literature review. These are to be expected especially once the energy transition has been largely realised. Likely will be the case of those areas of the world that are most dependent on external fossil fuel supplies, such as the European Union, but have also high financial and technological resources. An important dimension of this transformation is linked to the fact, mentioned earlier, that the minerals needed for a renewable energy economy can be recycled. Unlike fossil fuels, which are single-use, minerals are permanent materials and can be reused

and recycled. This will happen, of course, if the right infrastructure and technologies are in place. Another thing to consider is the discovery of deposits of critical minerals and rare earth elements. In Europe, for example, Sweden's state-owned mining company, Luossavaara-Kiirunavaara Aktiebolag (LKAB), recently announced a major discovery. It said it had identified "significant deposits of rare earth elements in the Kiruna area, metals that are essential for, among other applications, the manufacture of electric vehicles and wind turbines." Thus, analysing the issue of critical minerals should also take into account the possibility—which will be confirmed (or not) in the future—that new mineral discoveries could significantly reduce the exposure to this new geopolitical risk in parts of the world such as the European Union. Important here is the European Raw Materials Act proposed by the European Commission. In addition to containing a list of critical raw materials also includes a list of "strategic raw materials, which are crucial for technologies important for Europe's green and digital ambitions" and for which "there are supply risks in the future", setting several (indicative) targets for Europe as a whole: (i) at least 10% of annual consumption for extraction; (ii) at least 40% of annual consumption for treatment; (iii) at least 15% of annual consumption for recycling; (iv) a maximum of 65% of annual consumption coming from a single third country for each strategic raw material at any relevant stage of treatment. Of course, we will need some years to realise the impact of this type of measures on the energy security of the European Union (European Commission, 2023).

4.2 The Geopolitics of Electricity Networks and Vulnerability to Cyberattacks

The German Institute for International and Security Affairs (Stiftung Wissenschaft und Politik—SWP) has carried out a comprehensive study on the geopolitics of electricity, focussing mainly on the relationships between networks, space and (geo)political power. In this text, the authors first draw attention to the geopolitical relevance of electricity, which "has traditionally been underestimated". However, with the transformation of the energy model from fossil fuels to renewables, "electricity grids are gaining importance and momentum". China, particularly, is driving global electricity interconnectivity with its Belt and Road Initiative (BRI). For all these reasons, "the impact of electricity interconnectivity on international relations and geopolitics deserves greater scrutiny" (Westphal et al., 2022, p. 5). The same study adds further insights on the problem: "The interaction of three factors—the electricity grid, space and geopolitical power—merits close scrutiny. Infrastructure networks create techno-political and techno-economic spheres of influence. Since electricity spaces extend beyond state borders and cross different jurisdictions, they allow for a diffusion of geopolitical power. The vulnerability of states to external power projection and influence also depends on the robustness and resilience of electricity networks". The following is also stated by the authors of the study: "The

interaction of three factors—the electricity grid, space and geopolitical power—merits close scrutiny. Infrastructure networks create techno-political and techno-economic spheres of influence. Since electricity spaces extend beyond state borders and cross different jurisdictions, they allow for a diffusion of geopolitical power. The vulnerability of states to external power projection and influence also depends on the robustness and resilience of electricity networks" (Westphal et al., 2022, p. idem). In its recommendations for policy makers in the European Union (and Germany) it is stated that "a robust external policy for electricity" is needed and that the "importance of electricity interconnectivity goes beyond the purely technical-physical necessity". In other words, electricity interconnectivity thus emerges as "a key area of geopolitical and geo-economic competition" in which the European Union should seek to play an increasingly important role, as it is both a sovereignty and a resilience issue (Westphal et al., 2022, p. 52).

Another recent publication, now from the Danish Institute of International Studies, also summarises the implications of the shift to renewable energy in terms of geopolitical power. It mainly points out the new vulnerabilities—and new geopolitical weapons—that will tend to emerge from the ongoing energy transformation. It is anticipated that "power cuts could become a new instrument of foreign policy" and cyber-attacks become a growing "threat to critical energy infrastructure around the world" (Berling et al., 2021). The researchers from the Danish Institute also emphasise that as "utilities around the world turn to renewable energy sources", which entails an increasing use of digital technologies and the Internet, cyber sabotage, even if on a small scale, "is likely to become a major feature of energy geopolitics". This will tend to happen because technological developments themselves, combined with increased reliance on electricity grids, tend to create new vulnerabilities as well as increase the ways to carry out cyber-attacks on grids.

In a similar analytical vein, Amy Myers Jaffe (2021a); (Jaffe, 2021b) spoke of the growing dependence on electricity grids around the world. Jaffe also recalled that about half a century ago it was OPEC countries that were the first to use "an energy weapon in the form of an oil embargo, causing shortages in the US and other parts of the world", which affected global politics and economics for a long time. "Now, as the world increasingly moves to electricity to power everything from communications to transport and industry, it may be that disruption of electricity supplies becomes the next energy weapon." She adds that "with more than half of the world's energy use expected to be generated by 2050 according to the International Renewable Energy Agency (IRENA), denial of electricity service has the potential to be a powerful weapon. Smart devices and the Internet of Things—which refers to physical objects embedded with sensors and software that can exchange data with each other and other systems over the internet, often to perform autonomous actions—expand the surface area for hackers to attack. One area of particular concern is supervisory control and data acquisition software systems, known as SCADA[6] systems, which are increasingly being used to remotely monitor and control industrial infrastructure, including power grids. An attack on such systems can be extremely dangerous" (Jaffe,

[6] Supervisory Control and Data Acquisition.

2021a). In short, probably one of the side effects of the energy transition will be to increase the degree of geopolitical risk exposure of electricity networks, including to increasing cyberattacks.

5 Final Thoughts: The Trouble of the Intersection of Two Geopolitics

The first idea to emphasise is that the exploratory analysis carried out here reinforces the conviction of the necessity to avoid the trap of linearity in international events. It also shows the added value of using complexity theories and concepts on the issue of energy transition, which help overcome the shortcomings of a classical approach using (only) neorealist lenses. The energy transition and the intersection of the two geopolitics (the old of the fossil fuels, and the new of the renewables), as long as this occurs, can have unexpected consequences in its speed, in the energy security, in the well-being of populations, in the power of states in current or future international conflicts, etc.

The second idea is, despite the uncertainty, that the energy transition from fossil fuels to sustainable energy will transform the geopolitics of energy, but it will not make the geopolitical dimension of energy supply and energy security disappear. Although the pressing need to reduce CO2 emissions—and techno-economic progress in renewable energy technologies—there is probably still a long way to go before the end of fossil fuels. As previous explained, the transition is extraordinarily complex involving transformations that require very substantial changes in the economy and society. Thus, from the data available until now, it's not likely that the old geopolitics of fossil fuels will lose relevance quickly, although this also depends on the parts of the world we consider in particular. At the global level, what seems most likely to happen in the next years is a continued and growing demand for oil and other fossil fuels in economies such as China, India and others, which will shift consumption mainly to Asia (and a decline in consumption in the West)—but Asia is also becoming the centre the world economy.

The third idea, although it may seem (excessively) pessimistic for some, is quoted here from the work of Bordoff and O'Sullivan (2022, pp. 2–3). "Talk of a smooth transition to clean energy is fanciful: there is no way the world can avoid major disruption by remaking the entire energy system, which is the lifeblood of the global economy and underpins the geopolitical order." Moreover, "dependence on dominant fossil fuel suppliers such as Russia and Saudi Arabia is likely to increase even before it collapses". As for the world's poorest countries, "they will need to use large amounts of energy—more than in the past—to prosper, even while facing the worst consequences of climate change". Thus, "clean energy will come to represent a new source of national power", but it also brings with it "new risks and uncertainties." As they emphasise, it should be made clear that "these are not arguments for delaying

or abandoning the energy transition". On the contrary, they are even additional arguments for accelerating "efforts to combat climate change". However, it is necessary to properly assess "the risks and dangers that will result from an interspersed transition" to a new energy model, in order to minimise the costs of such a transition.

To summarise the key ideas of this chapter, the exploratory analysis carried out allows us to conclude that the intersection of two geopolitics, of the old and of the new energy models, probably for several years or decades to come, will significantly complexify the energy transition. (However, it may be a powerful stimulus for its acceleration by technical innovation and public policies, in Western countries and China, both largely dependent on fossil fuels). Thus, both bring with them a great deal of unpredictability. The most critical problem to manage during the ongoing energy transition—especially for fossil fuel-dependent areas of the world, such as the European Union —, it's the very complex intersection between the supply and demand of the new renewables and the old oil and natural gas. It may create a chronic mismatch (deliberately provoked by some big fossil oil producers, or due to natural market contingencies that may occur) between supply and demand in the markets until it the energy transition will be fully completed. So, a turbulent period lies ahead, whatever its duration, geopolitics, the old one and the new one, cannot be ignored in energy supply and security.

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Turning Chaos into Meaning: A Cognitive Approach to Public Policy

Luísa Godinho and Carlos Oliveira Santos

Abstract Chaos dynamics are abundantly present in nature as well as in societies as an undesirable phenomenon. Sometimes, chaotic situations and problems are associated with a lack of meaning to understand their dynamics. The ability to control chaos, to enforce or suppress it, includes the capacity to understand those situations and problems, their meaning, and to develop new concepts and processes to manage them. This chapter presents a cognitive approach to public policy, identifying new concepts and processes to face social problems. Giving meaning to problems that were previously seen as chaotic. Generating a model of interventions to overcome them.

The concept of chaos as absence of meaning was defined a long time ago. Bolotin and Yanovsky (2017) made a brief review of the cosmological views present in ancient civilizations. The concept that chaos appears before everything was formulated by several Greek authors. For Hesiod in his *Theogony*, "in the beginning, there was only chaos. Then out of the void appeared Erebus, the unknowable place where death dwells, and Night. All else was empty, silent, endless, darkness. Then somehow Love was born bringing a start of order. From Love came Light and Day. Once there was light and Day, Gaea, the earth appeared" (lines 116–125).

Robert Fludd (1574–1647), the English cosmologist even tried to draw "this first matter, the primordial entity… the raw and undigested mass called Chaos" (1617, 24) as a black and dark obscure mess restrained by a square" (Fig. 1). "Et sic in infinitum."

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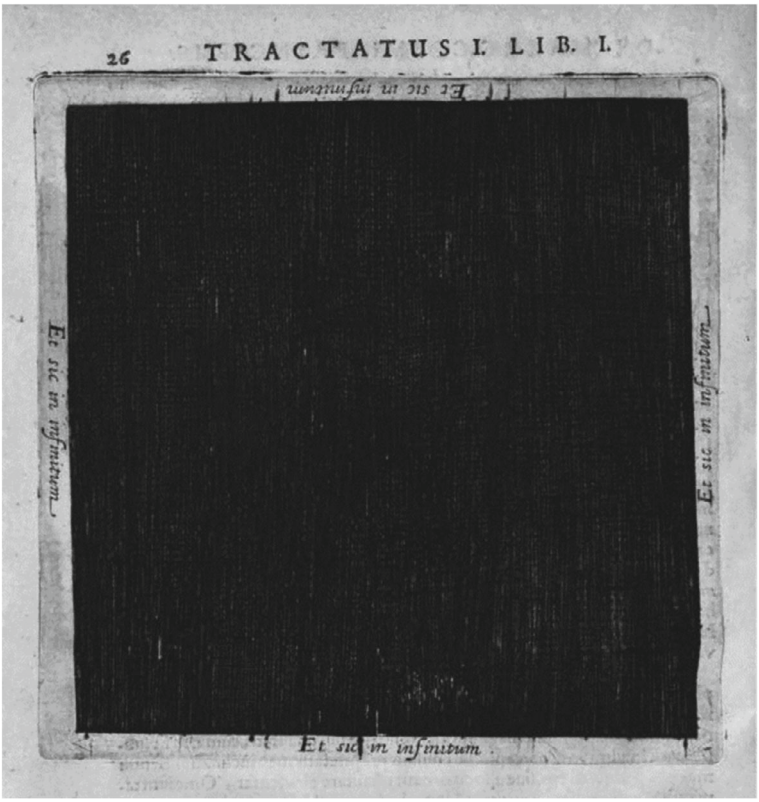

Fig. 1. A representation of chaos *in* Robert Fludd, *Utriusque Cosmi Maioris scilicet et Minoris Metaphysica, Physica Atqve Technica Historia*, 1617, 26

That change from chaos to some kind of order is also present in other mythologies (Bolotin, Y., Tur, A., and Yanovsky, V., Chaos: Concepts, Control and Constructive Use, Springer, 2017). In Egypt, the formless universe gave birth to the sun god Ra. In China, dragons emerged from a homogeneous and uniform space, imposing yang order on the four corners of yin substance. The same story also appears in the Brahmanical heritage as well as in Greek cosmology where chaos is an a-historical state from which time comes.

Interpretations of chaos remain associated with random behaviour, a state of maximum entropy, but in fact, chaos is not random at all. In a random system, anything is possible. In a chaotic system, given a specific point in the system's trajectory, the next point also cannot be predicted. However, this also does not mean that it can be anything. It is among many possible future states, but this number is never infinite. In this type of chaotic phenomenon, even if it is impossible to predict what will happen next, we know that what will happen will be drawn from a set

of alternatives larger than one, but smaller than a too high number which would be impossible to process (Byrne, 1998).

Nowadays, in terms borrowed from applied mathematics, chaos refers to complex, irregular, non-periodic deterministic behaviour with an appearance of randomness but maintaining latent order. This is a very important presupposition because it places chaos theory in a non-stochastic view of the world.

There is, however, a common thread in ancient and modern interpretations. The transition or the managing of the chaos is always a process of acquiring meaning, the meaning of chaos, or a new meaning created from it. As Andreas Höfele et al. stated, there exists "inevitable tension between the nothingness of chaos and the 'somethingness'… of its conceptualizing and representation" (2021, 5). Quoting Berger and Luckman (1966), Höfele et al. related this wandering for 'somethingness' with the social construction of reality where "institutions and roles are legitimated by locating them in a comprehensively meaningful world" (2021, 8). And this working principle is not limited to 'archaic' cultures. The maintenance of a comprehensively meaningful symbolic universe is just crucial for modern societies to produce proper solutions to social problems.

1 A Cognitive Approach

This search for meaning is particularly relevant to the challenges that public policies currently face. Societies constantly face new problems, many of which do not have adequate concepts and processes to understand and intervene in them. Such problems—from waves of massive immigration to the exponential growth of social exclusion, from urban violence to populist radicalism—often appear chaotic, given the inability of institutions and public leaders to understand them and generate effective measures to defeat them. In order to surmount that inability Bolotin et al. propose the concepts of control and constructive use of chaos.

One of the dimensions to approach these situations is the cognitive one, which has shown strong development in recent decades, both in academia and in public intervention. By demarcating from exclusively normative, institutional, behaviourist, functionalist, rational choice, or merely discursive approaches (see Marsh & Stoker, 1995), cognitive approaches are based, as Surel refers, on the importance of considering "elements of knowledge, ideas, representations or social beliefs in the elaboration of public policies", in the path of the "classic" approaches of cognitivism, namely those originating from psychology (Broadbent, 1958; Neisser, 1967).

The perspective of this chapter of giving meaning to problems that were previously seen as chaotic, fits into what is a common postulate to cognitive approaches, namely, "the major hypothesis that associates every significant change in public action to a transformation of the cognitive and normative elements characteristic of a policy, a problem or a specific sector of public intervention" (Surel, 2006, 85). This perspective which states that the State in action (Jobert & Muller, 1987) is not only a homogeneous and monolithic unit, of immediate and unilateral effectiveness, as well

as the awareness of the complexity "of the intellectual constructions which preside to the emergence and then the statement and the fulfilment of a policy" (Faure et al, 1995, 9), led to the development of numerous approaches to political processes.

In continental Europe there have been several approaches: the notion of *reference* (*référentiel*) from the so-called Grenoble school centered in Bruno Jobert and Pierre Muller (1987); Claudio M. Radaelli's concepts of *récits* (2000) or Giandomenico Majone's *argument and persuasion* in the political process (1989); in Germany, the *network approaches* from Renate Mayntz (1993), Gerhard Lehmbruch (1995a, 1995b), Franz-Urban Pappi (1995) or David Knoke et al.(1996), beyond its general incidence in the *Steuerungstheorie* school (see Giraud, 2002).

In England this procedural field is patent in Andrew G. Jordan and Jeremy J. Richardson's (1983) and Singer's (1990) *policy communities*; in the *policy networks* from David Marsh and Roderick A. W. Rhodes (1992), Martin J. Smith (1993), Keith Dowding (1995) and Mark Tatcher (1998); or in Emery M. Roe's (1998) *narrative policy analysis*.

In the United Sates there are the *open-systems frameworks* from Richard Hofferbert (1974); the by Hugh Heclo (1978); the Everett M. Rogers' *innovation and diffusion models* (1983), applied namely by Berry and Berry (1990; 1992; 2007); the *multiple streams framework* by John Kingdon (1984) and Nikolaos Zahariadis (2007); the *public advocacy coalitions* from Paul A. Sabatier (1988) with Hank Jenkins-Smith (1993); the *policy paradigms* by Peter A. Hall (1993); the *punctuated-equilibrium theory* applied to political science by Frank R. Baumgartner and Bryan D. Jones (1993); the *road maps*, or *focal points & glue* by Judith Goldstein and Robert Keohane (1993); Katzenstein's *national traditions* (1996); the *public philosophies* or *public sentiments* by Campbell (1998, 2004); Berman's *programmatic beliefs* (1998); Blyth's *strategic weapons* (2002); the *collective memories* by Rothstein (2005); Nicolas Jabko's *strategic constructions* (2006); or the *discursive institutionalism* by Vivien A. Schmidt (2008), closely linked to the Grenoble school.

The new ways of thinking and intervening within the scope of public policy, which derive from these processes, constitute new conceptions of public action in the respective sectors, endowed with a structure of meaning that allows us to understand situations and problems and conceive solutions. These are processes of political *mediation*, involving *mediators* who ensure the transition of ideas from the intellectual field to a field of power, articulating successively in different dimensions, cognitive, normative, and instrumental (Fig. 2):

- "in the cognitive dimension; the references provide the elements of causal interpretation of the problems to be solved.
- in the normative dimension; they define the values that need to be respected to deal with these problems.
- in an instrumental dimension; the references define the principles that should guide action, depending on that knowledge and those values." (Jobert, 1992, 220–221)

These processes involve several cognitive components, such as *values*, *norms*, *algorithms,* and *images.*

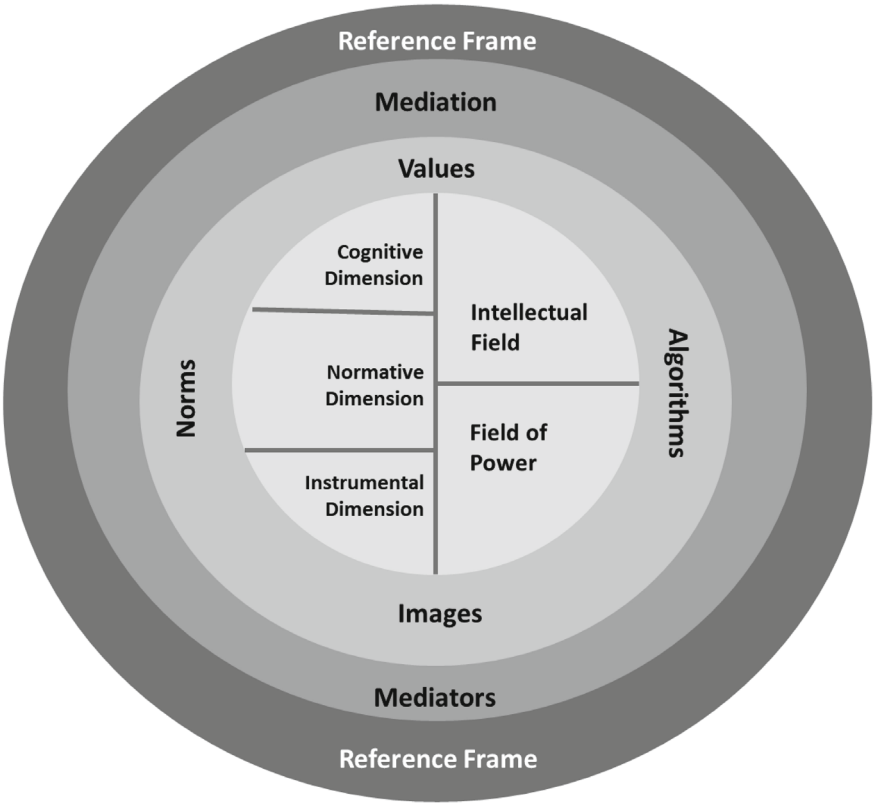

Fig. 2 Reference frame components (Santos, 2016)

> "Values are the most fundamental representations... about what is good and evil, desirable and rejectable"; "the norms define the differences between the real understood and the real wanted"; "the algorithms are the causal relations which express a theory of action"; "the images... make immediate sense without going through a long discursive course... they constitute a central element of a reference." (Muller, 1995, 158–159)

2 A New Reference on Public Health

Let us focus on the field of public health. In the 1940s, it became clear that public health policy could not be reduced to the medical field, to what was called by Antonovsky (1979, 1987, 1996) a *pathogenic* concept. The World Health Organization (WHO) was created in 1948, and in the preamble to its Constitution, adopted at the International Health Conference in New York in 1946, it was defined that "Health is a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity" (WHO, 1946, 100). This salutogenic (Antonovsky,

1996) definition would translate the incorporation of human sciences into that field where only medicine wanted to reign. In health and illness, the socioeconomic dimensions that involve the individual should also be considered, and, in the fight against illness, the role that they, individually and collectively, physically, psychologically, and socially, would have to play should also be considered. This role implies, on the one hand, State intervention in the social and environmental factors of health, and, on the other hand, the citizen's own active position in adopting behaviours that can combat, control, or prevent illnesses.

A new reference thus began its mediation, in the cognitive dimension and in the intellectual field. Its decisive transition to a normative dimension and to the field of power would take place, namely, in 1974, when the Canadian government, presided over by Pierre Trudeau, with Marc Lalonde as Minister of National Health and Welfare, undertook and adopted the document A New Perspective on the Health of Canadians, known as the *Lalonde Report*, considered internationally as a very important milestone in the new public health (Bunton & Macdonald, 1992/2002).

Its starting point was the observation of an increasingly chaotic situation. Within the framework of the modernization of society, and despite the profound improvement of the public health system from the perspective of medicine and medical services, numerous problems arose: among others pollution, sedentary habits, dangerous road behaviour, abuse of alcohol, tobacco or drugs, harmful eating patterns, which caused increasing cases of illness, for which the health system established healthcare couldn't do much more than to be a network to catch victims.

In this evidence, of which some data was exposed, the Lalonde Report also noted that the health system itself, only considered from its perspective of the medicalization of society, revealed growing problems (which would dominate, as we know, the following decades in countless countries): a worrying escalation in costs; a disproportionate burden on the construction of equipment, particularly hospitals; persistence of inequality in access to healthcare, particularly between urban and rural areas; deficient but recurring forms of organization and management of resources; constant shortages, given the demand for services, doctors and staff; increase in situations lacking outpatient support, with no response capacity on the part of the installed system.

To support its new cognitive dimension, the *Lalonde Report* sought to deepen the WHO's 1946 definition, creating its Health Field Concept that would incorporate four major elements: human biology, the environment, lifestyles, and the organization of health provision.

The *reference* for a new public health would have to affect all of them, and its mediators could not be limited to traditional health personnel and institutions, but encompass the government, various institutions and, above all, the citizens themselves.

The Canadian Government, understanding its responsibility arising from this new framework, introduced several appropriate disciplines, among them, expressly, social marketing, which had been defined only three years ago (Kotler & Zaltman, 1971).

> The ultimate philosophical issue raised by the Concept is whether, and to what extent, government can get into the business of modifying human behaviour, even if it does so to improve health. The marketing of social change is a new field which applies the marketing techniques of the business world to getting people to change their behaviour, i.e. eating habits, exercise habits, smoking habits, driving habits, etc. It is argued by some that proficiency in social marketing would inevitably lead government into all kinds of undesirable thought control and propaganda. The dangers of governmental proficiency in social marketing are recognized but so are the evident abuses resulting from all other kinds of marketing. If the siren song of coloured television, for example, is creating an indolent and passive use of leisure time, has the government not the duty to counteract its effects by marketing programs aimed at promoting physical recreation?... One must inevitably conclude that society, through government, owes it to itself to develop protective marketing techniques to counteract those abuses. (*Lalonde Report*, 1974, 36-37).

In this way, a pattern began that encouraged the emergence of a social marketing framework, with an impact on public policies, based on the new public health framework, reinforced, namely, by the Alma-Ata Declaration, adopted in 1978., at the International Conference on Primary Health Care and by the Global Strategy for Health for All by the Year 2000, of 1981, as well as by the Ottawa Charter of the International Conference on Health Promotion, of 1986.

However, several international organizations, such as the Academy for Educational Development, the World Bank, and UNICEF, were promoting that new social marketing framework in improving health behaviors. Appropriate national policies and institutions were created, such as the Health Canada Social Marketing Unit (currently part of the Social Marketing Network and Health Canada's Marketing and Communications Services Directorate) in Canada, the Health Sponsorship Council in New Zealand, the National Center for Health Marketing (currently the Gateway to Health Communication & Social Marketing Practice of the Centers for Disease Control) in the USA, and the National Social Marketing Center in England (French, 2015). Let's look at the English case in more detail (Santos, 2016).

3 The English Case

During the 1990s, in England, the problems of the English National Health Service (NHS) were evident: the increasing costs of the public health *pathogenical* paradigm; the scarce inclusion of principles and processes of the New Public Health (NPH) presented by the WHO decades earlier; the ineffectiveness of behavioral interventions based solely on communication. However, the influence of two very determining global references was being processed. On the one hand, that of NPH. Several government deliberations and reports, under different leaderships, introduced NPH concepts and approaches to the United Kingdom (see DHSS, 1980; DoH, 1992). On the other hand, the social marketing reference in public health created diverse and decisive influences and mediators in England (Fig. 3). A context was generated with an impact both on academia (especially with Gerard Hastings and the Institute for Social Marketing at the University of Stirling), as well as on the Government itself

and its Department of Health (DoH), as well as on the National Consumer Council, an institution established by the Government in 1975 to give an independent voice to consumers in the UK. Also very important was the influence on some public officers directly involved with health communication (at the Communication Health Development Agency with Jeff French and Clive Blair-Stevens) and its impasses.

The intellectual field of the new reference was reinforced by the *Wanless Reports* (2002, 2004), a review of the long-term trends affecting the health service in the UK, giving way to a strategic field of power, and moving decisively towards a normative dimension through the *Choosing Health* deliberation (2004), the creation of a National Social Marketing Strategy Team (Fig. 4), the *It's Our Health* study (NSMC, 2006a) and the establishment of an intervention institution, the National Social Marketing Center (NSMC), generating countless normative and procedural

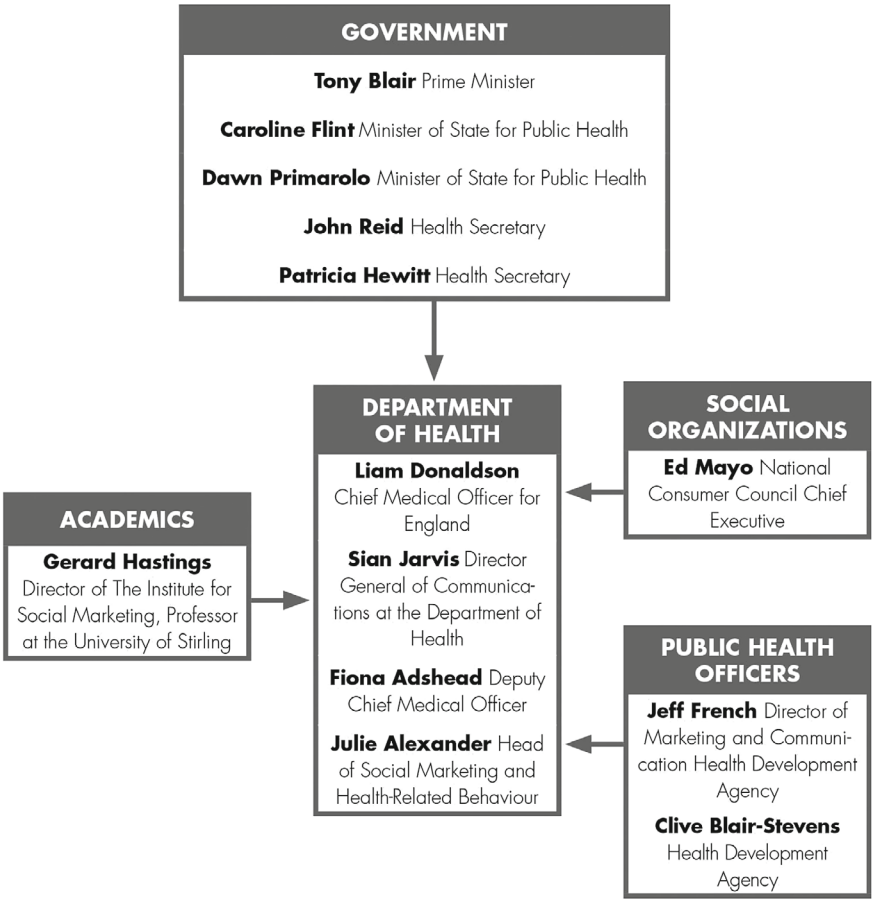

Fig. 3 English social marketing on public health reference main mediators (DoH, 2004; NSMC, 2006a; DoH, 2008; Santos, 2016)

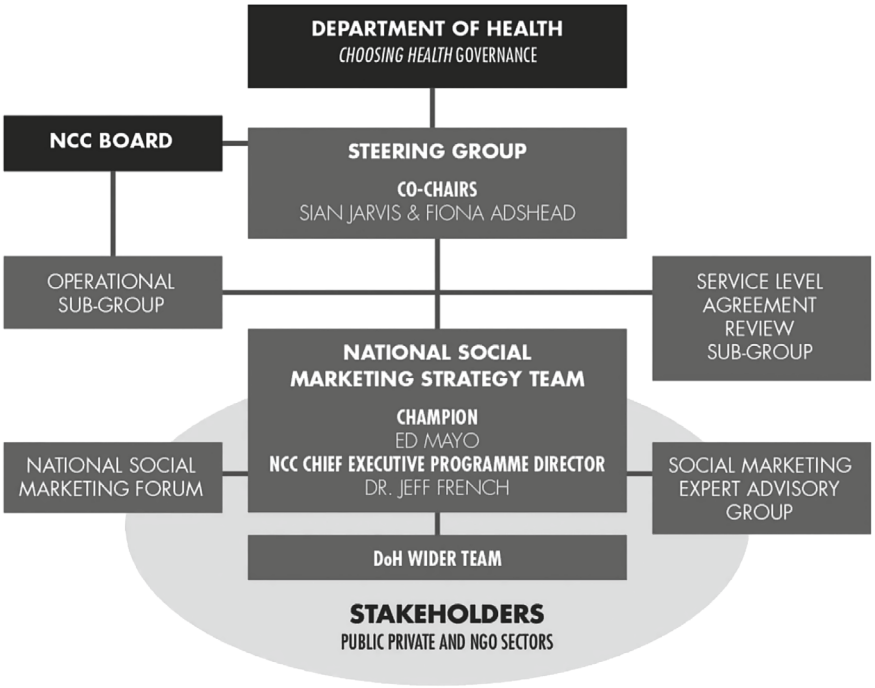

Fig. 4 English reference strategical governance (NSMS, 2005; Santos, 2016)

contributions (NSMC, 2006b, 2006c; French & Blair-Stevens, 2007; NSMC and French, 2008; NSMC and Eagle, 2009; DoH, 2010) Among them the definition of the National Occupational Standards for Social Marketing (NSMC, 2009d), through a vast process concluded in 2009 under the leadership of the Marketing Sales and Standard Setting Body (MSSSB), an institution licensed by the Government to define professional qualification standards.

This intense normative work supported many training and coordination actions with DoH entities at different levels, creating conditions for the emergence and progression of an instrumental dimension. This dimension took shape in several Learning Demonstration Sites (NSMC, 2009a) in various locations in England, and in a so called Beacon Partnership Project (NSMC, 2009b) with local social organizations, to promote and monitor good practices. However, regional structures were created to implement the national strategy. An online Showcase (https://www.thensmc.com/resources/showcase/browse) ensured the knowledge and dissemination of significant cases.

Mobilizing thousands of stakeholders and generating new mediators, at regional and local level, the framework incorporated major national interventions to improve behavior, in areas such as obesity (*Change4Life*), prevention of drug use (*FRANK*), reduction of consumption of alcohol (*Know Your Limits*) or encouraging the consumption of vegetables and fruit (*5-a-Day*) (Fig. 5).

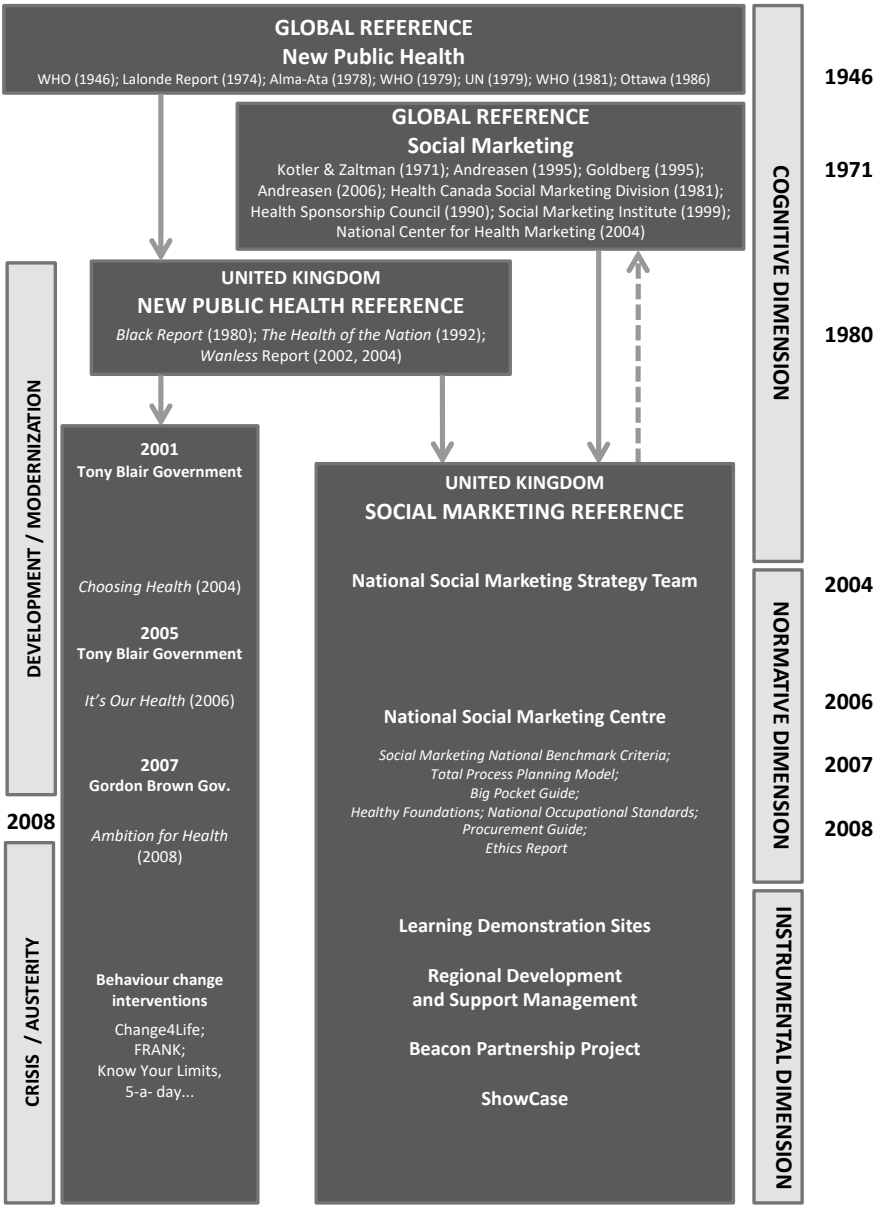

Fig. 5 English reference timeline

4 The English Reference Evolution

The global crisis of 2008, intensely felt in the United Kingdom, generated a significant change in several paradigms, with strong consequences in different areas of public policies. The area of social marketing in public health would not be alien to this profound change, but what was verified is that it remained (Fig. 6), although showing inflections towards reinforcing its effectiveness and demonstrating its results. Another innovative aspect was the notorious interest in processes, such as those in behavioral economics, that are closer to this search for efficiency.

A notable aspect is that this mutation occurred during the Labor Government, led by Gordon Brown, and cannot, therefore, be exclusively attributable to the conservative-liberal governmental political change, which took place in 2010, even though it has accentuated those aspects, namely by the *Changing Behavior, Improving Outcomes* deliberation (DoH, 2011a). The NSMC was, in fact, channeled towards them, having developed a *Value for Money* assessment model (NSMC et al., 2011a; NSMC et al., 2011b).

Given that the reference gained new mediators, many stakeholders, and a considerable insertion, at various levels of the DoH, the NSMC ceased to be the central institution structurally linked to the DoH, to become an independent social enterprise, a community interest company, without losing its capabilities as an important consultant specializing in this area. Once again, it was not a question of "killing" the national social marketing policy, but of converting it to concepts of reducing central structures, increasing outsourcing and decentralization.

However, the change in the media and in the conditions of access for citizens had great reflection and impact on this policy. Influenced by the work of Jay Bernhardt (2011), all subsequent deliberations and normative documents of this policy emphasized those three components of the reference: effectiveness, increasing improvement of results and digital connection (social media, on-demand health, big data…).

In 2013, Public Health England (PHE) was founded as a new DoH entity to "protect, improve and reduce inequalities in health and well-being". PHE committed itself, in 2014, to the creation and implementation of a *Strategy 2014 to 2017* (PHE, 2014), whose first evaluation, in 2015, demonstrated positive results (PHE, 2015), having been successively renewed in 2017 (PHE, 2017) and in 2020 (PHE, 2020), ensuring the continued evolution of this social marketing policy in public health through numerous interventions and evaluations (see Department of Health and Social Care, 2023). The problems of the NHS didn't disappear in England but a considerable amount of them were solved by this systematic national policy on social marketing for public health.

The English policy on social marketing for public health was a significate contribution for the promotion of this field all around the world. In 2017, the International Social Marketing Association (ISMA) and the other regional social marketing associations developed a *Global Consensus on Social Marketing Principles, Concepts and Techniques*:

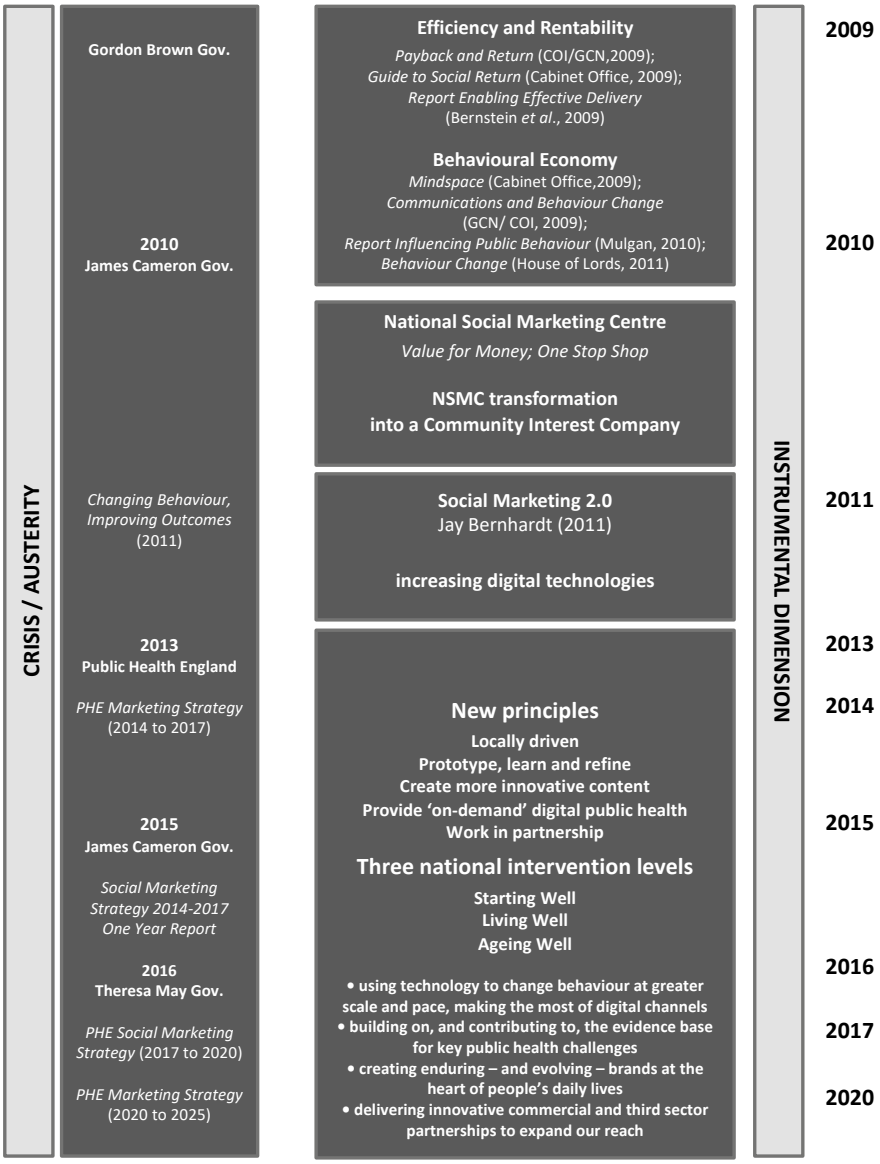

Fig. 6 English reference evolution timeline

Social Marketing seeks to develop and integrate marketing concepts with other approaches to influence behaviour that benefit individuals and communities for the greater social good. Social Marketing practice is guided by ethical principles. It seeks to integrate research, best practice, theory, audience, and partnership insight, to inform the delivery of competition sensitive and segmented social change programs that are effective, efficient, equitable and sustainable.

Meanwhile, ISMA requested a systematic review which was published in 2018: the *Compilation of Social Marketing Evidence of Effectiveness: Key References* (2018) coordinated by Jeff French and Doug Evans. It shows a large amount of evidence of the capacity of social marketing to improve health and social behaviours.

5 A Reference Model to Public Policy

Under Yin's (1984–2003) or Eisenhardt's (1989) perspective, it is admissible to generalize analytically the results of a case study research into a theoretical cognitive framework. According to Feagin et al. (1991) and to the crucial case concept developed by Eckstein (1975) and by Gerring (2008), even if such model is built based only on a single case, its pertinence is justifiable. Yin is also very clear on this aspect:

> Analytic generalization can be used whether your case study involves one or several cases... The main point at this juncture is that you should try to aim toward analytic generalization in doing cases studies, and you should avoid thinking in such confusing terms as "the sample of cases" or the "small sample size of cases", as if a single case study were like a single respondent in a survey or a single subject in an experiment. (Yin, 2003, 33)

Figure 7 attempts to represent a generic framework for a national policy based on a new reference, in a cognitive perspective. On a national level, to find what Immergut (1993) names as *access points*, the global-sectorial reference frame needs what Hill (1997–2005) designates as *nesting process*, an incubator framed in a compatible public policy field.

It is from there that one can generate a new national reference, through a mediation process which involves:

- Mediators, including individuals and institutions.
- Research processes which substantiate normative and instrumental dimensions.
- Norms and standards' establishment.
- Training sessions and mediators' extension.
- The establishment of instrumental processes and means.
- The implementation of interventions.
- Its evaluation and possible reformulation.

Mediation between those agents and processes runs through the specific elaboration of the new frame of reference, its *creation*, its *sedimentation* (considered as "a progressive adaptation of the reference by differentiation", Jobert & Muller, 1987, 132).) and its *mutation*, which can be translated or not by the creation of a new reference or, in case of decline, by the disappearance of the reference itself.

During its process, the reference mediation in order to become effective goes through three dimensions: cognitive, normative and instrumental, with consonant transition from the intellectual field into the power field, through policies capable of supporting the mediation in all those dimensions.

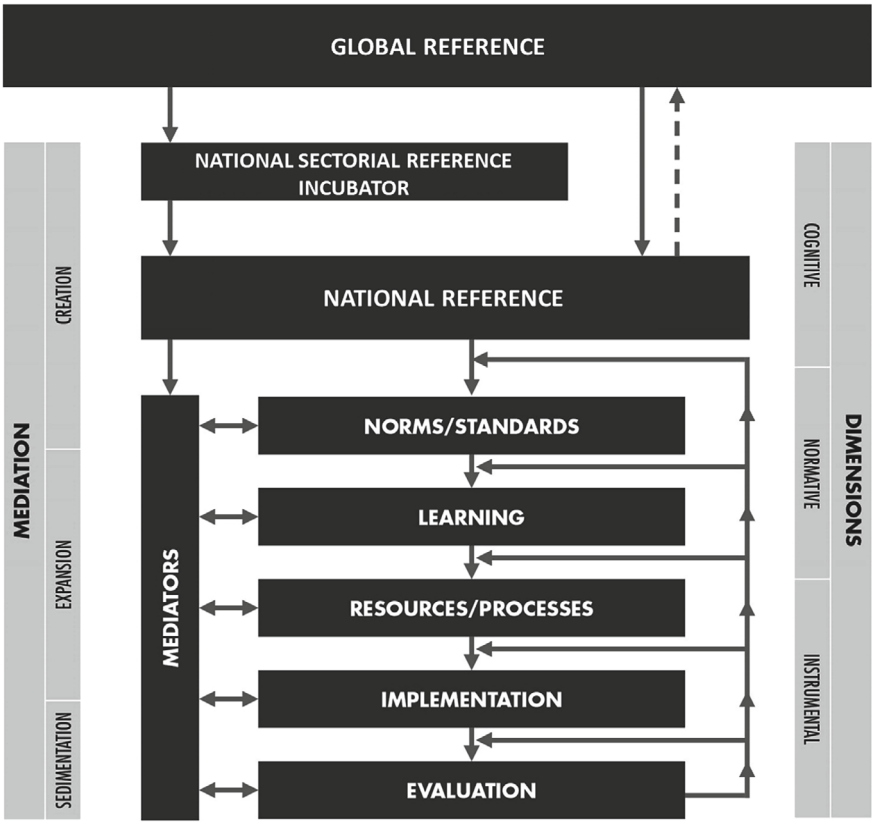

Fig. 7 A new reference framework

This process of policy based in a new reference supposes a responsive and accountable public governance, subject to pragmatic concepts and criteria, and to adequate empirical processes. The strength of this theoretical framework lies in its capacity to generate policies and interventions facing serious social problems. The different aspects of the principles and the performances of this cognitive approach of a national policy based on a new reference can be tested, verified, and discussed. In this sense, its formulation, as Evera (1997) stresses, can show a large explanatory power, elucidate by simplifying, be clearly framed, be falsifiable, explaining important phenomena, and be possessed by considerable prescriptive richness.

Based on the English experience about social marketing in public policy, we can formulate 12 lessons for the creation of a new reference on national public policy to face complex social problems:

1. Pay attention to global-sectorial references.
2. You need good mediators.
3. Decisions based in good research.

4. Articulate the three cognitive dimensions (cognitive, normative, instrumental).
5. Create proper organizations and allocate resources.
6. Establish appropriate norms and standards.
7. Promote good learning, training, and cooperation.
8. Combine national and local levels.
9. Promote learning demonstration sites.
10. Evaluate and ensure evidence and insight in people's wellbeing perspective.
11. Manage the evolution of your reference frame.
12. Good knowledge and policy transfer.

6 From Chaos to Policy

There are already attempts to face chaotic social problems with a cognitive approach. Some of these attempts were presented at the International Symposiums of Chaos, Complexity and Leadership (Istanbul).

Erçetin and Açıkalın (2018) in order to face the "law of the jungle" on the conventional leadership terrain, proposed "an educational or training program to develop a leadership model premised on women values and etiquette" (23).

Şişman (2016) reflected on language as a management and leadership "tool for understanding organizational life and subjective aspects of organizational life by trying to show the importance of language and discourse in analyzing organizations… In crisis situations, discourse, and the language that managers used are also extremely effective for overcoming the crisis, for ending the chaos… and for the formation of new order" (15).

This chapter underlines the proactive dimension of a meaningful cognitive approach on a national public policy level. As stated by Muller (1995, 161), "it is not only speech or ideas… it is ideas in action". On that dimension, "the discursive interactions may involve policy actors in discourse coalitions, epistemic communities and advocacy coalitions engaged in a "coordinative" discourse of policy construction and/or political actors and the public engaged in a "communicative" discourse of deliberation, contestation, and legitimization of the policies" (Schmidt, 2012, 86). Creating a model based on a crucial case study to introduce and manage new references on public policy is our contribution to face chaotic social problems.

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The Paradigms of Complexity and Chaos and the Economy: Some Evidence and Clues

Sandra Ribeiro and Henrique Morais

Abstract The world has been shaken by crises of unusual intensity: first there was the financial crisis of 2007/2008, soon followed by the sovereign debt crises of the countries of Southern Europe. Because the economic recovery was not consolidated and inflation remained at dangerously low levels, it was necessary for central banks to implement unprecedented unconventional monetary policy programs, the so-called quantitative easing. Finally, in a phenomenon only partly explainable by the COVID-19 pandemic and Russia's invasion of Ukraine, inflation soared, forcing monetary policy to make upward adjustments to official interest rates, also unparalleled in decades. Given all this, the question arises: if science and economic analysis are increasingly sophisticated and use very powerful predictive and explanatory tools, why are economists unable to predict these mega-crises? As Queen Elizabeth II said after the financial crisis, "It's awful—why did nobody see it coming?" The purpose of this paper is to demonstrate the fragility of the traditional tools of economics and economic policy in explaining a reality that is increasingly less linear and, furthermore, to demonstrate the important contribution of the theories of complexity and chaos in this explanation and in opening horizons for a less linear approach to economic phenomena. We divide the paper in four sections: we begin stating the economic mainstream (Sect. 1); in Sect. 2 and Sect. 3, respectively, we analyze the complexity theory (or paradigm) and the chaos paradigm and its relations with economics; and, finaly, in Sect. 4 we present our conclusions.

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1 Economic Mainstream

The scientific approach relentlessly seeks to discover phenomena with standardized behaviour, whose characteristics of regularity and repetition make them susceptible to being better explained. These characteristics provide the scientist with a solid basis for prediction, something that has always been an objective of science, but which in modern times, due to strong media pressure, has made this prediction of phenomena or certain variables a core objective for the comfort of public opinion.[1]

The social sciences, and in particular economics and international relations, are no exception to this rule, and have intensified this incessant search for models, which can be sophisticated (more or less) from the point of view of using qualitative or quantitative methods, to explain social phenomena.

In economics, as early as the classics, particularly David Ricardo, it was possible to see the importance of modeling. The theory of comparative advantage, based on the so-called factor endowments of two countries likely to engage in international trade, sketches out a fantastic model that makes it possible to understand how the two countries can benefit from renouncing the situation of autarky and engaging in international trade. The model, which was very sophisticated for its time (late 19th and early twentieth centuries), was not only decisive in dispelling the dominant mercantilist doctrine, but also because it made it possible to anticipate what the pattern of productive specialization of the countries involved in trade should be.[2]

Neoclassic authors such as Heckscher and Ohlin created mathematical general equilibrium models for international trade, which led to the famous Stolper-Samuelson theorem, which shows how an increase in the relative price of a good leads to an increase in the real income of the factor most used in the production of that good and, conversely, to a decrease in the real income of the other factor. This also highlights the attempt to predict the evolution of a variable based on the observed behavior of another variable/factor.

Perhaps the greatest economist of the twentieth century, John M. Keynes revolutionized macroeconomics with his General Theory, precisely by introducing the concepts and practices of the science in which he was originally trained, mathematics. The crowd of admirers he won from a very young age, who gradually came to form one of the two main schools of economics in the twentieth century (along with monetarism), was probably also associated with the novelty that Keynes brought to academia: the massive use of highly advanced mathematics, which demonstrated, at least to his admirers, that it was possible to explain social phenomena using the

[1] Recent examples seems to confirm this need to comfort public opinion, namely the pressure on the Hawaiian authorities for supposedly not being able to predict the intensity of the fires that caused hundreds of victims in August 2023 or, on another level, the permanent tension and millions of dollars of "incentive" for scientists to be able to find regularities in the behavior of the SARS-COV 2 virus and thus quickly find a vaccine for COVID-19.

[2] As it is not the purpose of this article, we must mention the geopolitical importance of the work of Adam Smith and David Ricardo, namely in promoting commercial cooperation to the detriment of the main (uncooperative) objective of mercantilism, that is, the accumulation of precious metals.

tools of the exact sciences. Keynes won the admiration of young economics students fascinated by his mentor's new linear approaches.

In essence, economists looked to mathematics and its linear behavior as a channel to strengthen their analysis and the perception of its merits in its ability to predict economic phenomena.[3] Moreover, these merits would be exponentiated by the ability of economic policy instruments, namely budgetary, fiscal, monetary and exchange rate policy, to be put at the service of political decision-makers to influence the economic cycle.

However, the assumption that the economic scientist would more easily be able to show the value of his postulates to the political decision-maker if he based them on mathematical models, supported by formulations that are often incomprehensible to that decision-maker, often hermetic, ends up being a kind of quasi-absolute truth for generations of economists.[4]

These formulations of the economic problem, or rather the attempt to explain the economic problem, are based on a set of principles/assumptions, of which we would highlight two that seem most fundamental: (i) equilibrium is by nature the point towards which economic systems/phenomena must converge; and (ii) economic systems/phenomena can be explained by linear models.

The first principle is profusely illustrated by modern economics. To illustrate, let's mention just two: the balance between supply and demand, or the relationship between interest rates and income explained by the IS/LM curves. Both are fundamental bastions of economic theory, taught at most economics universities and central to explaining the essential economic problem: how markets work, how the price of goods (the price of the money, that is, the interest rate) and the income of economic agents are determined.

In fact, perhaps this is where economics differs from other sciences, and certainly from the exact sciences, in that equilibrium is not as central to them as it is to the economic and business sciences: 'A characteristic feature that distinguishes economics from other scientific fields is that, for us, the equations of equilibrium constitute the center of our discipline. Other sciences, such as physics or even ecology, put comparatively more emphasis on determination of dynamic laws of change…Certainly there are intuitive dynamic principles…the difficulty is in transforming these informal principles into precise dynamic laws" (Mas-Colell et al.,; 1995, p. 620).

Returning to our examples, it is possible to find dynamic principles in the law of supply and demand, namely when it is postulated that the price increases (decreases) if demand is higher (lower) than supply. About IS/LM, we can also identify a dynamic principle, for example, when we explain the consequences for IS (a shift to the right) when the interest rate rises, resulting in an increase in income/output. But these "informal principles" are far from being dynamic laws. And yet economists' belief in

[3] There is also some analogy in phenomena of a very different nature, or at least a number of these phenomena are explained using very similar models. One example is the central equation of the Black–Scholes model for the price of financial options, which is very similar (or at least highly correlated) to the heat flow equation in physics.

[4] In a remarkable, albeit debatable, statement regarding the works of Collier and Hoeffler on greed and grievance in the Civil Wars, he calls these works "armchair empiricism".

equilibrium models is "almost blind", from business economics to macroeconomics, from finance to the currents associated with development economics.

As for the second principle, it has been consolidated in science in general and in economics, not only because of the intrinsic "beauty" of linear equations (they are generally easily understood by non-literary people and difficult to refute) but also because of the ease with which linear models can be identified and represented.

A quick glance at the economists who have been awarded prizes by the Nobel Committee shows the (overwhelming) preponderance of scientific work based on linear models, which would be surprising given that this is a social science.

Unsurprisingly, when it was realized that phenomena might be too complex to be represented, let alone explained, by linear equations, scientists resorted to a simple but effective "trick": linearizing the equations.[5] Once again, in the linearization of equations in economics, the subject of equilibrium arises, as does the scientist's incessant search for it. However, as Keynes himself recognized, systems usually tend to approach equilibrium without ever reaching it, at least as a steady state,[6] and for this reason in manysituations the attempt to express the behaviour of these systems by linear equations and models is hopelessly doomed to failure, or at least will be inefficient. A final word for the moment that perhaps marked the first major blow to economists' self-esteem, at least in their belief in the merits and predictive capacity of their models.

That moment was the oil crisis of the 1970s: in no time at all, a handful of countries united in a so-called Organization of Petroleum Exporting Countries (OPEC) were able to drastically increase crude oil prices and cause huge queues at petrol stations in industrialized countries, as well as generating, directly or indirectly, tremendous volatility in the markets and a significant inflationary surge. This gave rise to new products, particularly in managing hedging strategies, such as futures, options, swaps, caps, floors, and many others, which have become increasingly sophisticated over time, and new approaches and indicators for this activity. Curiously, not only did some of these products become fertile ground for speculation and, therefore, for ever greater unpredictability in the markets, but it doesn't seem that the ability to anticipate crises and predict the evolution of economic aggregates, from macro to microeconomic variables, has improved significantly.

Later, the exchange rate crisis of the early 1980s in Mexico and, between 1997 and 1999, the major exchange rate crises in Asia, Russia and Brazil were moments that further shook the general belief in the predictive capacity of economic science through mainstream models. These moments were, however, just the tip of the iceberg for what was to follow, specifically the financial crisis of 2007/2008, the European sovereign debt crisis between 2009 and 2014 and, finally, quantitative easing and unconventional monetary policies. It's interesting to see how the models used to

[5] In mathematics, it is simply a matter of finding, at a given point, the linear approximation of the function that can represent the variable under study. In economics and other sciences (physics, ecology, among many others) linearization assesses the stability of equilibrium points in non-linear systems/equations.

[6] Defined in physics as something that does not change over time.

explain these events and try to solve the crises, at least in the recent example of the sovereign debt crises and the lack of consolidated economic growth, more specifically the unconventional monetary policy measures, may have caused a phenomenon of the opposite sign and equally worrying: the excessive inflation that the world is experiencing these days. Skeptics will say that this inflation is the result of the pandemic and the invasion and war in Ukraine.

Well, so be it! But if that is the case, then once again it shows that linear models have failed, precisely because the relationship between agents and variables can be non-linear and therefore difficult to express by the set of assumptions inherent in the general equilibrium model for competitive markets.

2 Complexity Theory and Economics

As we tried to show in the previous chapter, determinism has probably been the main characteristic of the dominant paradigm in science, at least since the eighteenth century, in what some authors call the Newtonian paradigm (see, for example, Mateo set al. 2002). Economic science, assuming, with a high probability of error, that this science has its origins at the end of the eighteenth century, has not escaped to that rule, and scientific work has also been guided by the logic that when faced with the same set of factors we will see approximately the same behaviour, in time and space, of economic phenomena. This gave rise to the power of mathematical and statistical tools, which made it possible to develop models that economists believed in with increased conviction, precisely because these tools guaranteed the correct application of the dominant paradigm.

At the beginning of the twentieth century, the paradigm began to be questioned, curiously in quantum physics, when Nobel Prize winner Heisenberg postulated what became known as the uncertainty principle: the more precisely the position of some particle is determined, the less precisely its momentum can be predicted from initial conditions. The recognition that systems are complex and adaptive, often impossible to analyze using linear models alone, was certainly the first step in the development of Complexity Theory (or paradigm?).

There are no single definitions for complexity theory or complex systems, or, as Barkley (1999) mentioned "unsurprisingly, there is no agreed-upon definition of such a complex term as "complexity". Following Day's (1994) definition, which he considers attractive "because it is sufficiently broad that it includes not only most of what is now generally labelled complexity, but also nonlinear dynamics predecessors: cybernetics, catastrophe theory and chaos theory", Barkley argues that "a dynamical system is complex if it endogenously does not tend asymptotically to a fixed point, a limit cycle, or an explosion. Such systems can exhibit discontinuous behaviour and can be described by sets of nonlinear differential or differential equations, possible with stochastic elements".

Mason (2001) divides complexity into three "major divisions", namely "algorithmic complexity", in which complexity is associated with the difficulty of

describing the system's characteristics, "deterministic complexity", related to chaos theory and catastrophe theory, which states that the relationship between "two or three key variables can create largely stable systems prone to sudden discontinuities" and, finally, "aggregate complexity", related to the way in which individual elements work in defining the behaviour of complex systems. Schneider and Somers (2006) state that there are "three inter-related building blocks of CT—non-linear dynamics, chaos theory and adaptation and evolution", the last of which challenges the dominant Darwinian version that the evolution of species is dependent on natural selection, suggesting instead that "while selection does matter, species play a role in their evolution and adaptation to external changes". The corollary for systems in general, and not just living organisms, is that the capacity of systems to evolve is differentiated and that, in some cases, "small forces can result in systems disruption". According to Walby (2007) "Complexity theory is a loose collection of work that addresses fundamental questions on the nature of systems and their changes". Olmedo (2010) states that "Complexity science tries to study, describe and explain the behaviour of complex adaptative systems".

Even so, it is possible to identify a number of characteristics present in the approaches of the authors of the complexity paradigm, namely, the non-linearity behaviour of multiple phenomena, meaning that rarely does one find a model that covers all the characteristics of the phenomenon under study (the whole is not merely the sum of parts), the disequilibrium as the usual systems' state, self-organization, meaning that "abilities of their subunits characterize complex systems" (Lartey, 2020) or, as of David Ng (2013), self-organization is at the core of complexity theory and suggests a spontaneous appearance of new global patterns from local subunit interactions, and, last but not least, the disorder, instead of the order, as the typical systems' situation.

As analyzed in Sect. 1 of this article, economic phenomena increasingly seem to incorporate many of the characteristics identified as defining the complexity paradigm. Perhaps the most important indicator in this regard is precisely the behaviour of gross domestic product (GDP). In recent decades, especially in the so-called advanced economies, there has been what we would cautiously call "anemic" growth (zero would perhaps be a too strict word). The GDP performance was so unsatisfactory that it led to the revival of an approach practically forgotten since the Great Depression, Secular Stagnation, whose first voice had been that of Alvin Hansen. Suddenly, economists such as Nobel laureate Paul Krugman or, slightly earlier, Lawrence Summers, revived the topic around 2013/2014, convinced that it was a threat, especially in some advanced economies, such as the US and European economies.

In the meantime, ten years have passed, a pandemic, a war in Europe that is still going on, a series of unconventional monetary policy measures have been implemented, inflation, which seemed dead, has returned in force, but the question remains: are we "free" from the secular stagnation scenario that Hansen identified at the beginning of the twentieth century? Isn't this the perfect example to illustrate the imperfection (or rather complexity?) of our economic system?

Rosser (1999) argues that even in the context of complexity, the analyses carried out on state intervention continue to exist, albeit with some changes. They state that "it is possible that we can reject rational expectations and markets that continually clear and reach the global optimum, but in the face of empirical uncertainty and multiple equilibria we do not know which model or adjustment mechanism is appropriate for each situation". Finally, a note on the fragility of macroeconomic forecasts, which is probably a corollary of all the characteristics of systems, including economic systems, that give shape to and justify the complexity approach.

Recently, about inflation, the ECB (2022) recognised that "Recent projections by Eurosystem and ECB staff have substantially underestimated the surge in inflation, largely due to exceptional developments such as unprecedented energy price dynamics and supply bottlenecks". On the same subject and admitting the inability to predict the rise in inflation, the IMF (2023) says that "Ex post, the core inflation forecast errors for 2021 are potentially explained by four factors: a stronger-than-anticipated output recover; demand-induced pressure on supply chains; a temporary shift in demand from services to goods; and historically tight labour market. Ex ante, the COVID-19 fiscal stimulus appears as a significant predictor of the subsequent errors for advanced economies". An interesting explanation, which continues to assume that the high inflation we are witnessing can be explained by the same linear models of decades (centuries) ago, unable to incorporate the possibility that price behaviour is simply a non-linear phenomenon, capable of being conditioned, and conditioning, a set of other (vast) variables, in a context of general market disorder.

3 Chaos Theory and Economics

The dividing line between complexity and chaos doesn't seem very significant, at least judging by the almost indiscriminate use of the two terms in some scientific articles to characterise identical phenomena.

In any case, chaos and complexity are not synonymous and there are notable differences between them.

Cartwright (1991) says that "The basic idea of chaos theory is unsettling. In simple terms, chaos is order without predictability. That is, there are systems, physical and social, that are well understood (in the sense that they can be fully described by means of a finite set of conditions or rules) and yet are fundamentally unpredictable. Thus, chaos is not anarchy or randomness. Chaos is order, but it is order that is "invisible." Nor is chaos merely the result of "noise," or interference, or even insufficient knowledge. What chaos implies is a kind of inherent "uncertainty principle"—not just in how we perceive the world but in how the world actually works."

In a nutshell, Levy (1994) stated that "Chaos Theory is the study of complex, nonlinear, dynamic systems" and then claimed that chaos theory in the social sciences was still in its infancy, concluding that "Long-term forecasting is almost impossible for chaotic systems, and dramatic change can occur unexpectedly; as a result, flexibility and adaptiveness are essential for organizations to survive. Nevertheless,

chaotic systems exhibit a degree of order, enabling short-term forecasting to be undertaken and underlying patterns can be discerned".

Rosser (1999) argues that Chaos Theory cannot be associated with a single inventor and considers that since the late 1970s there have been numerous applications of chaos theory in almost all areas of economics. This idea is reinforced by Faggini (2014) who states that "there is a considerable literature in which Chaos Theory is applied to Economics for the theoretical construction of chaotic models".

Olmedo (2010), recognising the difficulty of finding a clear (we would say, unequivocal and comprehensive) definition, tells us that "Chaos Theory works with systems characterised as complex, non-linear, dynamic and far from equilibrium, unforecastable and ordered". Quoting Fitzgerald and Eijnatten (2002), he shows the subtle differences between Chaos and Complexity, expressed in three dimensions: (i) how simple systems could generate complex behaviours? (ii) simple non-linear systems produce extremely complicated behaviours; (iii) how to recognise, describe and forecast systems with sensitivity to initial conditions? The counterpoint to this approach from the complexity theory side would be: (i) how simple behaviour emerges from complex systems? (ii) simple interactions produce higher-level patterns; (iii) how to discover recognisable patterns when the complicated system is looked at as a whole?

Thus, according to these different approaches, we conclude that because the world is not characterised by order, but by chaos, the complex and unordered relationships that are established lead us to consider more non-linear, non-additive models and even those that do not depend on initial postulates, which means that for the same problem there is not just one solution defined from the outset.

Hommes et al. (1995) referred to the growing interest in non-linear deterministic modelling in the field of economics. This is because the resulting models provide an endogenous explanation of the periodic and erratic behaviour of economic variables.

Faggini and Parziale (2011) explain economists' interest in chaos theory because it increases "the probabilities of achieving good results in the modelling of phenomena and their empirical analysis". He adds that another advantage perceived by economists derives from the fact that chaos theory can "also offer a new perspective in system control strategies which has some particularly interesting insights for economic policies".

Guevara and Escot (2021) consider that there are still not many contributions that show that chaotic behaviour in economic models can be controlled. Chaos control theory studies the design of intervention rules to eliminate chaotic behaviour, associating the study of chaotic dynamic economic systems with chaos control and monetary policy rules.

From these analyses, we can see that by considering Chaos Theory as an integral part of the study of economic science, we are assuming the impossibility of forecasting over a longer time horizon.

However, as mentioned above, there are already economic models that try to take chaotic behaviour into account. Guevara and Escot (2021) consider that "this control theory of chaotic systems can provide a rigorous basis for Taylor's monetary policy rules. In fact, there is a great similarity between the structure and specification of

these monetary policy rules and the control rules derived from chaos control theory to stabilise chaotic evolutions."

If the question is asked correctly, perhaps economists should absorb the lessons of chaos theory, recalibrating their models so that they can be more resilient and, above all, more effective in explaining and/or predicting economic variables and phenomena, especially when we are on the verge of crisis situations, be they pandemic, financial, economic, or business.

4 Conclusion

Perhaps the revolutionary or, if we prefer, liberal origins of economic science have forever defined it as a science open to changes in working methods, to new paradigms, to evolve by taking new ways to look the reality.

This indelible characteristic of economic science was perhaps the main reason why Smith and Ricardo, in the late 18th/early nineteenth century, then Keynes and many others in the twentieth century, found followers willing to follow new ideals (certainly in the case of the founding fathers of economic science) and ways of looking at economic phenomena and the techniques that could be used to explain or predict them.

In this article we've tried to show how the paradigm, the mainstream of economics, runs the risk, which is not new and certainly dates to the second half of the twentieth century, of being emptied of what it is supposed to do: help decision-makers make the best decisions so that they can maximise the wealth and satisfaction of economic agents.

These decisions, we can call them economic policies, have been based on, or justified by, typically linear models, by the idea of seeking equilibrium, by a certain order that, strictly speaking, doesn't seem to characterise current phenomena.

Instead, crises abound and are unable to be predicted in time to avoid or minimise their impact, economic growth, at least in the so-called advanced economies, remains anemic or non-existent and, surprisingly, something that was supposed to be far from the medium and long-term horizon has suddenly emerged with enormous intensity. We are referring, of course, to inflation.

All this calls on us, especially the economists, to take a humble and flexible look, to be attentive to new approaches, new ways of looking at economic phenomena. This is how the theories of complexity and chaos came about.

These approaches, which are sometimes confused given the fine line between the two, point to the non-linear behaviour of multiple phenomena (which are therefore difficult to explain by linear models), meaning that it will be difficult to see a valid model capable of covering the whole characteristics of the phenomenon. They also reinforce that a situation of disequilibrium will be the predominant characteristic of Systems, as well as self-organisation, which suggests the spontaneous appearance of new global patterns from local subunit interactions, and, last but not least, the disorder, instead of the order, as the typical systems' situation.

We should refute the idea that the theory of complexity or chaos is the missing answer to all of science's challenges, but rather see it as an alternative approach to the mainstream that, here and there, can complement or even give more significant value to the models used in economics, whose results, also in terms of forecasting, are far from satisfactory and far from what economists would like.

The latest crises, coupled with their unpredictable and mostly undesirable effects, have shown that the economy is highly complex, dynamic and evolving, which leads us to conclude that this complexity needs to be properly taken into account in the science underlying political analysis, as well as in the political decision-making process itself.

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The Compassionate Leadership in Chaotic Environments

Erkan Döner

Abstract In an era characterized by constant change, uncertainty, and disruptive forces, the concept of compassionate leadership has emerged as a crucial and multifaceted approach to navigating turbulent organizational landscapes. Compassionate leadership fosters a culture of psychological safety, enabling teams to voice concerns and engage in innovative problem-solving during the VUCA times. In a world characterized by constant change and uncertainty, compassionate leadership stands as a foundational element in promoting the well-being of individuals, the strength of teams, and the success of organizations. It serves as a cornerstone for nurturing organizational cultures that are adaptive, inclusive, and sustainable, while also aligning with the broader societal calls for more ethical and responsible leadership. Compassionate leadership is not without its challenges, as it demands emotional intelligence, self-awareness, and the ability to balance empathy with decision-making in turbulent situations. While the practice of compassionate leadership poses challenges, such as emotional intelligence and the balancing of empathy with decision-making in turbulent situations, the benefits far outweigh the challenges. Compassionate leadership promotes resilience, collaboration, and organizational agility, facilitating effective adaptation and learning in times of crisis. Empirical studies have revealed that leaders who practice compassion in chaotic environments can positively influence employee well-being, job satisfaction, and overall organizational performance. This chapter provides an overview of compassionate leadership in chaotic environments through business, health, social, and political perspectives to emphasize the significance of compassion on both leaders' and followers' behavior. Compassionate leadership, backed by a growing body of research, can represent a compelling case for its efficacy in chaotic settings by fostering psychological safety, promoting resilience, shaping positive organizational cultures, boosting performance, and enhancing employee retention and engagement. However, for its sustained success, leaders must be equipped to balance outward compassion with self-care, ensuring that they remain resilient catalysts for positive change. Future research should continue to explore the various dimensions of compassionate leadership, its impact on diverse contexts, and strategies for promoting compassionate leadership behaviors in organizations. Amid

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today's chaotic environments, compassionate leadership can be indispensable for sustaining the well-being and resilience of followers (e.g., employees) and drivers of organizations (e.g., leaders) alike.

Keywords Compassion · Compassionate leadership · Leadership · Chaotic environments

1 Introduction

As the world has been globalized and more digitalized enabling individuals to access everything timelessly, the increased amount of information and interconnectedness of unpredictable events can be remarkable in consequences from state-level to individual-level affected decisions and behaviors. The highly interconnected structure of the globalized world represents the chaotic environment in which controlling any situation as expected by leaders is a compelling issue when followers have an unignorable place in keeping leaders' entity of authority (Gharajedaghi, 2011). In chaotic environments consisting of inadequately preserving followers' well-being, social rights, and subsistence at the macro-level (Castles & Davidson, 2020) and carrying out motivation, trust, performance, and job commitment at the micro-level, the followers can tend to lose strong beliefs, being part of the specific group (belongingness), and seek other potential companies they working for or other countries they using citizenship services and possessing rights (King, 2010; Williams & Arrigo, 2002). Employees (followers) have a remarkable consideration on endeavors that distract themselves from business performances to attain job security, trust, well-being, and health concerns (Celuch et al., 2023) to retain family peace and self-happiness, especially during the COVID-19 pandemic and political conflicts (i.e., Ukraine Russia War, Israel-Palestine War, USA-China Trade War). Moreover, employees possess drawbacks whether their job performance and quality counterbalance both department and company goals mainly considered by leaders in the business landscape (Shoss, 2017). On the other hand, nurses feel burnout and distrust during global and local health crises, maintaining patient relationships, and actualizing medical doctors' requests in complex treatment periods (Garrett, 2008). Therefore, it becomes crucial to be a leader in how to transform followers' adverse behavioral traits, negative emotional states, and distrust in a beneficial manner without permitting them to leave the organization itself through lack of motivation and intolerance to uncertainty (Cartwright & Holmes, 2006; Kelloway et al., 2012). Recent studies express that, being a leader with ordinary leadership skills (e.g., traditional leadership) does not have enough capacity to deal with followers' concerns, expectations, and negative considerations toward any challenges in chaotic environments (Obolensky, 2017; Wheatley, 2011). There should be soft skills acquired by leaders to retain collaborativeness, enhanced resilience, flexible decision-making, and employee engagement throughout the organization in case of any failures included in the business cycles (Cimatti, 2016; Moldoveanu &

Narayandas, 2019). In light of these considerations, the compassionate leadership style is one of the beneficial leadership styles throughout the organization by directing leaders to empathize with followers' behavioral traits and emotional states including mental and physical suffering and pains (Binagwaho, 2020; Boyatzis et al., 2006; Dutton et al., 2014). The way providing a positive contribution to employees' level of motivation, commitment, and engagement, compassionate leaders generally tend to search for possible remedies and solutions to mitigate employees' adverse emotion and perception of business progresses, especially during the change (D'Auria et al., 2020).

2 Compassionate Leadership

Before examining the description of compassionate leadership, it can be more contributive to probe the "compassion" word etymologically. The word compassion is formed of "com" as a prefix, and "passion" as a suffix when both combined reflect the expression of "suffering togetherly" which includes the meaning of compassion (Etymonline, 2023). Thus, it could be possible to use the "CP" abbreviation for "compassion" when the art and standards of the abbreviation are considered (Moustafa, 2023). Compassionate leadership (CPL) goes beyond traditional leadership styles by prioritizing the well-being and development of individuals within an organization (Ramachandran et al., 2023). CPL provides a unique perspective on leading in chaotic environments. It acknowledges the emotional and psychological harm that end up with turbulence can have on individuals and teams, while also recognizing the potential for growth and development amidst chaos (Ostergard et al., 2023). In chaotic environments, where uncertainty and stress are prevalent, CPL becomes even more critical.

CPL is an approach that highlights empathy, understanding, and care for individuals and teams. It goes beyond the traditional command-and-control model and recognizes the importance of emotional intelligence, ethical decision-making, and fostering human connections (Shuck et al., 2019). CPL involves being present, actively listening, and providing support to team members. While traditional leadership styles may focus more on task-oriented goals, CPL recognizes the importance of the human element in achieving success (Kanov et al., 2004). Compassionate leaders possess the ability to understand the emotions and concerns of their team members, create a supportive environment, and inspire trust and resilience (Richard, 2020). It creates a supportive and nurturing work environment that fosters resilience, collaboration, and innovation.

Research has shown that compassionate leaders have a positive impact on employee engagement, job satisfaction, and overall organizational performance (Binagwaho, 2020; Boyatzis et al., 2006; Ramachandran et al., 2023; Shuck et al., 2019). By demonstrating empathy, actively listening, and providing emotional support, compassionate leaders build trust and enhance team cohesion, even in

chaotic situations (Nolan et al., 2022). This, in turn, promotes employee well-being and motivation, leading to increased productivity and effectiveness.

CPL offers a beneficial perspective on leading in chaotic environments. It acknowledges the need for adaptability, flexibility, and emotional intelligence in times of uncertainty. By cultivating compassion and empathy, leaders can foster trust, reduce anxiety, and promote resilience among their team members (Pauley & McPherson, 2010).

CPL has a significant impact on individuals and organizations facing chaotic environments. By prioritizing empathy, understanding, and care, compassionate leaders create a supportive and inclusive environment that enhances employee well-being, engagement, and job satisfaction. This, in turn, fosters resilience and enables individuals and teams to navigate the challenges of chaotic environments with grace and effectiveness. Thoroughly, compassionate leaders promote collaboration and innovation in chaotic environments (de Zulueta, 2015). By creating a culture of psychological safety and trust, CPL encourages open communication, idea-sharing, and experimentation (D'Auria et al., 2020). This allows organizations to adapt to changing circumstances, identify new opportunities, and drive innovation even in times of uncertainty.

According to a recent study by Shuck et al. (2019), six distinctive dimensions point out leaders' compassion level as empathy, dignity, accountability, authenticity, presence, and integrity which are required for leaders aiming to mitigate adverse effects of situations on employees or followers. Whereas empathy, dignity, and presence can be perceived as care about followers or employees provided by the leader, integrity, authenticity, and accountability are traits that employees or followers frequently seek to maintain well-being performance, motivation, and trust in themselves. As follows, the CPL dimensions can be expressed through managerial and behavioral perspectives.

2.1 Empathy

Empathy is described as the capacity and inclination to perceive the emotions of individuals in emotional pain and to feel those emotions as if they were one's own (Salovey et al., 2001). Using the empathy mechanism applies cognitive, emotional, and behavioral traits to employ available empathy functioning that reflects others' perceptions of whether empathy is effective or not (Ramachandran et al., 2023). Empathy can be perceived as noticing and subsequently taking action to alleviate others' suffering among both leaders and followers (Vogus et al., 2021). Leadership with empathy can mitigate followers' suffering and concerns toward the organization, management, and social life as well through understanding the causes and seeking useful solutions (Lanaj et al., 2022). Empathy can be reflected in one's well-being, motivation, performance, engagement, and commitment level. The main dimension of CPL is empathy compared to others, which provides a supportive perception to individuals about being recognized by the leader's potential considering followers'

values, responsibilities, and presence (Shuck et al., 2019). Also, empathy has a positive contribution to organizational outcomes by enhancing followers' job engagement and job performance in a more compassionate environment (Boyatzis et al., 2006). Leaders' consideration of empathy can generate a conducive business environment, trust among followers and leaders, and great motivation to keep ethical values.

2.2 Integrity

Integrity is often considered the bedrock of effective leadership. Scholarly research underscores that leaders who demonstrate integrity are perceived as more trustworthy, reliable, and credible by their followers (Palanski & Yammarino, 2009; Shuck et al., 2019). Such leaders consistently align their words with their actions, uphold ethical standards, and make decisions based on moral principles (Treviño et al., 2000). When leaders operate with integrity, it not only sets a positive example for employees to emulate but also nurtures an organizational environment conducive to long-term success, as employees are more likely to be committed, engaged, and motivated in their roles (Den Hartog, 2015). When leaders operate with integrity, they not only adhere to ethical principles and maintain consistency in their actions and decisions, but they also act with genuine care for those they lead. Such leaders prioritize the emotional and psychological needs of their team members, ensuring an environment where individuals feel valued, understood, and supported (Boyatzis et al., 2006). This combination of integrity and compassion fosters trust and encourages open communication, ultimately leading to more resilient and cohesive teams, higher employee morale, and better organizational outcomes (Kanov et al., 2004). In essence, compassionate leadership intertwined with integrity offers a holistic approach that melds ethical decision-making with empathetic connection.

2.3 Presence

Presence often referred to as a conscious, attentive, and grounded engagement in the current moment, takes on profound depth when viewed through the lens of compassion. Presence in compassionate leadership is characterized by a leader's profound attention and attunement to the immediate emotional and situational dynamics of their environment. Rooted in mindfulness practices, presence is not merely about being physically available but entails a heightened sense of awareness and responsiveness to the emotional and psychological landscape of the workplace (Kabat-Zinn, 2003). This kind of presence goes beyond mere physical or cognitive engagement; it emphasizes a deep emotional connection and understanding of team members and stakeholders (Boyatzis et al., 2006). Compassionate leaders, endowed with such presence, actively listen, resonate with the emotions of others, and discern the subtleties

in their environments, enabling them to make decisions that align with both the organization's goals and the well-being of its members (Lilius et al., 2008). By being fully present, one can better understand and respond to the nuances of human emotion, fostering more meaningful and empathetic interactions (Neff, 2003). This active and attuned presence paves the way for fostering trust, facilitating open communication, and creating an environment where individuals feel genuinely seen, heard, and valued (Shuck et al., 2019). It allows leaders to make informed decisions based on a holistic understanding of situations, ensuring both organizational objectives and employee well-being are addressed (Kanov et al., 2004). In essence, presence in compassionate leadership is about nurturing a deeply empathetic and responsive leadership style that prioritizes genuine human connections.

2.4 Dignity

In compassionate leadership, "dignity" stands as a cornerstone principle, emphasizing the intrinsic worth and value of every team member and stakeholder. Leaders who embrace compassionate leadership understand that every individual, irrespective of their role or contribution, possesses inherent dignity that must be recognized and upheld (Lilius et al., 2008). Dignity entails recognizing the worth and contributions of every individual during their daily interactions, serving as a method to foster positive encounters and affirm genuine human connections with colleagues (Shuck et al., 2019) This not only promotes psychological safety and well-being but also encourages open dialogue, mutual respect, and collaboration within teams (Hodson, 2001). Upholding dignity further facilitates open communication, mutual trust, and a culture of inclusivity, where diverse voices are acknowledged and celebrated (Boyatzis et al., 2006). Compassionate leaders who champion dignity are likely to foster more inclusive work environments, recognizing the unique values and perspectives that diverse individuals bring (Nembhard & Edmondson, 2006). By prioritizing the dignity of all stakeholders, leaders are often better positioned to make decisions that are ethically sound and aligned with the organization's values (Brown et al., 2005). Organizations that prioritize dignity under compassionate leadership are often viewed more favorably by stakeholders, potential talent, and the wider community, enhancing their reputation and attractiveness (Carmeli et al., 2014). In a nutshell, by integrating the principle of dignity into the CPL approach, leaders can foster trust, promote effective communication, and drive both ethical and operational excellence.

2.5 Authenticity

Through the lens of compassion, "authenticity" is perceived as the genuine expression and alignment of one's internal values, emotions, and intentions with external

actions and communications. When leaders operate with authenticity, they foster a transparent environment where their true self, including their compassionate inclinations, is consistently displayed (Bayır-Toper et al., 2020). This openness not only promotes trust and understanding among team members (Hu et al., 2018) but also encourages others to act authentically and compassionately. Authentic leaders transparently express their true selves, allowing them to engage with their teams sincerely and with empathy (Avolio et al., 2009). Authentic leaders who view situations and people through a compassionate lens are better equipped to address challenges in ways that uphold the dignity and well-being of all involved, fostering a culture of genuine care and understanding (Lilius et al., 2008). When paired with compassion, this openness ensures that concerns are addressed with understanding and empathy, fostering a culture of psychological safety (Edmondson, 1999). Authenticity, coupled with compassion, drives leaders to make decisions anchored in ethical considerations, ensuring the well-being of all stakeholders (Brown & Treviño, 2006). Authenticity in compassionate leadership is more than just being true to oneself; it's about consistently demonstrating a genuine commitment to the well-being of others, reinforcing a culture where team members feel valued, understood, and cared for (Gardner et al., 2011). In such an environment, the intertwined virtues of authenticity and compassion promote a holistic approach to leadership that prioritizes both organizational objectives and the human essence of every team member.

2.6 Accountability

At its core, accountability involves taking responsibility for actions or decisions and following through on commitments (Burke et al., 2007). It's about being answerable to others and being transparent about successes and failures. Accountability ensures that leaders and their teams remain committed to their goals, make ethical decisions, and maintain a level of responsibility toward stakeholders (Hall et al., 2017). Leaders who successfully integrate accountability and compassionate leadership can create a balanced environment where high standards are set and maintained, but where individuals also feel supported and valued (Raelin, 2011). When accountability is paired with compassion, employees are more likely to take responsibility for their actions because they believe their leaders care about their well-being. This leads to improved performance and a stronger commitment to organizational goals (Dutton et al., 2014). When leaders integrate accountability with compassion, they build environments where team members feel valued, understood, and supported, all while being held to a high standard of responsibility. This balance is essential for creating workplaces that are both productive and nurturing (Shuck et al., 2019). By fostering a culture of accountability and compassion, leaders can enhance the engagement, motivation, and overall well-being of their team members, leading to higher levels of organizational performance and innovation.

3 Chaotic Environments

Chaotic environments, in the context of modern research, are systems characterized by complex and unpredictable dynamics that emerge from deterministic, yet sensitive, underlying processes (Sprott, 2003). These environments are not limited to physical systems; they pervade areas like biology, economics, and even social systems. Chaotic environments, whether in business, social contexts, health sectors, or political arenas, present a series of unpredictable, nonlinear, and often unstable factors that challenge traditional models of understanding and intervention. A deeper understanding of chaotic dynamics has led to the recognition that such behavior, often considered random, is deterministic but highly sensitive to initial conditions, making long-term prediction challenging (Ott, 2002). Recent studies have also explored the potential to control or harness chaos, suggesting that with the right interventions, chaotic systems can be stabilized or directed in desirable directions (Pyragas, 2006). In business and social landscapes, chaotic environments are often used metaphorically to describe scenarios marked by rapid changes, high levels of unpredictability, and complex interdependencies (Uhl-Bien & Marion, 2009). Businesses operating in these conditions often find themselves in a state of continuous evolution, where the ability to innovate, adapt, and remain agile becomes a competitive advantage (Anderson, 2010). From a business perspective, a chaotic environment could stem from rapid technological changes, unpredictable consumer behaviors, political unrest, or economic downturns (Anderson et al., 2009). On the social front, chaos often emerges from socio-political upheavals, cultural shifts, or any significant disruptions that destabilize the known order (Urry, 2005). These environments are characterized by uncertainty, complexity, and ambiguity, forming an arena where the old rules may not necessarily apply, and new strategies have to be continually devised (Andriani & McKelvey, 2007). Complicated environments, like well-designed machines, function in predictable patterns, but complex systems, like the modern business world, are composed of countless interacting variables that can give rise to unanticipated occurrences (Mitleton-Kelly, 2003). Unlike stable environments where long-term plans can be safely made, in chaotic settings, businesses must be nimble and adaptive (Brown & Eisenhardt, 1998). As Sassen (2001) highlights, globalization has brought about significant shifts in urban centers, leading to the gentrification of some areas and the marginalization of others. These disparities can cause social tensions, leading to chaotic uprisings or movements as those marginalized seek to claim their rights.

With the advent of the internet and the proliferation of social media platforms, individuals are bombarded with vast amounts of information, leading to the challenge of discerning reliable information from noise (Pariser, 2011). The rise of social media has amplified the social chaos phenomenon, enabling real-time dissemination of information and facilitating rapid group mobilization (Castells, 2015). This phenomenon can result in the rapid spread of misinformation, contributing to chaos as society grapples with distinguishing fact from fiction.

In health contexts, pandemics represent one of the most potent forms of chaos. The recent COVID-19 pandemic highlighted the intricate interplay between health, social, and economic dimensions in a chaotic setting. Initial responses to the outbreak were mired in uncertainty, with healthcare systems worldwide grappling with overburdened capacities, shortages of essential supplies, and rapidly evolving information (Dong et al., 2020). The 2020 COVID-19 pandemic serves as a quintessential example, wherein the rapid spread of a novel virus led to unprecedented global chaos, affecting health systems, economies, and societies at large (Horton, 2021). The nonlinear growth of infections, driven by factors ranging from individual behaviors to policy interventions, added layers of complexity to the situation (Brauer et al., 2019). Pandemics, by their very nature, disrupt the status quo, challenging both health infrastructures and societal norms.

Politically, chaotic environments often emerge from conflicts, wars, or civil unrest. Such environments are characterized by instability, a breakdown of law and order, and often, human rights violations (Kalyvas, 2006). Political chaos can result from power vacuums, sectarian tensions, or external interventions (Pape, 2005). The rise and spread of non-state actors like ISIS further complicate the traditional paradigms of understanding warfare (Byman, 2016). At times, external interventions in conflicts, to establish order, inadvertently escalate chaos, as was seen in the aftermath of the 2003 Iraq invasion (Dodge, 2012). Such political chaos not only has immediate ramifications on the ground but also reshapes the international order, challenging alliances and geopolitical strategies.

Leaders across business, social, health, and political areas must develop an interdisciplinary lens, drawing insights from diverse fields, to navigate and possibly thrive in chaotic settings. As the world grows increasingly interconnected, the ripples of chaos in one domain can swiftly permeate others, underscoring the imperative of holistic, integrated strategies for the challenges of the twenty-first century.

4 The Benefits of Compassionate Leadership in a Chaotic Environment

In the face of chaos, organizations look to their leaders to guide them through turbulent times, and the traditional view of leadership often emphasizes authority, command, and control. Traditional command-and-control methods have increasingly shown their limitations, especially in volatile, uncertain, complex, and ambiguous (VUCA) situations (Bennett & Lemoine, 2014). In such chaotic environments, compassionate leadership emerges as a potent antidote, offering an array of benefits for organizations, teams, and individuals alike. However, an evolving paradigm underscores the immense potential of compassionate leadership as an effective approach in such environments. Compassionate leadership, at its core, entails understanding and empathizing with the needs, challenges, and feelings of others, and then taking thoughtful action to assist them (Shuck et al., 2019).

Research by Poulin (2017) suggests that compassion can buffer against stress, with leaders acting as vital agents in promoting coping strategies. Leaders who exemplify compassion aid in fostering resilience among their team members, enabling them to bounce back from setbacks and maintain performance amidst adversity (Cameron & Caza, 2004). Schein (2010) emphasizes that leaders are primary culture creators. When leaders consistently act with compassion, they set the tone for the entire organization, thus cultivating a culture where people support, trust, and help each other. Such cultures are shown to be more adaptive and agile in the face of change (Hogan & Coote, 2014). Training in mindfulness and self-compassion, as highlighted by Jazaieri et al. (2013), can be particularly effective in equipping leaders with the necessary tools to balance compassion towards others with self-care.

In the business domain, compassionate leadership contributes to better organizational outcomes. A study by Worline and Dutton (2017) found that compassionate leaders fostered a sense of psychological safety among employees. This safety, in turn, promoted innovation, adaptability, and resilience—crucial traits for organizations navigating chaotic environments. In line with this, Lilius et al. (2011) indicated that organizations with compassionate leaders tended to have employees who were more engaged and exhibited lower levels of burnout, leading to enhanced overall performance.

In the health sector, the emphasis on compassionate leadership has profound effects. West and Chowla (2017) argued that compassionate leadership in healthcare resulted in improved patient care outcomes. This sentiment is supported by research from the King's Fund (2012), which found that leadership grounded in compassion led to a decrease in patient complaints and better patient satisfaction scores.

From a social perspective, compassionate leadership plays a vital role in fostering cohesion. As chaotic environments often breed divisiveness and uncertainty, leaders who exhibit compassion promote understanding and unity among diverse groups (Boyatzis et al., 2017). Such leaders can bridge divides, reducing the prevalence of misunderstandings and conflicts in heterogeneous societies.

Politically, compassionate leadership lays the foundation for more constructive dialogue and cooperation. Traditional partisan divides can be bridged when leaders prioritize understanding and empathy over divisive rhetoric. Ansell and Gash (2008) found that compassionate leadership was integral in creating collaborative governance, wherein parties could engage in productive dialogue even amidst chaos.

In general view, Compassionate leadership nurtures trust, an essential ingredient for successful teamwork. When leaders show genuine concern for their employees' well-being, it fosters a sense of safety and security. During chaos, employees are more likely to trust a compassionate leader, facilitating smoother decision-making and reduced resistance to change. According to Dirks and Ferrin (2002), trust in leadership is positively associated with several beneficial outcomes, including job performance, organizational commitment, and job satisfaction. A compassionate leadership approach promotes open communication and collaboration. In a study by Riggio et al. (2010), it was found that when leaders were perceived as compassionate, teams had better communication, which in turn led to improved collaboration and performance, particularly in challenging circumstances. Chaotic environments

require teams to be resilient and adaptable. Compassionate leadership can foster these traits by creating a supportive environment where failures are seen as learning opportunities. According to Luthar et al. (2000), resilience is significantly influenced by supportive relationships, which compassionate leaders actively cultivate. Chaotic environments demand rapid and effective decisions. By fostering trust and open communication, compassionate leaders can gather diverse perspectives, leading to better-informed decisions. This idea is supported by Dinh et al. (2014), who found that inclusive decision-making processes, promoted by compassionate leadership, resulted in superior organizational outcomes.

5 Conclusion

CPL in chaotic environments is not just a novel concept; it is a critical and indispensable approach for navigating the turbulent journey of today's world. As we have explored throughout this discussion, leaders who incorporate compassion into their leadership style demonstrate a remarkable ability to inspire, unite, and guide their teams, even in the most tumultuous circumstances. Compassionate leaders understand that chaos and uncertainty can breed fear, anxiety, and disorder. However, leaders' behavior with care and empathy provides a stabilizing force, fostering trust, resilience, and a sense of belonging within their teams. By recognizing the human element in all aspects of their leadership, they create an environment where people feel valued and supported, allowing for the emergence of creative solutions and the nurturing of long-term relationships.

In an era where change and uncertainty are constants, CPL serves as a beacon of hope, a source of comfort, and a catalyst for progress. It empowers individuals to confront challenges with courage and resilience, ensuring that, even in the most chaotic of settings, there remains a sense of purpose, camaraderie, and shared vision. It is clear that CPL is not just an option; it is a moral imperative and a strategic advantage, essential for the success and well-being of individuals, teams, and organizations in chaotic environments.

Therefore, it is evident that CPL is not just a relevant topic of study but a crucial one. Future research should continue to explore the various dimensions of compassionate leadership, its impact on diverse contexts, and the development of strategies and training programs to promote compassionate leadership behaviors in organizations.

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Anticipating the Servant Leaders' Reflex to VUCA Effects Through Chaos Theory Perspective

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Abstract In today's fast-paced and unpredictable business environment, leaders need to anticipate and respond effectively to the volatile, uncertain, complex, and ambiguous (VUCA) effects that can disrupt their organizations. This chapter explores the concept of servant leadership and its reflex to VUCA effects through the lens of chaos theory. By grasping the principles of servant leadership and harnessing the dynamics of chaos theory, leaders can cultivate a proactive approach to traverse turbulent periods and instill resilience within their teams. This research study illuminates servant leadership's pivotal attributes, expounds upon chaos theory principles, and elucidates how these two concepts can harmoniously merge to anticipate and tackle the challenges posed by VUCA effects. The chaos theory perspective reflects that leaders can better understand the interconnectedness of events, adapt their leadership approach accordingly, and proactively anticipate and respond to VUCA effects. Through this comprehensive exploration, leaders will gain valuable insights into adapting their leadership style and effectively guiding their teams in a VUCA world.

Keywords Chaos theory · Servant leadership · Chaos theory

1 Introduction

At the core of the global socio-economic structure, commonly referred to as globalization, lie multifarious activities intertwined with an infinite array of variables (Held & McGrew, 2007). These intricate interconnections transcend the mere interaction of decisions, objectives, and strategies. Moreover, extending beyond a simple cause-and-effect dynamic, these connections operate independently while concurrently harboring the potential for profound impacts on environmental conditions,

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circumstances, and preservation. In the present-day swiftly evolving and changing business environment, organizations confront unparalleled challenges characterized by volatility, uncertainty, complexity, and ambiguity (VUCA) (Sinha & Sinha, 2020). To navigate through such conditions, leaders must embrace an alternative approach to leadership—one that embraces chaos and uncertainty (Rimita, 2019). Chaos theory, a mathematical branch, scrutinizes the behavior of complex systems highly sensitive to initial conditions, suggesting that minute changes can yield significant and unpredictable outcomes (Robertson & Combs, 2014). A key concept regarding chaos theory is the "butterfly effect," where small alterations, like the flapping of a butterfly's wings, can have far-reaching consequences, potentially leading to a tornado on the opposite side of the globe (Galacgac & Singh, 2016). Another essential principle is the existence of strange attractors, patterns that emerge within chaotic systems, enabling the identification of underlying order amidst apparent randomness. These attractors provide insights into the behavior and dynamics of complex systems. Chaos theory also emphasizes the nonlinearity of intricate systems. Unlike linear systems, where cause and effect maintain direct proportionality, nonlinear systems exhibit intricate relationships where small inputs can yield disproportionate effects (Prokhorov, 2008). Feedback loops play a pivotal role in nonlinear systems, amplifying or dampening the effects of initial conditions (Galbraith, 2004). Chaos theory, a scientific discipline exploring complex systems and their behavior, investigates how seemingly random and unpredictable events give rise to patterns and order (Olmedo, 2010). It acknowledges that organizations are complex systems influenced by numerous internal and external factors. Applied to leadership, chaos theory posits that leaders should embrace uncertainty and complexity instead of seeking to control or predict outcomes (Galbraith, 2004). Servant leadership, which places emphasis on serving others and empowering them, aligns harmoniously with the principles of chaos theory (Rennaker, 2006). Servant leadership is a philosophy that underscores the leader's role as a servant first and foremost (Patterson, 2003). It embodies a people-centric approach to leadership, focusing on meeting the needs of individuals, including employees, customers, and the community. Servant leaders prioritize the growth and well-being of their followers, cultivating a culture of trust, collaboration, and empowerment (Sendjaya et al., 2008). The main objective of servant leaders is to create a supportive environment where individuals can flourish and reach their maximum potential (Finley, 2012). This chapter delves into the servant leaders' reflexes from the perspective of chaos theory within the context of managerial and organizational extent arising from VUCA effects.

2 Chaos Theory and the Vuca Effects

Today's uncertainty in decision-making and rapidly changing environment (e.g., business, politics, and technology) has gradually stimulated the interaction of existing and possible variations among actual and potential outcomes of activities that drive individuals to recognize these circumstances as "chaos", whose meaning is more

unoffending rather than being perceived. Chaos theory provides insights into the behavior of complex systems, such as those described by the VUCA framework. VUCA is a term originally coined by the U.S. Army War College to describe the volatile, uncertain, complex, and ambiguous nature of the post-Cold War world (Codreanu, 2016). In today's context, VUCA refers to the unpredictable and rapidly changing business environment characterized by constant disruption, technological advancements, and global interconnectedness (Taskan et al., 2022). The VUCA effects can manifest as market volatility, disruptive innovations, geopolitical instability, and shifting customer preferences. The principles of chaos theory, such as sensitivity to initial conditions and nonlinear dynamics, align with the characteristics of VUCA environments (Rimita, 2019). Both concepts highlight the non-linear and unpredictable nature of complex systems. Chaos theory emphasizes the importance of embracing complexity and uncertainty rather than trying to simplify or control them (Galacgac & Singh, 2016). Similarly, the VUCA framework encourages individuals and organizations to develop a mindset that embraces change, ambiguity, and the inherent complexity of the environment (Mack & Khare, 2016). Both chaos theory and the VUCA framework emphasize the need for adaptability and resilience in complex and uncertain environments. Understanding the principles of chaos theory can help individuals and organizations build resilience by recognizing patterns, identifying opportunities for innovation, and adapting quickly to changing circumstances (Balas-Timar, 2015; Pelissier, 2011). By embracing chaos theory and understanding the VUCA effects, individuals and organizations can leverage uncertainty and complexity to their advantage (Bennett & Lemoine, 2014). Therefore, individuals being part of organizations can identify emerging patterns, spot opportunities for innovation, and make informed decisions that lead to positive outcomes in volatile and unpredictable environments.

3 Chaos Theory and the Servant Leadership

Servant leadership is a distinguished leadership philosophy that places the leader's primary focus on serving others rather than pursuing personal power or achieving organizational goals (Savage-Austin & Honeycutt, 2011). It was first introduced by Robert K. Greenleaf in the 1970s and has since gained significant attention in various fields, including business, education, and healthcare. The core principles of servant leadership include empathy, humility, listening, and a commitment to the growth and development of followers (Finley, 2012). Servant leaders prioritize the well-being and success of their team members, fostering a positive and supportive work environment (Sendjaya et al., 2008). By empowering others and enabling their personal and professional growth, servant leaders create a culture of trust, collaboration, and high performance (Heyler & Martin, 2018). The chaos theory, also known as complexity theory, explores the behavior of complex systems that are highly sensitive to initial conditions and exhibit non-linear dynamics. Coined by Edward Lorenz in the 1960s,

this theory challenges traditional linear thinking and highlights the inherent unpredictability and interconnectedness of complex systems (Prokhorov, 2008). According to the chaos theory, small changes or actions in a system can lead to significant and unexpected outcomes, often referred to as the "butterfly effect." Complex systems, such as organizations or societies, are influenced by numerous interconnected variables and are susceptible to emergent behaviors that can be difficult to predict or control (Olmedo, 2010). While servant leadership and the chaos theory may appear distinct at first glance, they can actually complement each other and enhance leadership effectiveness in complex and unpredictable environments (Rimita, 2019). Here are some of the concepts and approaches integrating the chaos theory and servant leadership as follows.

3.1 Embracing Uncertainty and Adaptability

Both servant leadership and the chaos theory acknowledge the unpredictable and dynamic nature of the world we live in. Servant leaders embody a mindset of flexibility and adaptability, recognizing that change is inevitable and embracing uncertainty as an opportunity for growth (Hai & Van, 2021). Similarly, the chaos theory emphasizes embracing complexity and adapting to ever-changing conditions (Pryor, 2016). By combining these perspectives, leaders can navigate through uncertainty with resilience and agility, fostering a culture of innovation and continuous learning.

3.2 Valuing Diverse Perspectives and Collaborative Decision-Making

Servant leadership emphasizes the importance of listening to others and valuing diverse perspectives (Sims, 2018). This aligns well with the chaos theory, which recognizes the value of collective intelligence and the power of collaboration (Chadwick, 2010). By involving team members in decision-making processes and fostering an inclusive environment, leaders can tap into the collective wisdom of their teams, enabling innovative solutions and enhanced problem-solving capabilities.

3.3 Nurturing Empowerment and Self-Organization

Servant leaders empower their followers by providing them with autonomy, trust, and support (Russell, 2001). This approach resonates with the chaos theory's emphasis on self-organization and emergent behaviors (Galacgac & Singh, 2016). By

fostering an environment that encourages individual initiative and allows for decentralized decision-making, leaders can utilize the creativity and potential of their team members (Wong et al., 2018). This enables the organization to adapt and respond effectively to complex and rapidly changing circumstances.

3.4 Creating a Culture of Learning and Resilience

Servant leaders are committed to the growth and development of their followers, promoting a culture of continuous learning (Van Dierendonck & Patterson, 2018). The chaos theory recognizes the importance of adaptability and resilience in complex systems (Russell, 2006). By combining these perspectives, leaders can create a learning organization that embraces change, encourages experimentation, and learns from failures. This enables the organization to thrive in turbulent times and seize opportunities for innovation and growth.

4 The Servant Leadership and the Vuca Effects

Operating from a chaos theory perspective, servant leaders perceive VUCA effects as opportunities for growth, innovation, and adaptation (Sarkar, 2016). Also, servant leaders can understand that change is inevitable and that organizations need to be flexible and responsive. Instead of perceiving VUCA as threats, servant leaders view them as catalysts for transformation and positive change. Servant leaders focus on the growth and well-being of their team members, which can have a significant impact on how organizations navigate VUCA effects (Ramakrishnan, 2021). In light of these circumstances, they tend to encourage their teams to embrace uncertainty and explore new possibilities. Behaviors of servant leaders in VUCA environments are as follows.

4.1 Embracing Complexity

Servant leaders, in their wisdom, recognize the intricate nature of VUCA environments and inspire their teams to skillfully traverse the realms of ambiguity. Servant leaders cultivate a culture that cherishes the pursuit of knowledge, embraces experimentation, and embraces adaptability (Staats, 2016). These leaders champion a growth mindset, urging their employees to delve into diverse viewpoints and explore myriad solutions.

4.2 Resilience and Emotional Intelligence

Servant leaders recognize that VUCA conditions can be emotionally and mentally challenging for employees. Also, these leaders foster a supportive and inclusive work environment that builds resilience by providing emotional support, encouraging self-care, and promoting work-life balance (Haar et al., 2017).

4.3 Empowering Followers

Servant leaders understand that traditional hierarchical structures may not be effective in VUCA environments (Coetzer et al., 2017). Empowering their team members by delegating authority, encouraging decision-making at all levels, and fostering a sense of ownership may create a safe space for innovation and encourage employees to take calculated risks.

4.4 Facilitating Collaboration

Servant leaders recognize that collaboration is essential in navigating through VUCA effects. Promoting cross-functional collaboration, knowledge sharing, and open communication may design platforms for employees to exchange ideas, foster creativity, and leverage diverse perspectives (Pearce et al., 2009).

4.5 Vision and Purpose

Servant leaders provide a clear vision and purpose that inspires and motivates employees in uncertain times. Also, servant leaders communicate the organization's mission and values effectively and align individual goals with the larger purpose to emphasize the importance of values-driven decision-making and ethical conduct (Paesen et al., 2019).

4.6 Providing Clarity

Servant leaders set clear goals and objectives, define roles and responsibilities, and establish well-defined processes (Coetzer et al., 2017). Also, servant leaders ensure that team members have a clear understanding of expectations and provide necessary guidance and support (Galacgac & Singh, 2016).

4.7 Nurturing Learning and Growth

Servant leaders prioritize the growth and development of their team members. Providing mentoring, coaching, and opportunities for learning and skill development to empower individuals to take ownership of their own growth and career progression (Dierendonck & Patterson, 2018). Also, servant leaders encourage a culture of continuous learning, experimentation, and adaptation (Russell, 2006).

Consequently, in a VUCA environment where knowledge and skills quickly become outdated, servant leaders foster a growth mindset that enables individuals to embrace change and acquire new competencies.

5 The Servant Leaders' Response to VUCA Effects Through Chaos Theory Perspective

Chaos theory suggests that organizations can be viewed as complex adaptive systems, where small changes can lead to significant and unpredictable outcomes (Mbengue et al., 2018). By embracing chaos theory principles, servant leaders can effectively respond to VUCA effects. Combining servant leadership with a chaos theory perspective offers a powerful response to the VUCA effects. Servant leaders, with their focus on empathy, collaboration, and empowerment, create a supportive environment that enables individuals and teams to thrive amidst volatility, uncertainty, complexity, and ambiguity (Frear, 2011). By embracing complexity, facilitating self-organization, and creating learning systems, servant leaders foster adaptability, innovation, and resilience in their organizations (Galacgac & Singh, 2016). Servant leadership also aligns with the principles of chaos theory by acknowledging the interconnectedness of individuals and the nonlinear nature of change (Dierendonck & Patterson, 2018). Through their servant leadership approach, leaders can nurture emergent behaviors, encourage creative problem-solving, and facilitate the emergence of novel solutions to complex challenges. Here are several ways in which chaos theory principles can be applied to servant leadership in VUCA environments as follows.

5.1 Embrace Complexity

Instead of fearing or avoiding complexity, servant leaders embrace it by being aware that complexity is an inherent part of the business environment and that it can lead to new opportunities (Winston & Fields, 2015). Through acknowledging and accepting the complexity, servant leaders can develop a mindset that is open to change and innovation (Wang et al., 2019). Servant leaders recognize that complex systems have innate order and patterns that lead them to explore the underlying dynamics and leverage them to make informed decisions.

5.2 Foster Emergence and Adaptability

Servant leaders create an environment that allows for emergence, where innovative ideas and solutions can arise organically. Servant leaders encourage experimentation, creativity, and collaboration, allowing for the emergence of new possibilities to deploy adaptability within their organizations (Staats, 2016). Also, servant leaders promote a culture of continuous learning and improvement, where employees are encouraged to experiment, take risks, and learn from failures (Dierendonck & Patterson, 2010). By fostering adaptability, servant leaders enable their organizations to respond effectively to VUCA effects and make necessary adjustments.

5.3 Emphasize Self-Organization

Servant leaders empower their teams to self-organize and make decisions based on their knowledge and expertise (Hai & Van, 2021). Servant leaders provide autonomy and trust, allowing individuals to take ownership of their work and contribute to the overall success of the organization (Russell, 2006).

5.4 Embrace Feedback Loops and Iterations

Servant leaders value feedback and create feedback loops within their teams and organizations. Moreover, servant leaders encourage open and honest communication, seek input from team members, and use feedback to drive continuous improvement (Finley, 2012; Savage-Austin & Honeycutt, 2011). Servant leaders understand that in complex and unpredictable environments, adaptation and iteration are essential which both lead them to embrace a flexible and iterative approach, constantly evaluating and adjusting their strategies to align with changing circumstances.

5.5 Encourage Collaboration

Collaboration is essential in a VUCA environment. Servant leaders promote collaboration among team members, departments, and even with external stakeholders. Also, servant leaders encourage the sharing of ideas, knowledge, and resources, fostering a collective intelligence that can help navigate the complexities and uncertainties of the business landscape (Heyler & Martin, 2018).

5.6 Promote Learning and Growth

Servant leaders cultivate a culture of continuous learning and growth, urging individuals to constantly enhance their skills and knowledge through training, mentorship, and learning from both successes and failures (Liden et al., 2014). Leaders prioritize learning and reflection as a means to understand and make sense of the VUCA effects (Rimita, 2019). Also, servant leaders drive individuals and teams to reflect on their experiences, learn from them, and apply the insights gained to future situations (Coetzer et al., 2017). This continuous learning cycle enables servant leaders to adapt and refine their strategies in response to VUCA effects.

6 Conclusion

In a VUCA world, servant leaders embracing the chaos theory principles can effectively guide their organizations through uncertainty and complexity. By perceiving VUCA effects as opportunities and adopting behaviors that encourage adaptability, resilience, empowerment, collaboration, and a clear sense of purpose, servant leaders can create a positive and thriving organizational culture. The integration of servant leadership and chaos theory provides a valuable framework for leaders to navigate the challenges of the modern business landscape and foster long-term success (Dierendonck & Patterson, 2018). Servant leadership and the chaos theory offer valuable insights and approaches for navigating the complexities of leadership in today's unpredictable world. By embracing uncertainty, valuing diverse perspectives, nurturing empowerment, and fostering a culture of learning and resilience, leaders can effectively respond to the challenges and opportunities presented by complex systems. Servant leaders can inspire and empower their teams, drive organizational success, and make a positive impact in their respective fields through synergistically integrating these concepts, especially learning culture and empowerment. By embracing the principles of servant leadership, Moreover, servant leaders can navigate through uncertainty, complexity, and ambiguity while empowering their followers to adapt and thrive in a rapidly changing environment. With a strong vision, trust, effective communication, and a focus on continuous learning, servant leaders can create resilient organizations capable of embracing and leveraging chaos for innovation and growth (Haar et al., 2017).

Anticipating and responding to VUCA effects is a critical challenge for leaders in today's business environment. Through chaos theory, servant leaders can recognize the non-linear and unpredictable nature of VUCA effects. Servant leaders can adopt an adaptive and flexible leadership approach that allows them to thrive in dynamic and ever-changing circumstances. By embracing the inherent complexity of their organizations and the external environment, servant leaders can make informed decisions, identify patterns, and uncover hidden opportunities (Wang et al., 2019). Thus, servant leaders who understand the principles of chaos theory can anticipate and respond to

VUCA effects more effectively, fostering a culture of innovation, collaboration, and growth within their organizations.

Servant leaders are compelled to develop a mindset that embraces uncertainty and ambiguity if transforming the adverse effects of the VUCA into a more opportunistic structure is the main goal of an organization to survive in the chaotic business environment. By creating an environment where individuals feel safe to take risks and explore innovative solutions, servant leaders can harness the potential of chaos and turn it into a catalyst for growth and innovation (Hai & Van, 2021; Ramakrishnan, 2021). Therefore, encouraging open communication, empowering teams, and fostering a culture of learning and experimentation have carried out potential opportunities to integrate individuals self-organizing with high motivation.

Furthermore, servant leaders should prioritize building strong relationships with their teams and stakeholders. By nurturing trust, collaboration, and transparency, servant leaders can create a sense of stability and coherence amidst chaos. Servant leaders should actively listen to their team members, understand their concerns, and provide support and guidance when needed. By fostering a culture of servant leadership, it can be possible to inspire teams to adapt, overcome challenges, and thrive in the face of VUCA effects.

In light of these observations pointing out both organizational and individual patterns, anticipating the servant leaders' reflex to VUCA effects through a chaos theory perspective requires embracing complexity, adopting an adaptive mindset, nurturing strong communication and collaboration, and fostering a culture of empowerment. By doing so, servant leaders can effectively navigate the uncertainties of the business landscape and guide their teams toward success in an increasingly VUCA world.

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Parameter Estimation for Kumaraswamy Weibull Distribution Under Ranked Set Sampling

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Abstract In this study, modified maximum likelihood (MML) estimators for the location and scale parameters of the Kumaraswamy Weibull (Kw-Weibull) distribution are derived based on ranked set sampling (RSS) method under the assumption of known shape parameters, see Tiku (1967, 1968) in the context of MML methodology. MML estimators based on RSS are compared with the traditional maximum likelihood (ML) estimators based on simple random sampling (SRS) via Monte-Carlo simulation study in terms of bias, mean squares error (MSE) and relative efficiency (RE) criteria. According to the results of the simulation study, MML estimators based on RSS are found to be more efficient than the ML estimators based on SRS in most of the simulation scenarios.

1 Introduction

The Weibull distribution, which takes its name from Waloddi Weibull, is one of the most popular probability distributions having widespread usage in different areas of science, such as reliability theory, engineering, biology, hydrology, etc., see Weibull (1939). However, it fails to provide a good fit to data sets having bathtub-shaped or upside-down bathtub-shaped failure rates that are commonly observed in the fields of engineering and reliability. In order to model such datasets, many different forms

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of Weibull distribution have been proposed in the literature, for example, inverse Weibull, exponentiated Weibull, modified Weibull, transmuted inverse Weibull, etc. The Kumaraswamy Weibull (Kw-Weibull) distribution proposed by Cordeiro et al. (2010) is another form of the Weibull distribution, for the details of Kumaraswamy distribution, see Kumaraswamy (1980). It has a high degree of flexibility for modeling positive data encountered especially in the area of reliability.

It is worthy to mention that obtaining a sample that is fairly representative of the population is an important step in statistical inference about the real world. Simple random sampling (SRS) is the most widely used sampling method in the literature. Nevertheless, sample selected via SRS may not represent the population well enough. To overcome this problem, the ranked set sampling (RSS) method is used as a powerful alternative to SRS especially for circumstances when the variable of interest is expensive or cannot easily be measured but can easily be ranked at a negligible cost, see McIntyre (1952). It offers the benefit of increasing the efficiency of the estimators for population parameters by containing the information provided not only by measured observations but also by the ranking process.

There is an extensive literature focusing on the performance of RSS and its different forms in parameter estimation. Dell and Clutter (1972) showed that an unbiased estimator for the population mean is obtained based on RSS irrespective of ranking errors and it is at least as efficient as the estimator obtained based on SRS with the same sample size. Stokes (1980a, b) and Stokes and Sager (1988) proved that RSS provides more precise estimators for the variance, Pearson correlation coefficient and cumulative distribution function, respectively. Stokes (1995) examined the maximum likelihood (ML) and the best linear unbiased estimators for the location and scale parameters of the location-scale distribution family based on RSS. Barabesi and El-Sharaawi (2001) showed that parametric inference based on RSS provides more information than SRS. Abu-Dayyeh et al. (2004) proposed different estimators for the location and scale parameters of the logistic distribution using SRS, RSS or some modifications of RSS. Helu et al. (2010) compared ML, method of moments (MoM) and Bayesian estimators for the Weibull distribution parameters based on different sampling schemes such as SRS, RSS and modified ranked set sample (MRSS). Al-Omari and Al-Hadhrami (2011) compared ML estimators for the parameters of the modified Weibull distribution based on the extreme ranked set sampling (ERSS) and SRS. Balci et al. (2013) derived modified maximum likelihood (MML) estimators for the population mean and variance under RSS. Hussian (2014) compared the ML and Bayesian estimators for the Kumaraswamy distribution parameters based on SRS and RSS. Yousef and Al-Subh (2014) compared ML estimators for the Gumbel distribution parameters based on SRS and RSS with MoM and regression estimators based on SRS. Dey et al. (2017) discussed the estimation of the parameter of the Rayleigh distribution using different estimation approaches based on different sampling methods such as SRS, RSS, MRSS and median RSS. Samuh et al. (2020) investigated the ML estimators for the new Weibull-Pareto distribution parameters based on SRS, RSS and some forms of RSS. Taconeli and de Lara (2022) evaluated the performance of nine different estimators for the discrete Weibull distribution parameters based on SRS and RSS.

In this study, the MML estimators for the location and scale parameters of Kw-Weibull distribution based on RSS are obtained when the shape parameters are assumed to be known. Then, they are compared with the traditional ML estimators based on SRS in terms of bias, mean squares error (MSE) and relative efficiency (RE) criteria via Monte Carlo simulation. The reason why we include MML methodology into the study is its capability to avoid problems due to iterative methods by providing explicit solutions. MML estimators are also asymptotically equivalent to ML estimators as well as having high efficiencies even for small sample sizes. As far as we know, this is the first study investigating the efficiencies of the MML estimators for Kw-Weibull parameters in the context of RSS. Also, note that all the computations are conducted under the assumption of perfect ranking. See Ergenc and Senoglu (2023) for the ML estimators of Kw-Weibull parameters based on SRS.

The remaining sections of this work are organized as follows. In Sect. 2, Kw-Weibull distribution is described and the MML estimators for the location and scale parameters of the Kw-Weibull distribution based on RSS are derived. Section 3 presents the results of the Monte Carlo simulation study. Finally, concluding remarks are given in Sect. 4.

2 Parameter Estimation

In this section, Kw-Weibull distribution is briefly described and the MML estimators based on RSS for its location and scale parameters are obtained with the assumption of known shape parameters.

2.1 Kw-Weibull Distribution

Let X be a random variable with Kw-Weibull density function

$$f_X(x) = \frac{abp}{\sigma}\left(\frac{x-\mu}{\sigma}\right)^{p-1}\exp\left\{-\left(\frac{x-\mu}{\sigma}\right)^{p}\right\}\left[1-\exp\left\{-\left(\frac{x-\mu}{\sigma}\right)^{p}\right\}\right]^{a-1} \times\left\{1-\left[1-\exp\left\{-\left(\frac{x-\mu}{\sigma}\right)^{p}\right\}\right]^{a}\right\}^{b-1}; x\geq\mu;\sigma>0;a,b,p\geq 0 \tag{1}$$

and distribution function

$$F_X(x) = 1-\left\{1-\left[1-exp\left\{-\left(\frac{x-\mu}{\sigma}\right)^{p}\right\}\right]^{a}\right\}^{b}. \tag{2}$$

Here, a, b and p are the shape parameters, μ and σ are the location and scale parameters, respectively. The random variable X having Kw-Weibull distribution with the mentioned parameters is shortly denoted by $X \sim$ Kw-Weibull(a, b, p, σ, μ).

Kw-Weibull distribution is negatively or positively skewed in addition to being leptokurtic (having kurtosis greater than 3) or platykurtic (having kurtosis less than 3) based on the values of the shape parameters. It is also reduced to some well-known probability distributions, such as Weibull, exponentiated Weibull, Rayleigh, exponentiated Rayleigh, Exponential and exponentiated Exponential for some specific values of its shape parameters. For the details of the Kw-Weibull distribution, one may refer to Cordeiro et al. (2010), Guven and Senoglu (2023).

2.2 MML Estimators Based on RSS

In order to obtain a ranked set sample, firstly m sets of size m are selected by using SRS. Then, the sample units in each set are ranked in ascending order according to some inexpensive criterion, e.g., visual inspection, expert opinion or a concomitant variable without any exact measurement. After ranking, the unit with the smallest rank is selected from the first set. The unit with the second smallest rank is selected from the second set and this procedure is continued until the largest ranked unit is selected from the mth set. The entire process constitutes a cycle and can be repeated for r times yielding a sample of size $n = mr$, if needed. At the end, only the selected units are actually measured.

For this study, let $X_{(i)ic}, i = 1, \ldots, m; c = 1, \ldots, r$, be the resulted sample with size $n = mr$ from Kw-Weibull(a, b, p, σ, μ) distribution. Realize that $X_{(i)ic}$ denotes the ith order statistics for the ith set from the cth cycle. In the rest of this study, X_{ic} is used instead of $X_{(i)ic}$ for the sake of simplicity.

The probability density function (pdf) of X_{ic} is obtained as

$$f_{X_{ic}}(x_{ic}) = \frac{m!}{(i-1)!(m-i)!} [F_X(x_{ic})]^{i-1} [1 - F_X(x_{ic})]^{m-i} f_X(x_{ic}) \tag{3}$$

where f and F are the density and distribution functions of Kw-Weibull distribution given in equations (1) and (2), respectively.

In order to obtain the ML estimators for the location and scale parameters of Kw-Weibull distribution based on RSS, first the likelihood (L) function is written as follows

$$L = \prod_{c=1}^{r} \prod_{i=1}^{m} \frac{m!}{(i-1)!(m-i)!} \frac{1}{\sigma} [F(z_{ic})]^{i-1} [1 - F(z_{ic})]^{m-i} f(z_{ic}) \tag{4}$$

where $z_{ic} = \frac{x_{ic}-\mu}{\sigma}$. Then, the log-likelihood ($\ln L$) function is obtained by taking the logarithm of L as given below

$$\ln L = \ln\left(\prod_{c=1}^{r}\prod_{i=1}^{m}\frac{m!}{(i-1)!(m-i)!}\right) - n\ln(\sigma) + \sum_{c=1}^{r}\sum_{i=1}^{m}(i-1)\ln\left[F\left(z_{ic}\right)\right] + \sum_{c=1}^{r}\sum_{i=1}^{m}(m-i)\ln\left[1-F\left(z_{ic}\right)\right] + \sum_{c=1}^{r}\sum_{i=1}^{m}\ln\left[f\left(z_{ic}\right)\right]. \quad (5)$$

By taking the partial derivatives of $\ln L$ with respect to the parameters μ and σ and setting them equal to zero, the likelihood equations are obtained as

$$\frac{\partial \ln L}{\partial \mu} = -\frac{1}{\sigma}\left(\sum_{c=1}^{r}\sum_{i=1}^{m}(i-1)\frac{f(z_{ic})}{F(z_{ic})} - \sum_{c=1}^{r}\sum_{i=1}^{m}(m-i)\frac{f(z_{ic})}{1-F(z_{ic})} + \sum_{c=1}^{r}\sum_{i=1}^{m}\frac{f'(z_{ic})}{f(z_{ic})}\right) = 0 \quad (6)$$

and

$$\frac{\partial \ln L}{\partial \sigma} = -\frac{1}{\sigma}\left(n + \sum_{c=1}^{r}\sum_{i=1}^{m}(i-1)z_{ic}\frac{f(z_{ic})}{F(z_{ic})} - \sum_{c=1}^{r}\sum_{i=1}^{m}(m-i)z_{ic}\frac{f(z_{ic})}{1-F(z_{ic})} + \sum_{c=1}^{r}\sum_{i=1}^{m}z_{ic}\frac{f'(z_{ic})}{f(z_{ic})}\right) = 0. \quad (7)$$

Likelihood equations in (6) and (7) cannot be solved in closed form since they include nonlinear functions of the parameters. Therefore, in order to obtain ML estimators, numerical methods should be used. However, they have some drawbacks such as i) non-convergence, ii) convergence to wrong roots and iii) convergence to multiple roots. Thus, in this study Tiku's MML methodology is used, which provides explicit estimators maintaining the same asymptotic properties with ML estimators. In MML methodology, since the complete sums are invariant to ordering, i.e. $\sum_{c=1}^{r}\sum_{i=1}^{m} z_{(i)c} = \sum_{c=1}^{r}\sum_{i=1}^{m} z_{ic}$, first the likelihood equations in (6) and (7) are written in terms of standardized order statistics $z_{(1)c} < z_{(2)c} < \cdots < z_{(m)c}$ $(c = 1, \ldots, r)$ as follows

$$\frac{\partial \ln L}{\partial \mu} = -\frac{1}{\sigma}\left(\sum_{c=1}^{r}\sum_{i=1}^{m}(i-1)g_1(z_{(i)c}) - \sum_{c=1}^{r}\sum_{i=1}^{m}(m-i)g_2(z_{(i)c}) + \sum_{c=1}^{r}\sum_{i=1}^{m}g_3(z_{(i)c})\right) = 0 \quad (8)$$

and

$$\frac{\partial \ln L}{\partial \sigma} = -\frac{1}{\sigma}\left(n + \sum_{c=1}^{r}\sum_{i=1}^{m}(i-1)z_{(i)c}g_1(z_{(i)c}) - \sum_{c=1}^{r}\sum_{i=1}^{m}(m-i)z_{(i)c}g_2(z_{(i)c}) + \sum_{c=1}^{r}\sum_{i=1}^{m}z_{(i)c}g_3(z_{(i)c})\right) = 0. \tag{9}$$

Here, $z_{(i)c} = \frac{x_{(i)c}-\mu}{\sigma}$, $g_1(z_{(i)c}) = \frac{f(z_{(i)c})}{F(z_{(i)c})}$, $g_2(z_{(i)c}) = \frac{f(z_{(i)c})}{1-F(z_{(i)c})}$ and $g_3(z_{(i)c}) = \frac{f'(z_{(i)c})}{f(z_{(i)c})}$.

Secondly, nonlinear functions, $g_1(z_{(i)c})$, $g_2(z_{(i)c})$ and $g_3(z_{(i)c})$ are linearized around the expected values of the ordered statistics, i.e. $t_{(i)c} = E(z_{(i)c})$, by using the first two terms of the Taylor series expansion as follows

$$\begin{aligned} g_1(z_{(i)c}) &\cong \alpha_{1i} - \beta_{1i}z_{(i)c}, \\ g_2(z_{(i)c}) &\cong \alpha_{2i} + \beta_{2i}z_{(i)c}, \\ g_3(z_{(i)c}) &\cong \alpha_{3i} - \beta_{3i}z_{(i)c} \end{aligned} \tag{10}$$

where

$$\begin{aligned} \alpha_{1i} &= \frac{f(t_{(i)c})}{F(t_{(i)c})} + \beta_{1i}t_{(i)c}, \quad \beta_{1i} = -\left(\frac{f'(t_{(i)c})}{F(t_{(i)c})} - \frac{(f(t_{(i)c}))^2}{(F(t_{(i)c}))^2}\right), \\ \alpha_{2i} &= \frac{f(t_{(i)c})}{1-F(t_{(i)c})} - \beta_{2i}t_{(i)c}, \quad \beta_{2i} = \left(\frac{f'(t_{(i)c})}{1-F(t_{(i)c})} + \frac{(f(t_{(i)c}))^2}{(1-F(t_{(i)c}))^2}\right), \\ \alpha_{3i} &= \frac{f'(t_{(i)c})}{f(t_{(i)c})} + \beta_{3i}t_{(i)c} \quad \text{and} \quad \beta_{3i} = -\left(\frac{f''(t_{(i)c})f(t_{(i)c}) - (f'(t_{(i)c}))^2}{(f(t_{(i)c}))^2}\right). \end{aligned}$$

It should be noted that z_{ic} are independent and non-identically (inid) distributed, therefore expected values of standardized order statistics, $t_{(i)c}$, are calculated via Monte Carlo simulation to avoid mathematical difficulties in theory.

By incorporating the linearized functions in (10) into (8) and (9), the modified likelihood equations are obtained as below

$$\frac{\partial \ln L^*}{\partial \mu} = -\frac{1}{\sigma}\sum_{c=1}^{r}\sum_{i=1}^{m}(i-1)(\alpha_{1i} - \beta_{1i}z_{(i)c}) + \frac{1}{\sigma}\sum_{c=1}^{r}\sum_{i=1}^{m}(m-i)\left(\alpha_{2i} + \beta_{2i}z_{(i)c}\right) - \frac{1}{\sigma}\sum_{c=1}^{r}\sum_{i=1}^{m}\left(\alpha_{3i} - \beta_{3i}z_{(i)c}\right) = 0 \tag{11}$$

and

$$\frac{\partial \ln L^*}{\partial \sigma} = -\frac{n}{\sigma} - \frac{1}{\sigma}\sum_{c=1}^{r}\sum_{i=1}^{m}(i-1)z_{(i)c}(\alpha_{1i} - \beta_{1i}z_{(i)c}) + \frac{1}{\sigma}\sum_{c=1}^{r}\sum_{i=1}^{m}(m-i)z_{(i)c}\left(\alpha_{2i} + \beta_{2i}z_{(i)c}\right) - \frac{1}{\sigma}\sum_{c=1}^{r}\sum_{i=1}^{m}z_{(i)c}\left(\alpha_{3i} - \beta_{3i}z_{(i)c}\right) = 0. \tag{12}$$

Simultaneous solutions of the equations (11) and (12) give the following MML estimators

$$\hat{\mu} = K - D\hat{\sigma} \quad \text{and} \quad \hat{\sigma} = \frac{-B + \sqrt{B^2 + 4nC}}{2\sqrt{n(n-1)}} \tag{13}$$

where

$$K = \frac{\sum_{c=1}^{r}\sum_{i=1}^{m}\delta_i x_{(i)c}}{M}, \quad M = r\sum_{i=1}^{m}\delta_i, \quad D = \frac{r\sum_{i=1}^{m}\Delta_i}{M},$$

$$\delta_i = (i-1)\beta_{1i} + (m-i)\beta_{2i} + \beta_{3i}, \quad \Delta_i = (i-1)\alpha_{1i} - (m-i)\alpha_{2i} + \alpha_{3i},$$

$$B = \sum_{c=1}^{r}\sum_{i=1}^{m}\Delta_i\left(x_{(i)c} - K\right) \quad \text{and} \quad C = \sum_{c=1}^{r}\sum_{i=1}^{m}\delta_i\left(x_{(i)c} - K\right)^2.$$

Here, it should be noted if $\hat{\mu}$ is larger than $Min(x_{(1)c})$, it is taken as $Min(x_{(1)c}) - 10^{-4}$. Also, n in the divisor of $\hat{\sigma}$ is replaced by $\sqrt{n(n-1)}$ as a bias-correction. See also Akgül and Şenoğlu (2017) in the context of Weibull distribution.

3 Monte-Carlo Simulation

In this section, ML and MML estimators for the Kw-Weibull location and scale parameters are compared in terms of bias, MSE and RE criteria via an extensive Monte Carlo simulation study. REs are calculated using the following equalities

$$RE_1 = \frac{MSE(\hat{\mu}_{MML,RSS})}{MSE(\hat{\mu}_{ML,SRS})} \times 100 \tag{14}$$

and

$$RE_2 = \frac{MSE(\hat{\sigma}_{MML,RSS})}{MSE(\hat{\sigma}_{ML,SRS})} \times 100. \tag{15}$$

Here, $\hat{\mu}_{MML,RSS}$ and $\hat{\sigma}_{MML,RSS}$ denote the MML estimators for the location and scale parameters of the Kw-Weibull distribution based on RSS, respectively, while $\hat{\mu}_{ML,SRS}$ and $\hat{\sigma}_{ML,SRS}$ denote the ML estimators for the location and scale parameters of the Kw-Weibull distribution based on SRS, respectively. Note that ML estimates based on SRS and MML estimates based on RSS are calculated by using 10,000 replications. ML estimates of the parameters of interest are computed using optim function in R statistical software, while MML estimates are obtained explicitly.

In the simulation scenario, following values of the set size m, cycle size r and the shape parameters a, b and p are used

- (m, r)=(3,4), (4,3) and (6,2) for n=12
  (m, r)=(3,8), (4,6), (6,4) and (8,3) for n=24
- (a, b)= (1,1), (2,2), (5,6) and (6,3.5)

and

- p= 1.5, 3 and 6.

Simulated bias and MSE values for the estimators of the location and scale parameters of the Kw-Weibull distribution and the corresponding RE values are presented in Table 1.

The following conclusions can be drawn from Table 1.

- For small value of n, i.e., $n = 12$, $\hat{\mu}_{ML,SRS}$ and $\hat{\sigma}_{ML,SRS}$ do not perform well in terms of bias criterion while $\hat{\mu}_{MML,RSS}$ and $\hat{\sigma}_{MML,RSS}$ have negligibly small bias in majority of the cases except when $p = 1.5$, $(a, b) = (2, 2)$ and $p = 3$, $(a, b) = (1, 1)$. A point worthy of note for some of these exceptional cases is that biases of $\hat{\mu}_{MML,RSS}$ and $\hat{\sigma}_{MML,RSS}$ become smaller than $\hat{\mu}_{ML,SRS}$ and $\hat{\sigma}_{ML,SRS}$ as the set size m increases, respectively.
- MML estimators based on RSS and ML estimators based on SRS of the location parameter μ and scale parameter σ have negligibly small bias values for $n = 24$ except when $p = 1.5$, $(a, b) = (2, 2)$ and $p = 3$, $(a, b) = (1, 1)$. In the mentioned cases $\hat{\mu}_{MML,RSS}$ and $\hat{\sigma}_{MML,RSS}$ have considerably larger bias than their counterparts $\hat{\mu}_{ML,SRS}$ and $\hat{\sigma}_{ML,SRS}$, respectively.
- Overall, in view of bias, it can be deduced that MML estimators based on RSS of μ and σ have superiority over ML estimators based on SRS of μ and σ.
- $\hat{\mu}_{MML,RSS}$ outperforms $\hat{\mu}_{ML,SRS}$ in terms of efficiency in most of the cases and this superiority becomes more apparent as the set size m increases for a fixed n. Here, it should be noted that when $p = 1.5$, $(a, b) = (2, 2)$ and $p = 3$, $(a, b) = (1, 1)$, $\hat{\mu}_{ML,SRS}$ has higher efficiency than $\hat{\mu}_{MML,RSS}$ only for some small values of m, see RE_1 from Table 1.
- $\hat{\sigma}_{MML,RSS}$ performs better than $\hat{\sigma}_{ML,SRS}$ in terms of efficiency for almost all cases. However, when $n = 24$, $p = 1.5$, $(a, b) = (2, 2)$ and $p = 3$, $(a, b) = (1, 1)$, $\hat{\sigma}_{ML,SRS}$ has slightly better efficiencies than $\hat{\sigma}_{MML,RSS}$ for small values of m, see RE_2 from Table 1.
- RE_1 and RE_2 values also reveal that the efficiencies of MML estimators based on RSS increase as the set size m increases for a fixed sample size n.

Table 1 Simulated Bias, MSE and RE values for the MML estimators based on RSS and ML estimators based on SRS

$p = 1.5$								
			$\hat{\mu}$		$\hat{\sigma}$			
			Bias	MSE	Bias	MSE	RE_1	RE_2
		(m, r)	$(a, b) = (2, 2)$					
ML(SRS)	$n = 12$	–	0.072340	0.029763	–0.078016	0.045597		
MML(RSS)		(3, 4)	0.118564	0.034182	–0.070474	0.040843	114	90
		(4, 3)	0.097934	0.028135	–0.066931	0.036501	94	80
		(6, 2)	0.075475	0.021436	–0.058926	0.029582	72	65
ML(SRS)	$n = 24$	–	0.038350	0.013196	–0.041993	0.021870		
MML(RSS)		(3, 8)	0.113396	0.022673	–0.065169	0.022020	172	101
		(4, 6)	0.093946	0.017898	–0.060182	0.019451	136	89
		(6, 4)	0.072783	0.012764	–0.055847	0.015483	97	71
		(8, 3)	0.062998	0.010353	–0.052429	0.013266	79	61
		(m, r)	$(a, b) = (5, 6)$					
ML(SRS)	$n = 12$	–	0.070272	0.047452	–0.068373	0.044535		
MML(RSS)		(3, 4)	0.049735	0.040172	–0.038698	0.038343	85	86
		(4, 3)	0.046873	0.035764	–0.038293	0.033975	75	76
		(6, 2)	0.044277	0.029992	–0.039003	0.028480	63	64
ML(SRS)	$n = 24$	–	0.032074	0.022402	–0.031069	0.020975		
MML(RSS)		(3, 8)	0.041789	0.020389	–0.030900	0.018943	91	90
		(4, 6)	0.045113	0.018845	–0.036734	0.017521	84	84
		(6, 4)	0.043766	0.015529	–0.038443	0.014650	69	70
		(8, 3)	0.043015	0.013745	–0.039000	0.012994	61	62
$(a, b) = (6, 3.5)$								
ML(SRS)	$n = 12$	–	0.089519	0.070353	–0.071578	0.045657		
MML(RSS)		(3, 4)	0.065021	0.061448	–0.036593	0.039812	87	87
		(4, 3)	0.056816	0.055442	–0.034802	0.036263	79	79
		(6, 2)	0.050850	0.044862	–0.034203	0.029368	64	64
ML(SRS)	$n = 24$	–	0.041281	0.032912	–0.032437	0.021271		
MML(RSS)		(3, 8)	0.049610	0.029827	–0.025006	0.019225	91	90
		(4, 6)	0.050599	0.028167	–0.029468	0.017995	86	85
		(6, 4)	0.049945	0.023364	–0.032949	0.014921	71	70
		(8, 3)	0.050030	0.020102	–0.035115	0.013003	61	61
$p = 3$								
			$\hat{\mu}$		$\hat{\sigma}$			
			Bias	MSE	Bias	MSE	RE_1	RE_2
		(m, r)	$(a, b) = (1, 1)$					
ML(SRS)	$n = 12$	–	0.074350	0.036051	–0.080780	0.039964		
MML(RSS)		(3, 4)	0.083876	0.031710	–0.081147	0.035811	88	90
		(4, 3)	0.079154	0.028206	–0.078733	0.032574	78	82
		(6, 2)	0.069088	0.023539	–0.069279	0.027396	65	69

Table 1 (continued)

ML(SRS)	$n = 24$	–	0.038107	0.016294	–0.040955	0.018091		
MML(RSS)		(3, 8)	0.081924	0.018450	–0.078850	0.020235	113	112
		(4, 6)	0.074480	0.016125	–0.074630	0.018297	99	101
		(6, 4)	0.064266	0.013034	–0.065295	0.015079	80	83
		(8, 3)	0.058952	0.011039	–0.061466	0.012996	68	72
		(m, r)	$(a, b) = (2, 2)$					
ML(SRS)	$n = 12$	–	0.063038	0.040924	–0.066700	0.044006		
MML(RSS)		(3, 4)	0.043504	0.033315	–0.045686	0.037454	81	85
		(4, 3)	0.041683	0.029675	–0.044383	0.033306	73	76
		(6, 2)	0.041134	0.025014	–0.043584	0.028443	61	65
ML(SRS)	$n = 24$	–	0.031525	0.019718	–0.033480	0.021016		
MML(RSS)		(3, 8)	0.036230	0.016268	–0.037837	0.018210	83	87
		(4, 6)	0.036178	0.015217	–0.038019	0.017004	77	81
		(6, 4)	0.037944	0.012768	–0.040078	0.014503	65	69
		(8, 3)	0.038649	0.011388	–0.040665	0.012865	58	61
		(m, r)	$(a, b) = (5, 6)$					
ML(SRS)	$n = 12$	–	0.066067	0.049908	–0.065113	0.046415		
MML(RSS)		(3, 4)	0.023655	0.043534	–0.027627	0.040959	87	88
		(4, 3)	0.028471	0.038423	–0.030532	0.036367	77	78
		(6, 2)	0.028696	0.031618	–0.029825	0.030151	63	65
ML(SRS)	$n = 24$	–	0.031656	0.024048	–0.031556	0.022217		
MML(RSS)		(3, 8)	0.015219	0.020430	–0.019033	0.019377	85	87
		(4, 6)	0.021625	0.018428	–0.024169	0.017512	77	79
		(6, 4)	0.029105	0.015444	–0.030505	0.014800	64	67
		(8, 3)	0.030638	0.013605	–0.031642	0.013070	57	59
$p = 3$								
			$\hat{\mu}$		$\hat{\sigma}$			
			Bias	MSE	Bias	MSE	RE_1	RE_2
		(m, r)	$(a, b) = (6, 3.5)$					
ML(SRS)	$n = 12$	–	0.073271	0.058461	–0.065721	0.045182		
MML(RSS)		(3, 4)	0.025503	0.050083	–0.024275	0.039212	86	87
		(4, 3)	0.029301	0.046109	–0.026956	0.036219	79	80
		(6, 2)	0.034794	0.038262	–0.031707	0.030159	65	67
ML(SRS)	$n = 24$	–	0.035316	0.028058	–0.031097	0.021661		
MML(RSS)		(3, 8)	0.017353	0.023998	–0.016964	0.018845	86	87
		(4, 6)	0.024369	0.022289	–0.022939	0.017479	79	81
		(6, 4)	0.030895	0.019065	–0.028034	0.015003	68	69
		(8, 3)	0.033621	0.016752	–0.030527	0.013242	60	61
$p = 6$								
		(m, r)	$(a, b) = (1, 1)$					
ML(SRS)	$n = 12$	–	0.067451	0.044927	–0.070986	0.043264		
MML(RSS)		(3, 4)	0.034575	0.036711	–0.051248	0.037367	82	86
		(4, 3)	0.034040	0.032620	–0.046275	0.033504	73	77
		(6, 2)	0.033945	0.026890	–0.041317	0.027858	60	64

Table 1 (continued)

ML(SRS)	$n = 24$	–	0.031876	0.021009	–0.033776	0.020162		
MML(RSS)		(3, 8)	0.026835	0.017631	–0.042409	0.018324	83	91
		(4, 6)	0.032119	0.016027	–0.043968	0.016822	76	83
		(6, 4)	0.034754	0.013490	–0.042608	0.014250	64	71
		(8, 3)	0.036360	0.011805	–0.042345	0.012472	56	62
		(m, r)	$(a, b) = (2, 2)$					
ML(SRS)	$n = 12$	–	0.061994	0.046736	–0.065090	0.046791		
MML(RSS)		(3, 4)	0.015073	0.038908	–0.023530	0.039738	83	85
		(4, 3)	0.024646	0.035461	–0.030801	0.036364	76	78
		(6, 2)	0.024914	0.028947	–0.029336	0.030147	62	64
ML(SRS)	$n = 24$	–	0.031791	0.022503	–0.033409	0.022475		
MML(RSS)		(3, 8)	0.014317	0.018875	–0.022367	0.019448	84	87
		(4, 6)	0.021008	0.017164	–0.027384	0.017814	76	79
		(6, 4)	0.017814	0.014135	–0.030223	0.014779	63	66
		(8, 3)	0.030261	0.012393	–0.033767	0.013011	55	58
$p = 6$								
			$\hat{\mu}$		$\hat{\sigma}$			
			Bias	MSE	Bias	MSE	RE_1	RE_2
		(m, r)	$(a, b) = (5, 6)$					
ML(SRS)	$n = 12$	–	0.065423	0.049333	–0.065108	0.047079		
MML(RSS)		(3, 4)	0.015262	0.042233	–0.019471	0.040597	86	86
		(4, 3)	0.024357	0.037928	–0.027087	0.036563	77	78
		(6, 2)	0.025777	0.032181	–0.027499	0.031188	65	66
ML(SRS)	$n = 24$	–	0.029579	0.023694	–0.029604	0.022530		
MML(RSS)		(3, 8)	0.009252	0.021041	–0.013529	0.020209	89	90
		(4, 6)	0.015196	0.019067	–0.018253	0.018450	80	82
		(6, 4)	0.023697	0.015617	–0.025511	0.015168	66	67
		(8, 3)	0.025037	0.013430	–0.026268	0.013090	57	58
$(a, b) = (6, 3.5)$								
ML(SRS)	$n = 12$	–	0.067278	0.053691	–0.063828	0.046907		
MML(RSS)		(3, 4)	0.016559	0.046085	–0.018403	0.040374	86	86
		(4, 3)	0.022479	0.041768	–0.023273	0.036743	78	78
		(6, 2)	0.030241	0.034589	–0.029848	0.030468	64	65
ML(SRS)	$n = 24$	–	0.033218	0.025832	–0.031413	0.022463		
MML(RSS)		(3, 8)	0.011041	0.022555	–0.013359	0.019740	87	88
		(4, 6)	0.017659	0.020266	–0.018731	0.017864	78	80
		(6, 4)	0.027006	0.016983	–0.026798	0.014978	66	67
		(8, 3)	0.030047	0.014780	–0.029262	0.013084	57	58

The reason why we use various different values of m and r in this study is to see the tradeoff between the efficiencies of the MML estimators based on RSS and the practical issues. It is mentioned in the literature that the efficiency of an estimator based on RSS is an increasing function of the set size m, see for example, Patil et al. (1994) and Kowalczyk (2005). Results in Table 1 are consistent with the literature since the efficiencies of the MML estimators based on RSS increase as the set size m increases for a fixed n, see RE_1 and RE_2 values in Table 1. However, large values of set size m may cause an increase in cost and also difficulties in ranking, so in order to obtain enough number of measurements in statistical inference problems, the cycle size r is increased instead of m in RSS procedure.

4 Conclusion

In this study, MML estimators for the location and scale parameters of the Kw-Weibull distribution are obtained under RSS in explicit forms. Then the performances of the proposed estimators are compared with those of the traditional ML estimators based on SRS according to criteria of bias, MSE and RE using Monte Carlo simulation study. MML estimators based on RSS are found to be more efficient compared to the traditional ML estimators based on SRS in most of the cases defined in simulation scenario. Simulation results also indicate that the efficiencies of the MML estimators increase as the set size m increases as expected. Note that MML methodology based on RSS can easily be extended to other distributions belong to the location scale family.

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Job Satisfaction and Motivation of Teachers in Changing World

Kaan Bati

Abstract Global challenges and rapidly developing technology are creating a new (normal) life in the twenty-first century to which education systems will have to adapt. These rapid changes increase the need for qualified manpower in line with the requirements of the age, but education systems do not have the reflexes to respond to these needs. On the other hand, it is still unclear what kind of manpower will be needed in the coming years, what the new job descriptions will be and what skills will be required. In this chaotic environment, expectations from teachers, who are the locomotive of education systems, are increasing and this situation negatively affects their job satisfaction and motivation. In addition, the question "what do we expect from teachers in the digital world?" has yet to be answered. In this chapter, I have tried to examine teachers' motivation and job satisfaction in the light of societal changes and discussed what the future holds for the teaching profession and what education systems should do in this uncertain future.

Keywords Teachers · Job satisfaction · Motivation · Chaos

1 Teachers in Chaotic World

Changing job descriptions due to industrial and technological developments, which are the driving force of economic growth, define new skills and competencies for the manpower needed. The job descriptions and employee qualifications of the last century seem to be far from meeting our needs in today's world. Recognizing this gap, many researchers and theorists have proposed some skills that they define as twenty-first century skills (Saavedra & Opfer, 2012; Voogt & Roblin, 2012), twenty-first century skills are generally defined as higher order thinking skills, deeper learning outcomes, and complex thinking and communication skills (Saavedra & Opfer, 2012). The Partnership for 21st Century Skills (P21) grouped these skills under

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the sub-dimensions of (a) learning and innovation skills, (b) information, media and technology skills, and (c) life and career skills and emphasized that schools should support disciplinary and interdisciplinary teaching (Battelle for Kids 2019). However, these defined skills consist of skills such as creativity, problem solving and analytical thinking, which have been frequently discussed in the last century and are already included in education programs.

The rapid development of technology and the changes in job descriptions due to this development make it difficult for students to join the workforce quickly and be successful. The education provided in schools is far from providing students with these uncertain skills, so students are trying to increase their qualifications by participating in additional certificate programs. It is clear that there is an urgent need for students to develop twenty-first century skills. Many countries around the world have started to revise their education policies and curricula to include twenty-first century skills in their curricula (Charland 2014). However, despite all these initiatives and efforts, there is a clear problem: are we aware of the human qualities we will need in the coming years? I am not claiming that these so-called twenty-first century skills will not be useful in the current era, but I foresee that labeling them as twenty-first century skills may lead to a series of mistakes. We are about to complete the first quarter of the twenty-first century and let's look at the experiences of school-age children; pandemic, distance education, artificial intelligence applications (such as ChatGPT), global climate changes, etc. Even just these developments we have experienced in the last 5 years can give us clues about what kind of problems we may face in the rest of this century.

For example, we can foresee the possible consequences of global climate change, but we only have guesses about what kind of world awaits us afterwards. The IPCC (2018), in its Global Warming of 1.5 °C report, laid out many possible consequences such as health, energy, transportation, pollution, water and food shortages (https://www.ipcc.ch/sr15/). While all these changes are taking place, it is quite clear that employment and, in parallel, education systems will also be affected. Global climate change will soon demand manpower in many fields such as new agricultural practices, new energy production techniques, new transportation and communication solutions. Education systems and teachers will therefore be forced to adapt quickly to this transformation.

Unfortunately, transformations in education do not happen as fast as those in technology and industry, because it takes almost a generation to see the results of an approach or a paradigm introduced. Therefore, education systems may not be able to reflexively respond to rapid changes. When this happens, that is, when we need to find new solutions in areas such as food, energy, transportation and communication, will contemporary skills such as creative thinking, entrepreneurship and digital citizenship, which are currently included in curricula, be able to offer us solutions? On the other hand, the Sustainable Development Goals put forward by the United Nations are based on the vision of ending poverty, hunger and inequality worldwide by 2030 and ensuring the permanent protection of natural resources. One of these goals is Quality Education (SDG-4), which aims to provide inclusive and equitable lifelong quality education for all. This vision reveals that we have more pressing problems

than twenty-first century skills: the lack of equitable access to quality education for all.

It is obvious that digitalization and artificial intelligence, the second major change process ahead, will create new problems for the teaching profession. Bill Gates' predictions for the future of artificial intelligence show that "it is only a matter of time before artificial intelligence can teach children" (https://www.cnbc.com/2023/06/25/only-a-matter-of-time-before-ai-chatbots-are-teaching-kids-in-school.html), so shouldn't we re-evaluate the concept of teacher? I have stated above that the transformations in education systems are not as fast as technological developments, however, many studies examining the state of education systems during the pandemic process have revealed that education systems can also give some reflexes with the support of technology at some points.

UNICEF (2021) reported that 90% of countries closed their schools and switched to distance education during the pandemic. This is a great rate, but the fact that not every student can access distance education due to inequality of opportunity has made inequality in education and learning losses more visible all over the world during the pandemic. In addition, the decline in job satisfaction and motivation experienced by teachers during the pandemic raised questions about how executable the process was. All these developments are quite chaotic for teachers. To what extent do these chaotic situations affect teachers' motivation and job satisfaction? How does the potential decline in motivation and job satisfaction affect the quality of education? Does the resulting low quality of education put additional stress on teachers? As you can see, this is a vicious circle and I have tried to visualize it in Fig. 1.

Economic reasons and rising academic expectations are putting pressure on teachers' workloads. Particularly in countries with exam-based transition between education levels, students need to perform well in exams in order to achieve quality education, and this is a source of anxiety for parents as well as students. Teachers will bear the brunt of any possible failure. Many schools reflect such pressure from parents as an extra workload on teachers. This workload leads to low motivation, low motivation results in low quality of education, and low quality of education leads to low academic achievement. It is very difficult to get out of this vicious circle and it

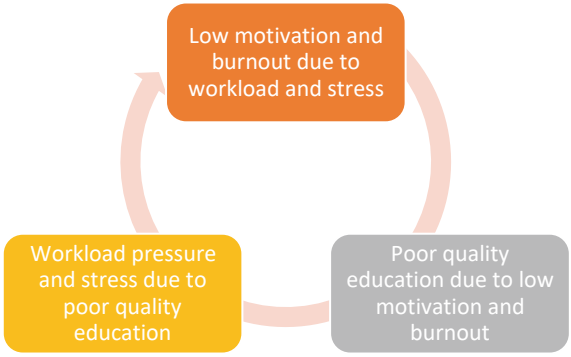

Fig. 1 Low motivation—poor quality education cycle

is not difficult to foresee that the expectations from teachers will increase, especially in the near future when they will have to keep up with the digital world. Before we tackle this vicious circle in the future, let's take a look at teachers' current job satisfaction and workload.

2 Workload and Burnout of Teachers

The school is a chaotic structure in itself, containing many parameters such as students, teachers, parents, programs, administrators, managers, administrators, skills, achievements and textbooks. In a system with so many variables, teachers are at the center of the showcase, and teachers are the ones who get the spotlight in the event of the slightest setback in education. A student's failure to perform as expected by the family in an exam often results in parents blaming teachers. Or a possible drop in school averages causes administrators to question teachers. Little thought is given to overcrowded schools, overworked teachers or insufficient materials for students. A review of studies on teachers' workload reveals that teachers think of workload as the time they spend on various daily tasks (Higton et al., 2017; Philipp & Kunter, 2013). In fact, although it is easy to calculate hours, it is possible that teachers with similar working hours do not complain about workload in the same way. This is because Kember and Leung (2006) found that workload is conceptualized by teachers as perceived workload rather than working hours.

The intense pace of work in schools over a long period of time causes teachers to suffer from health problems such as chronic stress and emotional fatigue, which can be associated with burnout (Sonnentag & Fritz, 2015). Because studies in this field reveal that teachers' job burnout is mostly caused by workload (Avanzi et al., 2018; Timms et al., 2012). There are many studies examining the relationship between teachers' burnout and job stress (Ho, 2017; Skaalvik & Skaalvik, 2016), and findings show that teachers who have to deal with larger classes often have to shoulder a greater burden (Yong & Yue, 2007). This situation causes teachers to experience high levels of job stress and consequently lower job performance (Ho, 2017). This leads us to the vicious circle I have tried to explain in Fig. 1.

The OECD Teaching and Learning International Survey (TALIS) is an international, large-scale survey of teachers, school leaders and the learning environment in schools. In the 2018 TALIS report, the distribution of the time teachers spend in the classroom is reported, with data dating back to 2008. TALIS 2018 reported that the amount of time teachers spend on active teaching and learning during a standardized lesson decreased from 2008 to 2018 in 12 out of 20 countries and economies with comparable data, with the largest decreases observed in Bulgaria, the Flemish Community of Belgium, Hungary and Turkey (OECD, 2019). It is not difficult to see that the result of this reduction in the time allocated for teaching in the classroom is lower quality of education.

3 Job Satisfaction of Teachers

Teacher job satisfaction is an important variable with far-reaching consequences for the school, students, the teaching profession and society. Research shows that teachers' job satisfaction increases with school quality (high standards), more effective school management and school adaptation (Ronfeldt et al., 2013). Teachers who are satisfied with their jobs are less likely to suffer from burnout syndrome (Anastasiou & Belios, 2020), have lower absenteeism rates (Ingersoll, 2017), and have higher job performance (Baroudi et al., 2022). Moreover, according to Hardy (2018), students of teachers with high job satisfaction also show better academic performance. However, it is difficult to conduct empirical studies to increase teachers' job satisfaction, as the factors on which teachers' job satisfaction depends, such as quality school environment, good standard of living, small class size, and social respect, are issues related to countries' economies and policies (Sims, 2020). For example, during the Covid-19 pandemic, studies providing evidence of teachers' job satisfaction and burnout were presented (Say et al., 2022), but experimental studies to address these shortcomings were not conducted. However, the literature suggests that improving self-efficacy, increasing participation in decision-making, providing job autonomy, and improving working conditions will increase teachers' job satisfaction (Sun & Xia, 2018).

As I have mentioned before, such variables are political and economic, so teachers' job satisfaction and motivation vary across countries, regions and even districts. Our social perception and some of our feelings from childhood tend to associate the teaching profession with sacrifice, and in some geographies even attribute sacredness to the teaching profession. However, poor working environments, low salaries and social status are unfortunately the realities of the teaching profession today. The social status of teachers is one of the variables of the professional teaching profession. The TALIS 2018 data also provides findings on the prestige of teachers or the perception of teaching in society. The results show that the extent to which teachers feel valued in the society they live in varies greatly from country to country, and this perception is highly subject to change (Mezza, 2022). This leads teachers to invest time and money in continuous professional development, otherwise their social acceptance is likely to suffer.

4 Inequality of Opportunity to Learn

Is the digitalization of education a threat? This is an issue that needs to be evaluated from many different perspectives. First of all, due to our positive view of technology, we have a belief that the technological is better. This also affects our view

of education. You can claim that your children will learn better with technology-supported teaching practices. However, the rising dominance of technology in education systems also brings some threats. The PISA 2018 Results Report (Effective Policies, Successful Schools, Vol. V) reported large disparities among OECD countries in students' access to educational technology. According to this report, in OECD countries, educational technology is more available in private schools than in public schools, in socio-economically advantaged schools than in disadvantaged schools, and this inequality has been increasing over the years. Between 2015 and 2018, the number of educational technologies increased in schools with students from higher socio-economic backgrounds, but not in schools with students from lower socio-economic backgrounds. This problem is of course not limited to educational technology, the same report mentions the emergence of a new type of social division: advantaged students versus disadvantaged students.

It is clear that advantaged students have higher opportunities to learn (OTL) than disadvantaged students, and that this translates into unequal job opportunities later in life. PISA investigates students' academic performance as well as the sources of that performance. Opportunity to Learn (OTL) is one of the sources of academic performance. The concept of Opportunity to Learn argues that differences in academic achievement are due to unequal learning conditions rather than students' abilities and includes conditions or opportunities that promote learning in schools and classrooms, such as curriculum, learning materials, physical conditions, teachers and their teaching experiences (Wijaya, 2017). Education systems are failing to provide children with equal opportunities to learn, and in this case, the teacher factor comes into play once again. How fair is it to expect teachers to pull rabbits out of hats when there are so many sources of students' low academic achievement?

5 Artificial Intelligence and the Future of Teaching

Before entering this discussion, I think it would be appropriate to define artificial intelligence; Luckin et al. (2016) define AI as […] "computer systems that have been designed to interact with the world through capabilities (for example, visual perception and speech recognition) and intelligent behaviors (for example, assessing the available information and then taking the most sensible action to achieve a stated goal) that we would think of as essentially human" (p. 14). As the definition suggests, AI is fundamentally capable of imitating humans. Therefore, given the state of today's digital technologies, it is not difficult to predict that artificial intelligence will be active in all areas of our lives, including education, in the near future. As I mentioned above, industry pioneers such as Bill Gates believe that the role of AI as a teacher is not far away. In addition, many "romantics" point to the social and emotional aspects of the teaching profession, saying that either AI cannot be a teacher because it lacks emotion, or that students will not accept AI teachers. Felix (2020) discussed many aspects of the use of AI in education and argued that AI in its current form is not capable of taking on the role of a teacher. According to Felix, AI is a machine that

has no will of its own, cannot think consciously, has no sense of self. Moreover, because it is programmed, it is incapable of flexible thinking and learning, so it lacks creativity and is not capable of the creative solutions and approaches that teachers demonstrate every day in the classroom.

On the other hand, there is also the possibility that our understanding of learning and schooling may change into something else in the future, and given the pace of development of AI, there is the potential for the use of AI in education in the future, but only as a secondary construct. This is where I differ from Felix and think that the AI-teacher concept will become widespread faster than expected due to the low-cost labor and long working hours it will offer. There are two main points in this debate, firstly, can the human—computer interaction between the AI-teacher and the student become as effective as the human—human interaction between the teacher and the student? So can AI mimic human communication? The work on this topic continues at a rapid pace and according to Edwards et al. (2018), it won't be long before AI mimics the components of human communication: credibility, attraction, immediacy and humor. Another point is the acceptance of the AI-teacher by humans, and more specifically by students, i.e. would they be willing to interact with the AI-teacher? Kim et al. (2020), in their research, found that students are predisposed to accept AI teaching assistants and are willing to communicate with them. Studies in the literature seem to vindicate Bill Gates.

We have been living with computers and algorithms for a long time, and we are quite happy with the convenience and speed they bring to our lives. Without realizing it, AI has already taken the lead in many sectors and others are likely to be next. While teachers may believe that AI can't teach because their profession is too human-centered, this change is closer than they think. In the near future, education, learning methods, thinking skills and teaching methods and approaches will need to be redefined. As individualized teaching assistants replace teachers, school will become more controversial and the teaching profession will need to be redefined. The advancement of AI is based on machine learning, and so AI algorithms may need to learn from teachers in order to take over teaching. In this case, competent teachers could review the learning and decisions made by personal AI assistants—perhaps for a while.

6 Conclusion

The world is changing very fast and education systems have to keep up with this change. We are discussing how our children can learn better with new approaches, methods, materials and we are making efforts to ensure that they will be able to have a job in the future. Teachers, who are the locomotive of education systems, are always in the spotlight and have to take criticism for the failures in education systems. In addition, the increasing labor force and low public image have a negative impact on teachers' job satisfaction and motivation. They are deprived of many supports due to inequality of opportunity. On top of all this, it seems quite possible that they face the

risk of losing their profession in the face of developing technologies. An education system in which personalized artificial intelligence applications start as support for teachers, and then the roles will change and teachers will support personal assistants may not be too far-fetched. The scary thing is that teachers will no longer be needed.

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Public Health Management Challenges During COVID-19

Tjandra Yoga Aditama

Abstract COVID-19 hits very hard the whole world. It was declared as Public Health Emergency of International Concern (PHEIC) by Director General WHO on 30th January 2020 (WHO, 2023). After about 3 years, on 4th May 2023, the WHO Emergency the Committee highlighted the decreasing trend in COVID-19 deaths, the decline in COVID-19 related hospitalizations and intensive care unit admissions, and the high levels of population immunity to SARS-CoV-2. The Committee advised that it is time to transition to long-term management of the COVID-19 pandemic. The WHO Director-General concurs with the advice offered by the Committee regarding the ongoing COVID-19 pandemic, and determines that COVID-19 is already an established and ongoing health issue which no longer constitutes a public health emergency of international concern (PHEIC) (WHO, 2023). As of 25 October 2023, there have been 771,549,718 confirmed cases of COVID-19 in the world, including 6,974,473 deaths, reported to WHO. As of 21 October 2023, a total of 13,533,465,652 vaccine doses have been administered globally (WHO Coronavirus (COVID-19) Dashboard, 2023). The three years experiences of COVID-19 has definitely become a game changer globally, even far more impactful than the invention of the engine during the industrial revolution. We also know that there will be another disease outbreak in the future, and even another pandemic. What we should do now is to learned our lesson from COVID-19 pandemic to be better prepare for the next health challenges that might occur.

1 Challenges

It's understandable that COVID-19 pandemic surpassed healthcare system. The model of crisis management during the pandemic highlights the great importance of "anticipating events", working "in a network" (Castro-Condea et al., 2021), between public health institutions as well other related agencies.

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Shamsiri et al. (2022) revealed nine categories of the COVID-19 management crisis which include challenges and management of workforce shortages; benefiting from the participation of volunteer staff; challenges and strategies for physical space, supplies, and personal protective equipment (PPE); designation of referral centers for COVID-19, protocolized patient transport, benefiting from donations and charity support, management of information about COVID-19; and learning from the prior stages of crisis. Their study revealed that in critical situations managers use multiple and, to some extent, unique strategies for decision-making and crisis control. Therefore, the health system can use the findings of this study for proper response to similar crises in the future.

We all know that hospital management were badly hit during COVID-19 pandemic. Hospitals are trying hard to manage problems it caused, searching for solutions to protect the health of citizens and reorienting operations. The implementation of resilience solutions in the coping phase and the ability to react promptly and redefine activities is essential. Publication by Donelli et al. (2022) integrate crisis management and resiliency literature on how health organizations were able to cope with adversity during the crisis. Their case reports actions taken in order to continue functioning and to maintain core activities despite severe adversity. The overall response was the result of the three types of response: behavioral (effective leadership), cognitive (rapid resource reallocation) and the contextual reinforcement (multiagency network response). The authors highlight how an integrative framework of crisis management and resiliency could be applied to healthcare organizations in the coping phase of the pandemic. Responding to crisis brings the opportunity to make innovations introduced during emergencies structural, and embed them moving forward.

Other study by Porter et al. (2021) stressed the importance of a one-team approach in hospital. They mentioned that previous research has demonstrated it is important for organizational members to pull together and act as a team during a crisis situation. A team approach offers a number of organizational benefits, however, most of the literature on teamwork is focused at the micro level (e.g., unit level) and does not address the importance of an organizational level team. The authors propose the importance of creating an organizational level team (e.g., one, which spans throughout the organization) as being key to successfully mitigating organizational crises. The authors offer an applied social identity approach as a theoretical lens to understand this phenomenon.

Hossny et al. (2022) published a study which aimed to explore the challenges, practices, and organizational support dealt with by nursing managers in the management of the COVID-19 pandemic. The authors used a qualitative content analysis study evaluated severel nursing managers in some university hospitals through a semi-structured interview. The Consolidated Criteria for Reporting Qualitative Research were used for this qualitative study. Their results showed that there are three main themes emerged, that is challenges include the development of a COVID-19 crisis management plan, a shortage in nursing staff, and psychological problems. Practices include changes in work schedules for nursing staff, the exchange process, hospital preparation, and training and education. It also needed an organizational support

includes both support at an organizational level and support at an individual level. Their study revealed that nursing managers are faced with many challenges in the management of COVID-19, requiring good practices and organizational support. This study offers evidence for nursing managers to expect problems that may arise during the pandemic.

It is clear that during COVId-19 pandemic the public health systems were not prepared to combat a novel viral pathogen that spread rapidly across the globe as containment measures were porous and inadequately implemented at the most crucial period (Combating COVID-19 Pandemic: The Best Management Practices of a Designated Hospital in Southern Philippines, 2023). After some time on the pandemic it has become apparent that cooperation in information sharing among governments and health care institutions, and clear and timely communication with the public, is critical to slow the incidence of continued infection and re-emergence of the pandemic (Bhatia & Khetrapal, 2020). Part of recovering from the pandemic requires restructuring public health care systems to be better prepared to manage novel disease outbreaks that overwhelmed the traditional hospital system and significantly impaired patient care quality and capacity. Thus, public health care systems need to be remodelled for efficient and capable management of emerging infectious disease outbreaks and formulated around five measures: management, protection, containment via control and suppression of transmission, information, and support. Latter on, the post-Covid-19 health care systems need to implement strategies that: (1) limit entry to heath care facilities to provide safety for patients and medical facility staff; (2) develop protocols and measures for retaining, protecting and supporting health care professionals and staff; (3) redirect non-urgent cases from hospitals to outpatient care facilities; (4) facilitate and coordinate communication among virologists, epidemiologists, point-of-care health care professionals, and health care facility staff; and (5) develop best practice guidelines and legislation to coordinate cooperative worldwide action against C19 and other emerging infectious diseases. Lessons from this pandemic point to the importance of digital transformation in health care, as well as the reorganization and streamlining of epidemiological registries that clearly need to be part of adapting health care systems to manage an outbreak or the next, pandemic. Reorganizing a robust health care system should be a priority for global health. A reorganization of health care systems can promote efficient health care by greater availability of therapeutic and otherwise life-saving drugs and personal preventative medicine, telemedicine approaches, and reduce the number of emergency ward visits and hospitalizations overall (Filip et al., 2022).

Beside direct impact of COVID-19 which discussed, the pandemic also overburdened health systems and has made significant disruption in health service delivery. The COVID-19 pandemic has disrupted both preventive and curative services for communicable and noncommunicable diseases, and many of essential services have been delayed by the healthcare facilities, The COVID-19 pandemic posed a significant risk of indirect morbidity and mortality from other preventable and treatable diseases as a result of essential health services disruption. Some or even most of SDG's target on health might not be achieved due to previous pandemic situation.

2 Indonesia

Indonesia is a country in South-East Asia, rich in diversity and inhabited by more than 270 million people, the world's fourth-most populous country. Indonesia also the largest archipelagic country, it spread across 17,504 islands. Indonesia was also hit quite hard by COVID-19. As of 13 September 2023, there have been confirmed 6,813,429 cases of COVID-19 in Indonesia, including 161,918 (2.4%) deaths (COVID-19, Indonesian Ministry of Health, 2023).

Mahendradhata et al. (2021) published an article that discussed the Indonesian Government policies to fight COVID-19. It's mentioned that during COVID-19 there is a need to assess the country's healthcare system's capacity to absorb and accommodate the varying healthcare demands. The authors reviewed the capacity of Indonesia's healthcare system to respond to COVID-19 based on the four essential elements of surge capacity, staff, stuff, structure, and system. During COVID-19 pandemic the availability of medical staffs are insufficient to deal with increasing demands as the pandemic highlighted the human resources challenges the health-care system has been struggling with. The pandemic has exposed the fragility of medical supply chains. Surges in the number of patients requiring hospitalization have led to depleted medical supplies. During pandemic time the existing healthcare infrastructure is still inadequate to deal with the rise of COVID-19 cases, which has also exposed the limited capacity of the healthcare infrastructure to manage medical waste. The COVID-19 pandemic has further exposed the weakness of the patient referral system and the limited capacity of the healthcare system to deliver essential health services under prolonged emergencies. The authors recommend that Indonesian Government needs to ramp up the country's healthcare capacity. A wide range of strategies has been proposed to address those mounting challenges. Notwithstanding, the challenges of increasing healthcare capacity highlight that such efforts could represent only one part of the pandemic response equation. Effective pandemic response ultimately requires government's commitment to increase healthcare capacity and flatten the curve concurrently.

It's predicted that countries with better healthcare systems will transition faster to the new reality post COVID-19. They will also provide a stronger foundation for resilience against and recovery from future pandemics, which are likely to emerge with greater frequency. In the case of Indonesia to prepare for the new reality after COVID-19, it needs to embrace a comprehensive and systematic approach to improve our healthcare system. This will require commitment to five key priorities. Firstly, promote healthy lifestyles and preventive care. Secondly, improve accessibility and quality of medical services. Third, strengthen the biopharma and medical technology industries. Fourth, develop a clear pandemic preparedness framework and fifth to accelerate adoption of digital and advanced healthcare analytics (Ikhsan and Yulius, 2020).

Aisyah et al. (2022) published a paper which provides a detailed narrative view of Indonesia's COVID-19 pandemic responses, as relating to the health security capacities. Although the overall pandemic response was considered proportional to

the magnitude of the public health pressure there were gaps and challenges identified in handling the pandemic. These include epidemiological surveillance (detect capacity), laboratory diagnostic testing (respond capacity) as well as data management and analysis (enable capacity). Further strengthening of these capacities in Indonesia would be needed in order to control any outbreak as well as preventing disease outbreaks, or even pandemic in the future time. The lessons learned would need to inform the future design of the emergency response mechanisms if substantial progress is to be achieved. It's also realized that the COVID-19 pandemic has been a catalyst for the rapid transformation of existing surveillance systems, interrelated stakeholder coordination and agile development from the pre-pandemic health security capacities.

A report by the United Nations Children's Fund (UNICEF), United Nations Development Program (UNDP), the Australia-Indonesia Partnership for Economic Development (PROSPERA) and SMERU Research (UNICEF Indonesia, 2023) published in December 2022 stated that Indonesia's most vulnerable communities, including households with children and persons with disabilities, remain at risk of slipping further into poverty following the COVID-19 pandemic and looming economic uncertainty. The report notes although the poverty rate fell to 9.54% in March 2022 from 10.14% in March 2021, there is still an urgent need to address the welfare of vulnerable groups who suffered the most from the impact of COVID-19 for Indonesia to achieve inclusive recovery. COVID-19 created unprecedented challenges for children and their caregivers across Indonesia. This report underscores how critical it is to enhance the social protection system, address the learning crisis and ensure children with disabilities are not left behind as the country recovers from COVID-19 and copes with the impacts of global crises. Tackling these issues will be key for Indonesia to achieve its long-term vision of becoming one of the world's 10 largest economies by 2030, achieving high-income status and reducing all types of poverty to nearly zero.

3 Conclusion

Based on our experience in the fight against the global pandemic, not only humanitarian support is needed but also there is a need for innovative solutions for the process and offered the outcomes to the service of its citizens and all of humanity. International public opinion should be aware that a new tool is needed that can be utilised to improve the efficiency of international mechanisms that cannot adequately contribute to the global community in many fields, particularly health. The COVID-19 pandemic has shown the negative aspects of globalization, indicating the necessity to alter the levels of interdependence and cooperation between countries. In this regard, there should be a clear effort of strengthen the regional and multilateral cooperation and solidarity for the world better prepare for tackling coming outbreak and future pandemic. In response to global challenges, the significance of international cooperation and solidarity will be fully needed.

On May 2023, the WHO Director-General has determined that COVID-19 is an established and ongoing health issue which no longer constitutes a public health emergency of international concern (PHEIC). In this regard, there are seven temporary recommendations issued by the WHO Director-General to all States Parties. The first is sustain the national capacity gains and prepare for future events to avoid the occurrence of a cycle of panic and neglect. Secondly, integrate COVID-19 vaccination into life course vaccination programmes. The third, bring together information from diverse respiratory pathogen surveillance data sources to allow for a comprehensive situational awareness and the fourth is prepare for medical countermeasures to be authorized within national regulatory frameworks to ensure long-term availability and supply. The fifth recommendation is continuing to work with communities and their leaders to achieve strong, resilient, and inclusive risk communications and community engagement (RCCE) and infodemic management programmes. The sixth recommendation is continuing to lift COVID-19 international travel related health measures, based on risk assessments, and to not require any proof of vaccination against COVID-19 as a prerequisite for international travel. The seventh recommendation stated that continue to support research to improve vaccines that reduce transmission and have broad applicability; to understand the full spectrum, incidence and impact of post COVID-19 condition and the evolution of SARS-COV-2 in immunocompromised populations; and to develop relevant integrated care pathways.

For Indonesia, at least there are five COVID-19 response pillars. The first one is preparedness and response coordination, secondly surveillance, laboratories, and public health intelligence and the third is vaccination, public health and social measures, and engaged communities. The fourth pillar is safe and scalable clinical care and resilient health systems and the fifth is research, development, and equitable access to countermeasures and essential supplies. These include serosurvey, developing the COVID-19 vaccine in Indonesia and other research initiatives. It is really needed to develop and strengthen the post-pandemic surveillance strategy using multisource surveillance, including integrating ILI (Influenza Like Illness) & SARI (severe acute respiratory infection) sentinel surveillance for COVID-19, influenza and other respiratory pathogens, whole genome sequencing (WGS), surveillance and surveillance with a One Health approach, and optimisation of surveillance data and risk assessment to inform public health measure decision making.

Since we are now in transitioning to long-term management of COVID-19, there are at least three things that we should still really consider, globally as well in Indonesia. Firstly, based on available evidence and experience from past pandemics, it is likely that the virus SARS-CoV-2 the virus of COVID-19 will continue to circulate after years to come, even after pandemic is end. It still can cause disease and even a serious health problem in high-risk group. Of course that overall situation is more under control, not like during pandemic time. In addition, we should carefully taking care of the long COVID cases of patients who recovered from the infection but still suffer some complaints. Secondly, there will be still many questions of COVID-19, and we will have clear answers for only some. The advance of science and technology will help us to know better on this disease and how to control it better. The third thing to considered is that continued vigilance is extremely important,

and surveillance, vaccination, and clinical management during the post-pandemic period in still needed, as well as vigilance for possible another health outbreak and/or pandemic in the future.

Finally, we all know that taking care of current and coming pandemic will not only depend on international collaboration. In this regard, health system strengthening in the country, including Indonesia, is really needed and will include a primary care strengthening, adequately training health workers, leveraging technology, supporting regulatory capacity, and good governance. Investment in health systems and services is investment in human capital. Healthy human capital is the foundation for productivity and prosperity. Equitable distribution of health care and equity in the health status of populations is the foundation for social cohesion, which is our best protection against social unrest. The country's focus on revitalizing primary health care as the cornerstone of a stronger and resilient public health system will give positive impact to national and global health security.

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Some Comments on Increasing Modelling Efficiency of Weibull Distribution

Huseyin Unozkan, Nihan Potas, and Mehmet Yilmaz

Abstract Obtaining new statistical distributions involves employing various techniques aimed at enhancing modeling efficiency. In this particular study, a novel distribution is introduced by extracting the conditional diagonal section from the bivariate Farlie-Gumbel-Morgenstern distribution, where the marginals follow the Weibull distribution. The characteristics and specifications of this newly proposed distribution are thoroughly examined. Statistical discussions are held regarding the structure of the distribution, and parameter estimation techniques are applied using established methods. Furthermore, reliability analysis is conducted to assess its performance. To gauge the effectiveness of this innovative distribution for statistical modeling, data sets sourced from existing literature are utilized. Based on the findings, it is deduced that this fresh approach offers an efficient and robust model specifically suited for analyzing lifetime datasets. With this methodology, according to Kolmogorov Smirnov test statistics, the modeling efficiency of the Weibull distribution is increased by more than 20% in some situations.

Keywords Copula · Farlie-Gumbel-Morgenstern distribution · Generating distribution · Reliability analysis · Weibull distribution

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1 Introduction

Weibull distribution is one of the most popular lifetime distributions. This valuable distribution has been used widely in mechanic engineering (University of Cambridge, 2003). Weibull has also been used in modelling strength data (University of Cambridge, 2003) and in modelling data sets of many other fields commonly. In some study areas, some parameters of this distribution engaged in demonstrating an important situation (Basu et al., 2009). In some analyses, only the parameter value represents the quality (University of Cambridge, 2003). Although this distribution is very capable of modelling very different kinds of lifetime datasets, in some datasets the modelling success rate may be lower. Some studies-to fix this situation-researchers add more parameters for better modelling (Marshall, 1997; Mudholkar & Srivastava, 1993). Weibull distribution has some specialties that this distribution has relations to other distributions (Rinne, 2008). In this study, the main aim is to increase the modeling efficiency of Weibull distribution by a different and special technique. By this approach, the Weibull distribution has three parameters and the new distribution may be more flexible in different kinds of datasets. This technique was used in a study for gaining new distribution (Ünözkan & Yilmaz, 2019). In this article, Weibull distribution gains a different capability than ever before.

2 Materials and Methods

In a study for gaining new distribution for flows a conditional Farlie-Gumbel-Morgenstern Distribution was used. In this process the marginal distributions were exponential. In order to realize this, the study used an important theorem.

2.1 Theorem (Sklar's Theorem)

Let F be a joint cumulative distribution function and H and G are marginals, then there is a copula function C in $\mathbb{R}$ for every x and y (Sklar, 1959).

$$F(x, y) = C(H(x), G(y))$$

Farlie-Gumbel-Morgenstern (FGM) copula with marginals u and v can be written as below (Nelsen, 2006).

$$C_\theta(u, v) = uv + \theta uv(1 - u)(1 - v)$$

Hence, two-dimensional bivariate FGM distribution with marginals $H(x)$ and $G(y)$ is as follows;

$$F(x, y) = H(x)G(y)\left[1 + \lambda\overline{H}(x)\overline{G}(y)\right].$$

The probability density function of this distribution is as below.

$$f(x, y) = h(x)g(y)\left[1 + \lambda(1 - 2H(x))(1 - 2G(y))\right]$$

Under $Y = y$ condition, X has a conditional probability density function as follows.

$$f_{X|Y=y}(x) = h(x)\left[1 + \lambda(1 - 2H(x))(1 - 2G(y))\right]$$

Under $Y = y$ condition, X has a conditional distribution as below.

$$F_{X|Y=y}(x) = \int h(x)\left[1 + \lambda(1 - 2H(x))(1 - 2G(y))\right]dx$$

$$F_{X|Y=y}(x) = H(x) - \lambda(1 - 2G(y))H(x)\overline{H}(x)$$

Under $T = t$ condition probability of $X \leq t$ is

$$F_{X|Y=y}(t) = H(t) - \lambda(1 - 2G(t))H(t)\overline{H}(t)$$

Provided (Ünözkan & Yilmaz, 2019).

Considering the models related to natural events, Weibull distribution has a wide range of usability. Because of modelling capability, Weibull distribution has been used widely.

Then we have

$$F(t) = (1 + \lambda)H(t) - \lambda H(t)^2(3 - 2H(t))$$

We know from the literature that the transmuted distribution with baseline $H(t)$ is $(1 + \lambda)H(t) - \lambda H(t)^2$. Here, $H(t)^2$ is the failure distribution of the two-component parallel system (with identical and independent) namely, represented as $H_{2:2}$. In the light of this idea, $F(t)$ can be also rewritten as the form of $(1 + \lambda)H(t) - \lambda H_{3:2}(t)$ where $H_{3:2}$ represents a failure distribution of 3 out of 2 system with independent and identical component. Thus, we have a different form of transmuted distribution. Hence when baseline distribution is assumed to be Weibull we have the following special form of distribution.

Suppose that $H(t) = G(t) = 1 - e^{-\left(\frac{t}{\beta}\right)^{\alpha}}$.

$$F(t) = (1+\lambda)\left(1-e^{-\left(\frac{t}{\beta}\right)^{\alpha}}\right) - \lambda\left(1-e^{-\left(\frac{t}{\beta}\right)^{\alpha}}\right)^{2}\left(3-2\left(1-e^{-\left(\frac{t}{\beta}\right)^{\alpha}}\right)\right) \quad (1)$$

The probability density function of conditional Farlie-Gumbel-Morgenstern with Weibull marginal (CFGM-W) is as below.

$$f(t) = \frac{d}{dt}(1+\lambda)\left(1-e^{-\left(\frac{t}{\beta}\right)^{\alpha}}\right) - \lambda\left(1-e^{-\left(\frac{t}{\beta}\right)^{\alpha}}\right)^{2}\left(3-2\left(1-e^{-\left(\frac{t}{\beta}\right)^{\alpha}}\right)\right)$$

$$f(t) = \left(\frac{\alpha}{\beta}\left(\frac{t}{\beta}\right)^{\alpha-1}e^{-\left(\frac{t}{\beta}\right)^{\alpha}}\right)$$

$$\left(1+\lambda-6\lambda\left(1-e^{-\left(\frac{t}{\beta}\right)^{\alpha}}\right)+6\lambda\left(1-e^{-\left(\frac{t}{\beta}\right)^{\alpha}}\right)^{2}\right), \lambda \in [-1,1], \alpha, \beta > 0 \quad (2)$$

Some shapes of probability density function are as below.

According to Fig. 1, we can easily see that parameter β determines location solely. The other two parameters change the shape of the probability density function effectively in Figs. 2 and 3. Therefore, we believe that CFGM-W can be used in interesting data groups that have bimodal data plots.

The survival function of CFGM-W is as follows;

$$S(t) = 1 - F(t)$$

$$= 1 - \left((1+\lambda)\left(1-e^{-\left(\frac{t}{\beta}\right)^{\alpha}}\right) - \lambda\left(1-e^{-\left(\frac{t}{\beta}\right)^{\alpha}}\right)^{2}\left(3-2\left(1-e^{-\left(\frac{t}{\beta}\right)^{\alpha}}\right)\right)\right)$$

$$= 1 - (1+\lambda)(H(t)) + \lambda(H(t))^{2}(3-2(H(t)))$$

$$S(t) = (1+\lambda)\overline{H}(t) - \lambda\left(3\left(\overline{H}(t)\right)^{2} - 2\left(\overline{H}(t)\right)^{3}\right)$$

The hazard rate function of CFGM-W is as below.

$$r(t) = \frac{f(t)}{S(t)}$$

$$= \frac{\left(\frac{\alpha}{\beta}\left(\frac{t}{\beta}\right)^{\alpha-1}e^{-\left(\frac{t}{\beta}\right)^{\alpha}}\right)\left(1+\lambda-6\lambda\left(1-e^{-\left(\frac{t}{\beta}\right)^{\alpha}}\right)+6\lambda\left(1-e^{-\left(\frac{t}{\beta}\right)^{\alpha}}\right)^{2}\right)}{1-\left((1+\lambda)\left(1-e^{-\left(\frac{t}{\beta}\right)^{\alpha}}\right) - \lambda\left(1-e^{-\left(\frac{t}{\beta}\right)^{\alpha}}\right)^{2}\left(3-2\left(1-e^{-\left(\frac{t}{\beta}\right)^{\alpha}}\right)\right)\right)}$$

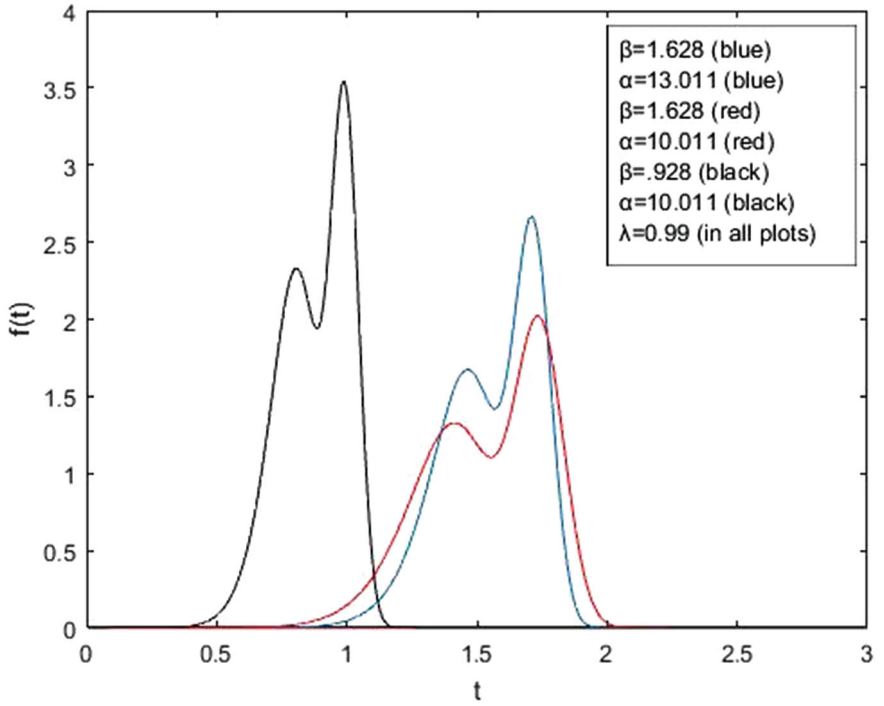

Fig. 1 Plots of the probability density function-1

$$= \frac{\left(\frac{\alpha}{\beta}\left(\frac{t}{\beta}\right)^{\alpha-1} e^{-\left(\frac{t}{\beta}\right)^{\alpha}}\right)\left(1+\lambda-6\lambda\left(1-e^{-\left(\frac{t}{\beta}\right)^{\alpha}}\right)+6\lambda\left(1-e^{-\left(\frac{t}{\beta}\right)^{\alpha}}\right)^{2}\right)}{\left((1+\lambda)e^{-\left(\frac{t}{\beta}\right)^{\alpha}}-3\lambda e^{-\left(\frac{t}{\beta}\right)^{2\alpha}}+2\lambda e^{-\left(\frac{t}{\beta}\right)^{3\alpha}}\right)}$$

Some shapes of hazard rate function are as below.

According to Figs. 4 and 5, we can easily see that parameter β has a big impact on both the probability density function and the hazard rate function. Thus, we believe that CFGM-W can be used in interesting data groups that may pose changeable types of risks.

Figures 4 and 5 show that there is an inverse relationship between the hazard rate function and the value of parameter β. When parameter β increases, the hazard rate function decreases. According to plots, there are initially changing proportions of deaths, and at the beginning, some components rapidly deteriorate. Thereafter a balance is formed and an almost constant hazard rate is observed.

According to Fig. 3 parameter α determines bimodality. When parameter α has a value bigger than 3 the second model has a bigger top. When parameter α has a value lower than 3 the first part of the model has a bigger top.

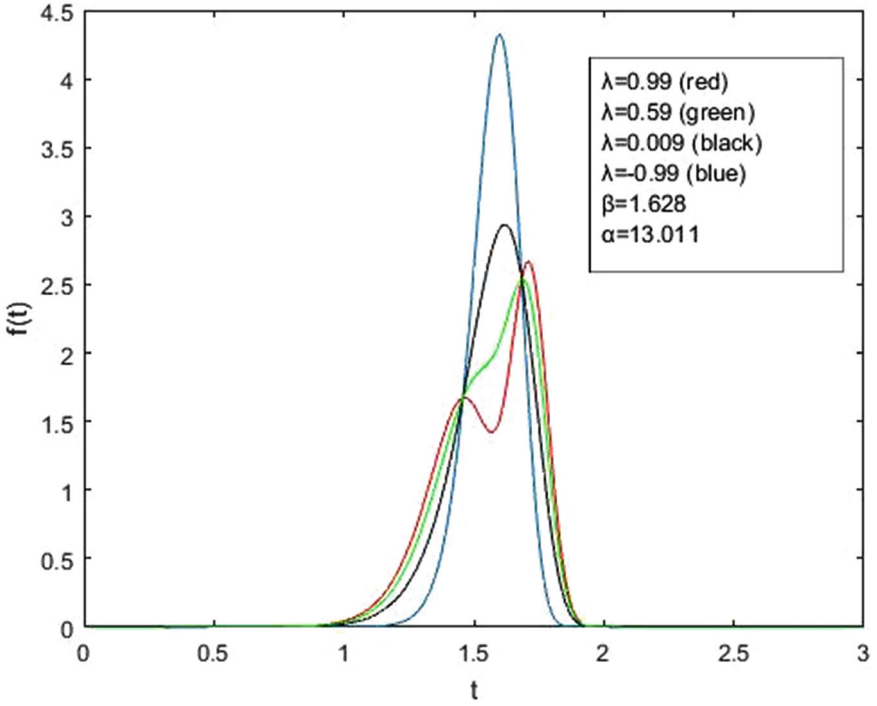

Fig. 2 Plots of the probability density function-2

2.2 Maximum Likelihood Estimation

$$L\left(\beta,\alpha,\lambda;\underset{\sim}{t}\right)=f(t_1,t_2,t_3,\ldots,t_n;\beta,\alpha,\lambda)=\prod_{i=1}^{n}f(t_i;\beta,\alpha,\lambda)$$

$$=\prod_{i=1}^{n}\left(\frac{\alpha}{\beta}\left(\frac{t}{\beta}\right)^{\alpha-1}e^{-\left(\frac{t}{\beta}\right)^{\alpha}}\right)\left(1+\lambda-6\lambda\left(1-e^{-\left(\frac{t}{\beta}\right)^{\alpha}}\right)+6\lambda\left(1-e^{-\left(\frac{t}{\beta}\right)^{\alpha}}\right)^{2}\right)$$

$$=\alpha^{n}\beta^{1-n-\alpha}\prod_{i=1}^{n}(t_i)^{\alpha-1}e^{-\sum_{i=1}^{n}\frac{t_i^{\alpha}}{\beta^{\alpha n}}}\prod_{i=1}^{n}\left(1+\lambda-6\lambda\left(1-e^{-\left(\frac{t_i}{\beta}\right)^{\alpha}}\right)\right)+(6\lambda)^{n}\prod_{i=1}^{n}\left(1-e^{-\left(\frac{t_i}{\beta}\right)^{\alpha}}\right)^{2}$$

By using Log Likelihood, the maximum likelihood estimation of parameters can be obtained with the derivation of β, α and λ.

$$\log\left(L\left(\beta,\alpha,\lambda;\underset{\sim}{t}\right)\right)=n\log\alpha-(n+\alpha-1)\log\beta+(\alpha+1)\sum_{i=1}^{n}\log(t_i)$$

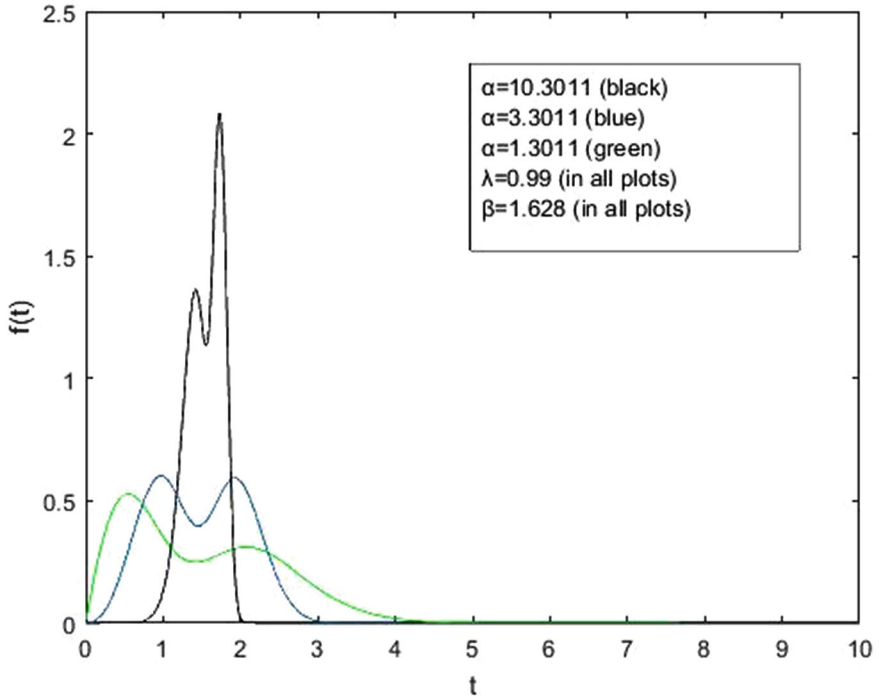

Fig. 3 Plots of the probability density function-3

$$-\sum_{i=1}^{n}\frac{{t_i}^{\alpha}}{\beta^{\alpha n}}+\sum_{i=1}^{n}\log\left(1+\lambda-6\lambda\left(1-e^{-\left(\frac{t_i}{\beta}\right)^{\alpha}}\right)\right)+n\log(6\lambda)$$

$$+2\sum_{i=1}^{n}\log\left(1-e^{-\left(\frac{t_i}{\beta}\right)^{\alpha}}\right)$$

$$\frac{\partial}{\partial\lambda}\log\left(L\left(\beta,\alpha,\lambda;\underset{\sim}{\boldsymbol{t}}\right)\right)=\frac{n}{6\lambda}+\sum_{i=1}^{n}\frac{6e^{-\left(\frac{t_i}{\beta}\right)^{\alpha}}-5}{1+\lambda-6\lambda\left(1-e^{-\left(\frac{t_i}{\beta}\right)^{\alpha}}\right)}=0$$

$$\frac{\partial}{\partial\beta}\log\left(L\left(\beta,\alpha,\lambda;\underset{\sim}{\boldsymbol{t}}\right)\right)=\frac{-(n+\alpha-1)}{\beta}+\frac{\alpha n\sum_{i=1}^{n}{t_i}^{\alpha}}{\beta^{\alpha n+1}}+$$

$$\sum_{i=1}^{n}\frac{6\lambda\alpha t_i e^{-\left(\frac{t_i}{\beta}\right)^{\alpha}}}{1+\lambda-6\lambda\left(1-e^{-\left(\frac{t_i}{\beta}\right)^{\alpha}}\right)}+\sum_{i=1}^{n}\frac{2\alpha t_i e^{-\left(\frac{t_i}{\beta}\right)^{\alpha}}}{\left(1-e^{-\left(\frac{t_i}{\beta}\right)^{\alpha}}\right)}=0$$

$$\frac{\partial}{\partial\alpha}\log\left(L\left(\beta,\alpha,\lambda;\underset{\sim}{\boldsymbol{t}}\right)\right)=0$$

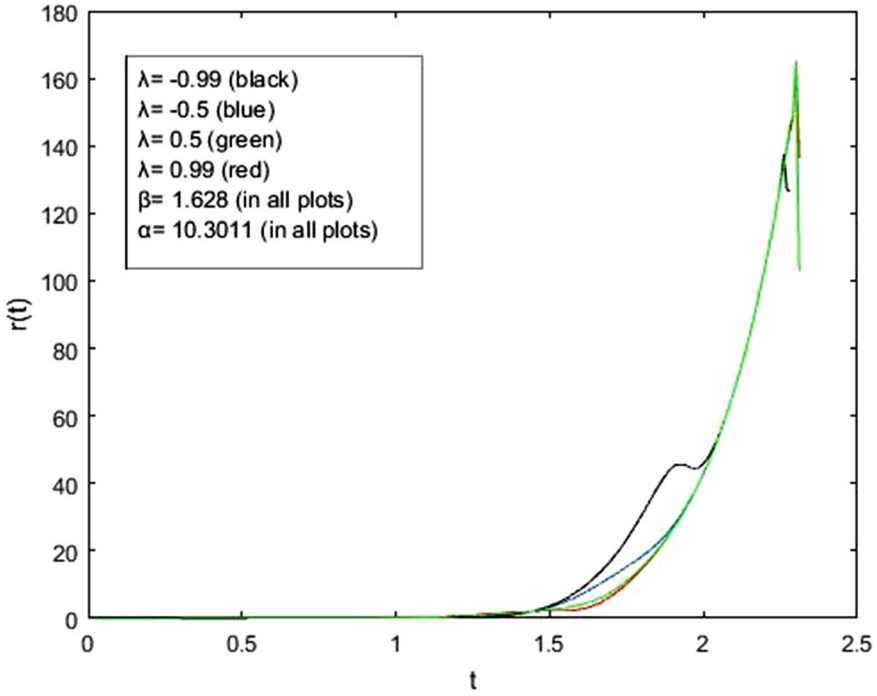

Fig. 4 Plots of hazard rate function-1

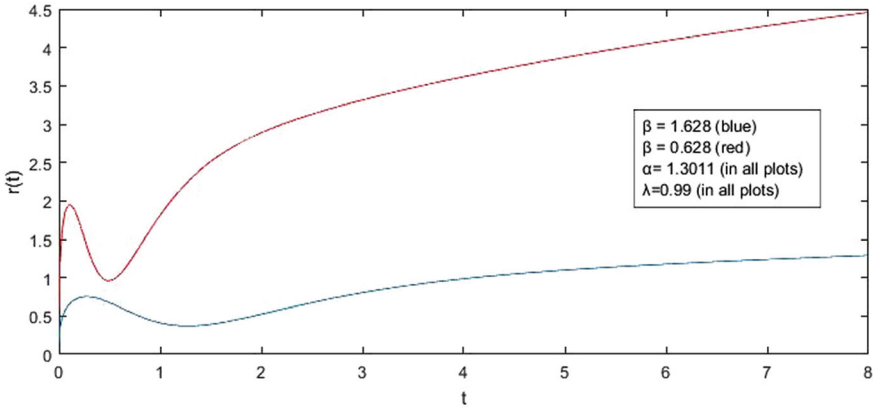

Fig. 5 Plots of hazard rate function-2

2.3 Least Squares Estimation

$$F(t) = (1+\lambda)\left(1 - e^{-\left(\frac{t}{\beta}\right)^{\alpha}}\right) - \lambda\left(1 - e^{-\left(\frac{t}{\beta}\right)^{\alpha}}\right)^2\left(3 - 2\left(1 - e^{-\left(\frac{t}{\beta}\right)^{\alpha}}\right)\right) = u$$

Suppose that $H(t) = 1 - e^{-\left(\frac{t}{\beta}\right)^{\alpha}}$,

$$\lambda H(t)(H(t)-1)(2H(t)-1) + H(t) - u = 0$$

$$SS = \sum_{i=1}^{n} (\lambda H(t_i)(H(t_i)-1)(2H(t_i)-1) + H(t_i) - u)^2$$

$$\frac{d}{d\lambda}\sum_{i=1}^{n} (\lambda H(t_i)(H(t_i)-1)(2H(t_i)-1) + H(t_i) - u)^2 = 0$$

$$\widehat{\lambda_{LSE}} = \frac{\sum_{i=1}^{n}(H(t_i)-u)(H(t_i)(H(t_i)-1)(2H(t_i)-1))}{\sum_{i=1}^{n}(H(t_i)(H(t_i)-1)(2H(t_i)-1))^2}$$

$$\frac{d}{d\beta}\sum_{i=1}^{n} (\lambda H(t_i)(H(t_i)-1)(2H(t_i)-1) + H(t_i) - u)^2 = 0$$

$$\frac{d}{d\alpha}\sum_{i=1}^{n} (\lambda H(t_i)(H(t_i)-1)(2H(t_i)-1) + H(t_i) - u)^2 = 0$$

With the least squares estimation, we can reach a close form of estimation for parameter λ. For the other parameters, α and β numerical methods may be used with software support.

In this study, Matlab 2016b software is used to obtain parameter estimations and Kolmogorov Smirnov test statistics.

3 Results and Discussion

Now, using some different data groups, we first compare CFGM-W with the most common statistical distributions. Subsequently, we offer CFGM-W as a new distribution for lifetime data with different kinds of data groups. While comparing distributions, we will use Kolmogorov–Smirnov test statistics for looking at the availability of our distribution to data sets. In Kolmogorov–Smirnov test statistics p-value indicates the success rate of distribution in the explanation (Næss, 2012; Ross, 2009).

Once we see that the two distributions are equal, we will have a new problem. Which distribution is better for this data set? Because according to the hypothesis test, there may be many distributions that are equal to nonparametric distribution. Akaike Information Criterion (AIC) can be used to compare these distributions. When AIC is used, the distribution with the minimum AIC value is selected as the best distribution (Akaike, 1974). Since the AIC is a penalty value and the minimum value represents the maximum similarity to the non-parametric distribution of the data set, the minimum AIC value is the maximum similarity to the distribution (Snipes & Taylor, 2014; University of Cambridge, 2003).

In this section, CFGM-W will be compared with the most known lifetime distributions using some different data groups. While comparing distributions, Kolmogorov–Smirnov test statistics will be used. When using Kolmogorov–Smirnov statistics, the least statistical value is considered to be the best modeling. The p-value of Kolmogorov–Smirnov statistics informs us about the plausibility of conformity.

Data 1: The first data we used are the flood peak values (in m^3/s) of the Wheaton River near Carcross in Yukon Territory, Canada. The data consist of 72 exceedances for the years 1958–1984, rounded to one decimal place. This data was analyzed in (Choulakian & Stephens, 2001) and after this the same data was used in Merovci and Puka (2014) and Ünözkan and Yilmaz (2019) (see Table 1).

In Table 2 the new distribution offers the best model. Other distributions have been used widely, but CFGM-W fits better than all other known distributions in flow modelling.

Data 2: This data group contains 56 measurements of total flows from Sefaatli Creek in April from 1953 to 2014. The data group was received from the Turkish State Water Affairs Directorate and was first used in a study for flow distribution [6] (see Table 3).

In Table 4 the new distribution offers the best model. Other distributions have been used widely, but CFGM-W fits better than all other known distributions in flow modelling.

Table 1 Wheaton river flood peaks (m^3/s) data

1.7	2.2	14.4	1.1	0.4	20.6	3.4
12	9.3	1.4	18.7	8.5	25.5	11.9
1.1	2.5	14.4	1.7	37.6	0.6	21.5
15	11	7.3	22.9	1.7	0.1	5.3
1.7	7	20.1	0.4	14.1	9.9	2.5
3.6	5.6	30.8	13.3	4.2	25.5	2.8
5.3	0.7	13	27.6	64	27.4	27.1
11.6	14.1	22.1	20.2	9.7	27	2.5
2.2	39	0.3	36.4	1.5	1	2.7
1.1	0.6	9	16.8	27.5	1.9	30
10.4	10.7					

Table 2 Wheaton river flood peaks (m^3/s) data test results

Model	K-S	*p*
GEV	0.1398	0.1087
Log Pearson III	0.09948	0.44568
Generalized Pareto	0.1005	0.43177
Weibull	0.09045	0.5666
Log-Normal	0.1394	0.1103
CFGMWEM	0.0827	0.6774
CFGM-W	**0.0693**	**0.856**

Table 3 Sefaatli Creek's mean flows (m^3/s) in April data

29	44.9	9.5	12.5	10.8	19.8	18.3
29.6	61.7	46.8	41.8	13.6	17.8	15.1
26.9	14.1	36.3	23	18.4	19.5	41.5
27.2	25.2	22	39.6	4.94	16.2	31.4
6.21	2.99	4.12	2.47	19.99	9.844	5.525
9.23	6.89	21.6	12.2	12.9	17.3	27.6
7.72	8.14	29	36.5	31	4.248	3.52
44.4	15.2	44.5	53.4	23.4	5.19	25.8

Table 4 Sefaatli Creek's mean flows (m^3/s) in April test results

Model	K-S	*p*
GEV	0.0545	0.993
Log Pearson III	0.0548	0.9926
Generalized Pareto	0.0495	0.998
Weibull (3P)	0.05	0.9977
Log-Normal (3P)	0.0626	0.9705
CFGMWEM	0.0536	0.9944
CFGM-W	**0.045**	**1**

Data 3: This data set was used by Bhaumik et al. (2009), this data set carries vinyl chloride data obtained from clean-up gradient monitoring wells in mg/l (see Table 5).

In Table 6 it is obvious that the new distribution increases the modelling capability of the Weibull distribution. Although Weibull distribution is used commonly this new distribution offers a better model than classic distribution.

Data 4: The last data set contains Kevlar Epoxy strength results in spaceships (Badrinarayan & Barlow, 1992). This test is implied on fibers under %90 pressure. The data represents failure times (see Table 7).

Table 5 Vinyl chloride data

5.1	1.2	1.3	0.6	0.5	2.4	0.5
0.4	2	0.5	5.3	3.2	2.7	2.9
1.8	0.9	2	4	6.8	1.2	0.4
1.1	8	0.8	0.4	0.6	0.9	0.2
2.5	2.3	1	0.2	0.2	0.1	

Table 6 Vinyl chloride data test results

Model	K-S	*p*
Weibull	0.0963	0.8377
CFGM-W	**0.095**	**0.888**

Table 7 Tensile strength under %90 pressure data

0.54	0.8	1.52	2.05	1.03	1.18	0.8
3.34	1.54	0.08	0.12	0.6	0.72	0.92
1.81	2.17	0.63	0.56	0.03	0.09	0.18
1.52	0.19	1.55	0.02	0.07	0.65	0.4
1.6	1.8	4.69	0.08	7.89	1.58	1.64
1.33	1.29	1.11	0.24	1.51	1.45	1.45
1.05	1.43	3.03	0.03	0.23	0.72	1.51
0.34						

Table 8 Tensile strength under %90 pressure data test results

Model	K-S	*p*
Weibull	0.107	0.5786
Weibull (3P)	0.1072	0.5757
CFGM-W	**0.086**	**0.761**

In Table 8 the new distribution offers the best model. Weibull and Weibull with three parameters are available either but CFGM-W fits better than the other two most known statistical distributions.

Table 9 Values of parameter estimation in models

Data group	β	λ	α
Wheaton river	10.353	1	1.0674
Sefaatli Creek	23.796	0.4351	1.7181
Vinyl chloride	1.9659	−1	0.6537
Kevlar strength	7.4862	0.8518	2.0922

4 Conclusion

In the results and discussion section, anybody determines the capability of this new distribution easily. Compare with other lifetime distributions this new distribution may be more appropriate for some data groups. In the Table below are the parameter values of appropriate models. The structure of CFGM-W changes effectively with differences in all three parameters. In Table 9 there are maximum likelihood estimation values for parameters in modeling data 1 to data 4.

We can easily see that CFGM-W gains conformity in different parameter values. According to test results for Data 1 to Data 4, we suggest that CFGM-W can be used in many kinds of lifetime data groups.

We examine that CFGM-W has the best results in all data groups. According to the Tables in the application part, we conclude that CFGM-W can be identified as a lifetime distribution.

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Studying the Complexity Through Turkish Epics

Hüseyin Çakır and Şefika Şule Erçetin

Abstract The twentieth century witnessed many scientific, technological and economic developments that triggered socio-cultural changes. People, organizations, and systems have begun to interact more than ever before, thus becoming even more interdependent to each other. Now any change anywhere can affect and change everyone else. The Covid-19 case, which we are dealing with globally, is the clearest example of this situation. To put it in the language of complexity, a virus flapping its wings in China has caused a pandemic in the world. Therefore, complexity has become the most fundamental feature of our current society, and understanding complexity has now become a necessity rather than a choice. This study, which is shaped around these thoughts, aims to explain the idea of complexity with its key concepts through Turkish epics. The choice of Turkish epics as intermediary texts is because they are rich in genre, structure and social events in their content. In this context, firstly, the idea of complexity was explained briefly in terms of its philosophical and historical foundations, and a metaphorical framework containing the key concepts of complexity was touched upon. Afterwards, Turkish epics were evaluated within the framework of this metaphorical complexity. The study, in a sense, is an epistemological attempt to explain complexity through Turkish epics.

Keywords Complexity · Complexity theory · Epic · Turkish epics

1 Introduction

Complexity, which is an ordinary concept describing objects with many interconnected components, has begun to express a scientific field with many branches since the second half of the last century (Holland, 2014). Pointing out that this situation

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is a paradigmatic change using Kuhn's terminology, Erçetin (2001: 8) evaluated this change as a synthesis that will meet the necessity of "looking at events multidimensionally, grasping the part in the whole and the whole in the part, and evaluating each event within itself.". Similarly, many scientists consider the idea of complexity as the emergence of a new paradigm against the classical understanding that dominated the natural and social sciences for a long time. In this context, it can be said that complexity is a new way of thinking that is positioned against the Newtonian paradigm, which is based on linear, reductionist, deterministic and objective knowledge (Morin, 2008: 87; Açıkalın, 2021; Cohen, 1999; Anderson, 1999). The central paradigm of this way of thinking is the multi-actor system. Although actors are independent in terms of their environment and future situations, they are interconnected in such a way that their local interactions create a global organization (Heylighen et al., 2006). In this context, we can roughly define a complex system as "a system with multiple actors interacting non-linearly" (Simon, 1962).

Heylighen et al. (2006) described complexity as the most fundamental feature of our current society. According to them, technological and economic developments; as production, transportation and communication become more effective than ever before, it has become inevitable to interact with more people, organizations, and systems than ever before. And as this interaction network grows and expands, social, economic, technological, and ecological systems become more interconnected, and the result is an ever more complex system of systems. In such an environment, a small change in any actor affects other actors or the system as a whole—often in a non-linear way. Emphasizing that we will find such complexities in the world of physics and also in the world of states (Morin, 2008: 84), he says that we are in the "planetary age, where what happens at any point in the world can have echoes at every other point." It can be said that Covid-19, which we are fighting globally today, is actually a suitable example of these findings. To put it in the terminology of complexity, a virus fluttering its wings in China's Hubei province has caused a hurricane in almost every part of the world.

It is clear that complexity is increasingly recognized as a fundamental feature of the world we live in and the systems that live with it (Simon, 1996: 181). Although it emerged as a paradigmatic change especially in the second half of the twentieth century, the formation of a very wide research literature in a short time (Mills, 2010: 207) and the fact that this idea has been/is being studied in a wide range from natural sciences to social sciences are manifestations of this acceptance. Drawing attention to the excitement of scientists as well as the public about this field, Bar-Yam (2002) interprets this situation as the potential impact of complexity on our ability to change our perspectives on the world and understand major social problems. As a result, knowing the basic philosophy and some key concepts of complexity has become a necessity rather than a choice for those living in an increasingly complex world.

The study was essentially shaped around these ideas and the idea of complexity was tried to be explained through Turkish epics. The selection of Turkish epics as intermediary texts is for a number of reasons. The first of these reasons is that the emergence of an epic reflects a complex process in itself. An epic that went through the stages of birth, dissemination and being written down has been reconsidered in

every generation since its birth and emerged as a result of the common interaction of generations (Sepetçioğlu, 1998: 9). The second reason is that epics bear traces of nations' efforts to become nations. Because a nation's journey to "becoming a nation" represents a complex process in itself. In this process, national identity and character are built by overcoming many difficulties. Thirdly, examining an epic also means examining the culture, history and stance of the nation that created that epic against complex problems. Therefore, almost all of these features actually emphasize complex phenomena.

In this context, first; the idea of complexity is briefly explained in terms of its philosophical and historical foundations, the general characteristics of systems that are subject to complexity are listed, and the "Metaphorical Complexity Framework" containing the key concepts of complexity is presented. Then, the concept of epic is discussed and general information about Turkish epics is provided. Finally, Turkish epics were evaluated within the metaphorical complexity framework and the key concepts related to complexity were tried to be explained in line with these evaluations. The main aim is to concretize the idea of complexity and provide an understanding of key concepts related to complexity. In addition, it is also aimed to reveal the relationship between complexity and the social world in line with the social facts and events in epics.

2 Complexity and Metaphorical Framework

The word complex is defined in the dictionary as "consisting of many things that are more or less contradictory to each other, containing many elements of the same kind.". Additionally, Complexity refers to the quality or state of being complex. Alhadeff-Jones (2008) states that the concept is adapted from the Latin expression "complexus" and is derived from the words "cum" and "pletere", meaning surrounding, perceiving, containing. According to him, complexity often characterizes personality, society, emotions, or thoughts that the mind has difficulty understanding and cannot easily analyze. Therefore, saying "complex" or "very complex" indicates a difficulty of explanation rather than an explanation. According to Morin (2008: 84), there is complexity wherever actions, interactions and feedback are combined. Bar-Yam (2002) defines complexity as "a new field of science that examines how the parts of a system and their relationships lead to the holistic behavior of the system and how the system establishes a relationship with its environment." In this respect, complexity as a discipline can be said to produce information about the non-linear dynamics of systems in various fields, from sandbanks and stock markets to weather systems, the immune system, and social networks (Açıkalın, 2021; Cohen, 1999).

Complexity has been described as a "new science" by many scientists studying in this field (Waldrop, 1997; Prigogine, 2004; Wheatley, 2006; Mills, 2010; Jörg, 2011; Erçetin et al., 2015). This qualification emphasizes the difference of complexity from the epistemology of the Newtonian Paradigm, or also known as Classical Science, which dominated the natural and social sciences for approximately three centuries.

Classical science has a linear, deterministic and reductionist understanding. Linear thinking is the proportionality of action and reaction, cause and result, input, and output. Deterministic thinking, on the other hand, foresees that when the initial conditions of a situation are known, its situation at any other time (regardless of past or future) can be known with complete accuracy. In reductionist thought, the belief that the whole can be examined by dividing it into its parts and that knowledge of the whole can be obtained from the parts is dominant (Pagels, 1989: 74, Ruelle, 1995: 26). In short, classical science, in Erçetin's (2001: 24) words, envisioned a mechanical universe that worked just like a wound clock. Complexity, on the other hand, opposes the classical understanding of science with its basic features of emergence and non-linearity (Preiser, 2012: 41). According to Byrne and Callaghan (2013: 19), this opposition does not mean that law-oriented classical science is wrong, but that its accuracy is limited. According to them, classical science works very well for some situations, but it cannot be considered as a universal approach to the whole of reality in which we live and experience. Nobel Prize-winning biochemist Ilya Prigogine, known for his studies on complexity and non-equilibrium thermodynamics, also emphasized the same point and expressed his opinion with the following words (Prigogine & Stengers, 1998: 29);

> Today Newtonian science still occupies a unique position. Some of the basic concepts it introduced represent a definitive acquisition that has survived all the mutations science has since undergone. However, today we know that the Golden Age of Classical Science is gone, and with it also the convention that Newtonian rationality, even with its various conflicting interpretations forms a suitable basis for our dialogue with nature... A more consistent conception of science and of nature seems to be emerging. This new conception paves the wayfor a new unity of knowledge and culture.

These are the philosophical foundations of characterizing complexity as a new field of science regarding reality. The historical development of complexity dates back to the early twentieth century (Açıkalın, 2021). Simon (1996: 169) mentioned three waves of interest in complexity and complex systems in this century. According to him, each of these waves of interest, which exhibited a repetitive feature, dealt with different aspects of complexity. The first wave is the emergence of the concept of "holism" after World War I. This wave is positioned against reductionism in the classical understanding, with the claim that the whole is more than the sum of its parts. "Information, feedback, cybernetics and general system theory", which was put forward after World War II, is the second wave. These focus on the role of feedback and homeostasis (self-balancing) in maintaining complex systems. The third wave, which includes the current situation, is the association of complexity with "chaos, adaptive systems, genetic algorithms and cellular automata". This wave focuses on the mechanisms that create and maintain complexity and simulative models that aim to describe and analyze these mechanisms. Preiser (2012: 43) traces the historical roots of complexity to the 1940s; he described the studies in the field of general systems theory, cybernetics, and artificial intelligence as founding studies on complexity. All of the studies that contributed to the historical development of complexity sciences can be seen in relation to each other in the comprehensive map prepared by Castellani and Gerits (2021) (Fig. 1).

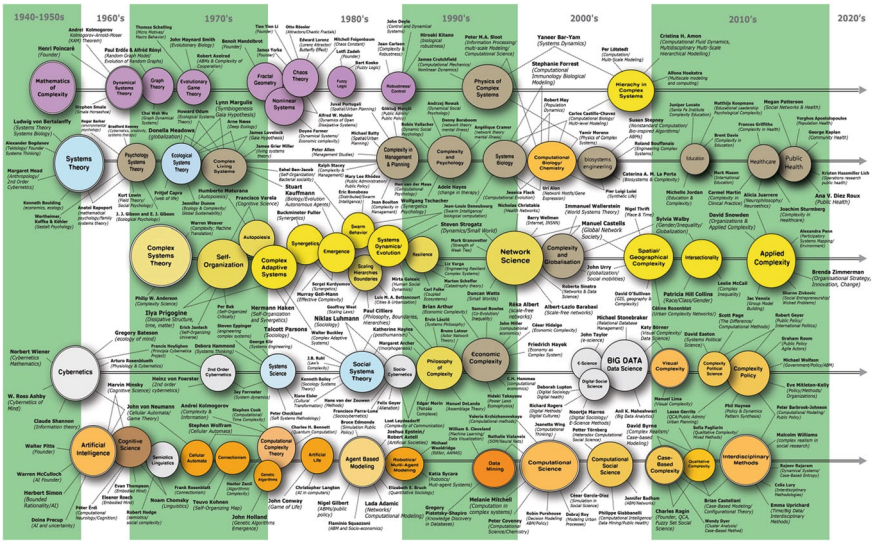

Fig. 1 Current complexity sciences map (Castellani & Gerits, 2021) (*Source* https://sacswebsite.blogspot.com/2021/09/q-for-2021-version-of-map-of-complexity.html)

When the comprehensive map (Fig. 1) that is the source of the idea of complexity is examined, it is seen that the emergence of complexity as a scientific idea is a complex process in itself. Based on this, it can be said that complexity is an interdisciplinary field of study that emerges from intense interactions between different disciplines (Maguire et al., 2011) and an umbrella term that includes nonlinear, complex, and chaotic system research (Açıkalın, 2021). This feature can perhaps be considered an important factor in the lack of a widely accepted definition of complexity (Marion & Bacon, 1999). Because making a singular definition may give rise to the idea that there is a unified theory or complexity science. This, in a sense, means ignoring the range of different understandings of complexity (Preiser, 2012: 61).

According to Holland (2014), the lack of a widely accepted common definition of complexity has not prevented a rigorous approach to complexity, and a number of features have emerged that scientists working on complexity sciences agree on Marion and Bacon (1999). These features of complex systems have a much more functional mission than a common definition in terms of understanding the nature of complexity. We can express the basic features of complex systems, which are expressed in common in different sources, as follows (Beinhocker, 1997; Marion & Bacon, 1999; Anderson, 1999; Erçetin, 2001: 4, Merali & Allen, 2011; Holland, 2014; Tomé & Açıkalın, 2019);

- Complex systems consist of many actors/components/parts/agents/elements. However, the presence of many actors is not sufficient for a complex system. At the same time, these actors must be dynamically interacting with each other

and their environment. The dynamism of the system means that it has a structure that can change over time.

- The actors that constitute complex systems are independent in their local locations but dependent on each other throughout the system. The independence of actors in their local positions means their ability to produce autonomous reactions to situations. However, at some point, a reaction produced autonomously has the potential to affect other actors or the whole system at different levels. This situation is a natural consequence of the actors' dependence on each other. In this context, it should be known that individual behavior is not meaningless in complex systems.
- In complex systems, interactions have a non-linear structure. Non-linearity is that small changes in the system can have large effects. Due to this feature, which is expressed as sensitive dependence on initial conditions, complex systems exhibit unpredictable behavior in terms of their results. That is, uncertainty is an inherent feature of complex systems.
- Complex systems operate under conditions far from equilibrium, called the "edge of chaos." This area describes a vibrant state in which the system is most open to stimuli and can exhibit a high level of creativity in response to changing conditions. Equilibrium is another name for death for complex systems.
- Complex systems have positive and negative feedback loops. While positive feedback loops play a developing and encouraging role, negative feedback loops play a reducing and inhibiting role, preventing deviation.
- In complex systems, interactions give rise to non-additive behavior. Emergence (Açıkalın, 2021; Akdeniz, 2019) means that in complex systems, the whole is more than the sum of its parts. This also means that the behavior of the whole cannot be explained by reducing it to the behavior of the individual parts. Therefore, in complex systems, the end of the process cannot be predicted from the beginning.
- Complex systems exhibit self-organizing properties. Maintaining a state of self-organization under changing conditions requires importing energy into the system. Especially in social complex systems, information functions as a kind of energy. When the system, which is on the border between chaos and order, is dragged into disorder, it consumes this energy/information and reaches a new state of order, which represents a more advanced level. This process occurs when the system self-organizes by increasing complexity as a result of local interactions.
- There is coevolution in complex systems. In the process of coevolution, any change at one point quickly affects and changes the others. In this process, causes drag the results, and results drag the causes into a cyclical, non-linear change. Thus, the system evolves together and reaches a much more complex state at the higher level.
- When these listed features are carefully examined, it can be easily concluded that the natural and social systems we live in and are a part of are compatible with the features of complexity in many ways. As a matter of fact, Holland (2014) states that many systems that are important for humans exhibit complex features. According to that; Just as markets with a variety of buyers and sellers participating in investment funds in an organized manner are a complex system, the internet with its users, sites, servers and web network is also a complex system. Haken

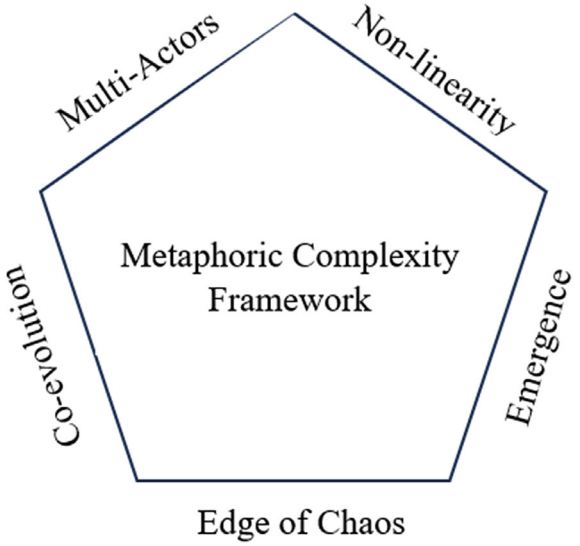

Fig. 2 Metaphoric complexity framework

(2006: 2) also states that various branches of science offer numerous examples of complex systems. Gas molecules constantly colliding with each other in physics, new molecules formed by the reaction of many molecules in chemistry, cells consisting of membrane, nucleus and cytoplasm, each containing many different components in biology, and the economy consisting of many components such as production, storage and logistics are different examples of complex systems in this context. In fact, according to him, modern science itself is a complex system, as can be understood from its interrelated sub-branches.

Based on the information given so far about complexity, the "Metaphorical Complexity Framework", which will serve as a basis for examining Turkish epics in the context of their genre, structure, and social events/organizations in their content, has been created as seen in Fig. 2. Key concepts that will provide a source for understanding complex thought and will be used metaphorically in examining epics; The concepts are multi-actors, non-linearity, emergence, edge of chaos and coevolution.

3 Epic and Turkish Epics

Epic originates from Persian "dâstân" (Yetiş, 1994) and is defined in the dictionary as "A poem about extraordinary events related to prehistoric gods, goddesses, demigods and heroes" (https://sozluk.gov.tr/). In this definition, epic is discussed mostly in terms of its relationship with "myth" and only its verse structure is emphasized. Stating that epics emerged after myths and therefore sometimes carry the shadows of myths, Kayabaşı (2016) defined epics as "stories with the main theme of heroism

that are transmitted in the context of face-to-face communication in the oral tradition environment". The common conclusion to be drawn from these two definitions, the first of which is a narrow definition and the second is a broad definition; epics have extraordinary events or features, and in addition to this extraordinariness, they develop by being passed down from generation to generation in connection with real people and societies.

Epics have a historical character in that they establish a connection between a nation's past, present, and future. In this respect, they are a tool that conveys information about the past to the present, and a lamp that uses the existence of the past to illuminate the future (Metin et al., 2018). However, epics also have a literary character in that they are based on the principle of narrative and present an aesthetic presentation by blending real events with imagination (Sepetçioğlu, 1998: 8). Basically, due to these two characters, it can be said that they are literary works that convey the feelings, thoughts, opinions and beliefs of societies and nations from ancient times to the present day (Küçük, 2013). Therefore, epic is not just history or just literature. In the words of Kayabaşı (2016), it can be said that "it is a folk literature production that is rooted in history and takes its inspiration from history". In this regard, Sepetçioğlu (1998: 7) describes epics as "treasures of wealth that animate the entire existence of a nation, its pains, sorrows, joys and enthusiasms, in short, all its excitements, and constitute its entire structure of emotions and thoughts."

Considering the formation process of epics, it is stated that they go through three stages: birth, dissemination and writing down. During the birth process, some historical and social events that left deep traces in society and some heroes who played a role in these events are glorified and brought to the fore. The dissemination phase essentially refers to the process in which the epic is reproduced while being transferred from region to region and from generation to generation. At this stage, the epic develops by adding new events and heroes. In the third and final stage, a literary person who is familiar with the oral tradition emerges and puts the epic into writing (Yetiş, 1994). Explaining the formation of epics with the avalanche metaphor, Sepetçioğlu (1998: 9) stated that just as a small piece of snow breaking off from a mountain peak turns into an avalanche by taking new pieces from the places it passes as it rolls down, epics also follow such a path in their formation process. According to him, this means that the epic is enriched with new and beautiful additions in the process.

Epics are divided into two main parts in terms of their structure: natural epics and artificial epics. The main difference between these is that the narrator of the epic is not clear at the beginning (Yetiş, 1994). Artificial epics were written by an author in accordance with ancient examples. Natural epics, on the other hand, have no known teller and emerged as a result of the stages of birth, dissemination and writing down. In terms of content, there are also some epics that take their subjects from various events that have left deep traces in the life of a nation and express national feelings in this context, and these are called national epics (Metin et al., 2018; Yetiş, 1994). Saying that nations that do not have national epics are barren in terms of historical richness, Sepetçioğlu (1998: 1) stated that such nations had to make up epics as if they were creating a new history for themselves in order to take their place in the history of civilization.

Having the qualification of a national epic in terms of content also means expecting different functions from epics in addition to their historical and literary functions. In other words, in the process of evolving from individual to society, from society to nation, epics, "seen with the eyes of the public, heard with the spirit of the people and turned into fairy tales in the imagination of the people", also undertake a sociological function as a manifestation of the common consciousness of the people (Kayabaşı, 2016). In this respect, it can be said that the most important function of epics, which reflect the common cultural, social, and traditional perspective of a nation, is to update and convey the values of the nation. In this respect, epics connect the past and the future and teach new generations the character, values and behaviors that will suit their culture and national identity (Kara Düzgün, 2018; Kayabaşı, 2016). In this context, many nations have national epics that connect their past and future and play an instructive role about the past to future generations. In comparative studies on epics from different nations, common and similar aspects have been encountered. The inevitable exchange between cultures and the fact that similar events give rise to similar feelings and thoughts can be considered among the reasons for common aspects (Sepetçioğlu, 1998: 93).

4 Turkish Epics

The Turkish world, which has spread over a wide area in the world both in terms of historical period and geographical area, has an important place among other nations in terms of the richness of epics (Kayabaşı, 2016). The influence of the large number of epics on the survival of historical information, cultural motifs and some value judgments of the Turkish nation to this day cannot be denied (Küçük, 2013). In this context, Bastem (2019) states that Turkish epics have a feature that embodies the Turks' understanding of cosmogony, beliefs, history, literary knowledge and even laws. This determination of Bars (2013), who states that it is possible to see the worldview, history, statism, and management system of the Turks in the Epic of Oghuz Khagan, can be considered as an example. In light of all this, it is possible to say that Turkish epics contain many principles regarding national unity and solidarity (Kara Düzgün, 2018).

Turkish epics, unlike the emergence process of natural epics, went through a long period of dissemination and development after the birth phase. In other words, it was written down relatively late. Stating that this situation resulted in the favor of Turkish epics, Sepetçioğlu (1998: 98) stated that the Turkish nation, who lived a rich and active life during this period, had the opportunity to deal with the extraordinary events without interruption. Thus, Turkish epics reached the writing stage with richer, more colorful and more dynamic elements compared to the epics of other nations. According to Sepetçioğlu (1998: 99), the ability to preserve epics as they were during the process of being written down is another superior feature of Turkish epics. According to him, this situation means "the national consciousness, the national structure, the feelings and thoughts of the society remaining in all their purity."

Turkish epics that emerged throughout the historical process are classified according to certain criteria. In this context, they are classified as national epics, religious epics and folk epics according to the topics they cover. In addition, they are also classified according to geographical, historical, and tribal groups (Yetiş, 1994). However, the most accepted classification for Turkish epics is the classification as "Turkish epics before Islam and Turkish epics after Islam", based on the Turks' acceptance of Islam. Because the Turks' entry into a great civilization field such as Islam indicates the enrichment of steppe Turkish culture with Islamic civilization values and the beginning of a remarkable period of military, political and cultural breakthrough in Turkish history (Kafesoğlu, 1980: 3). As a matter of fact, the events that took place in the following periods showed that this acceptance was an important turning point not only in Turkish history but also in world history.

When Fig. 3, which contains a comprehensive classification of Turkish epics, is examined, it is seen that epics show great diversity both before and after Islam. Sepetçioğlu (1998: 99) evaluated this diversity as data that reveals the richness of epics. In addition, according to him, another richness of Turkish epics is that the epics exhibit essentially the same character in both periods, and that even a few main elements of the pre-Islamic epics form the basis of the after-Islamic epics. Turkish epics, says Sepetçioğlu (1998: 100), seem to have been prepared to become a whole despite the differences in periods. And he bases this proposition with the following statements;

> It is as if a nation that has established perfect states in every period of history has prepared its epics as an empire of integrity that complements each other in the chain of states it has established. The world was created; will it remain empty? … Therefore, humans must also be created and derived. What will the increasing number of people do if they cannot fit in one place? Migration begins. Can every migration be successful? One can either settle or disappear where one arrives. When a vanished nation needs to exist and be resurrected, the Gray Wolf Epic begins to emerge. The Epic of Oghuz Khagan is the development and spread of this resurrected nation. But every expanding nation comes across an enemy, retreats into its shell and gathers strength. This Epic and Ergenekon are this gathering of power.

The qualities of Turkish epics expressed so far are also the main reasons why they are chosen as intermediary texts in explaining complexity. The work called "Comparative Turkish Epics" prepared by Sepetçioğlu (1998) was used as the main source for the epics. Şimşek (2007) analyzed this work on its usability in history education and concluded that the work can be a valuable teaching guide and source of information. The work titled "Old Turkish Epics and Orhun Monuments" prepared by Oy (1988) was used as an auxiliary source regarding the content of the epics. While a general approach was taken in the evaluations regarding genre and structure, four Pre-Islamic Turkish Epics were selected in order to limit the social events related to the content. These epics are respectively; Shu Epic, Oghuz Khagan Epic, Ergenekon Epic and Migration Epic. General information about epics can be expressed as follows (Oy, 1988; Sepetçioğlu, 1998).

The Epic of Shu: It is one of the epics of the Sakas. Ruler Shu, who gave his name to the epic as a hero, dates back to B.C. It is thought that he lived in the fourth century. The epic describes the expeditions of Alexander of Macedon to the eastern

Turkish Epics

Turkish Epics Before Islam	Turkish Epics After Islam
1. **Epic of Creation**	1. **Kazakh- Kyrgyz: Epic of Manas**
2. **Saka Epics** a. The Epic of Alp Er Tunga (B.C. 7th Century b. Epic of Shu (B.C. 4th Century)	2. **Turk- Mongol: The Epic of Genghis Khan**
3. **Hun-Oguz Epics** a. The Epic of Oguz Khagan (B.C. 4th Century) b. The Epic of Atilla	3. **Tatar-Crimea: Timur and Edige Epics**
4. **Göktürk Epics** a. Epic of the Grey Wolf (B.C. 2nd Century) b. Ergenekon Epic (7-8th Century)	4. **Karakhanid Period: Epic of Saltuk Buğra Khan**
5. **Siyempi Epics**	5. **Seljuk- Principalities and Ottoman Periods** a. Epic of Seyid Battal Gazi b. Epic of Danishmend Gazi c. Köroğlu Epic
6. **Uyghur Epics** **a.** Epic of Genesis (8-9th Century) b. The Epic of the Acceptance of the Manichaean Religion c. Migration Epic (8-9th Century)	

Fig. 3 Turkish epics (*Source* https://www.turkedebiyati.org/turk_destanlari.html)

countries and the actions of Ruler Shu to protect his nation from invasion and plunder. The formation of Turkish tribes and the Turks' beginning to live a city life are also indirect narratives in the epic.

Oghuz Khagan Epic: This epic, one of the most important of the National Turkish Epics, is the Hun-Oghuz epic. Oguz Khagan, the epic hero, dates back to B.C. He is a real historical figure as Mete Khan, who managed to establish a great Turkish Empire in the second century. In the epic; the birth of Oghuz, the process leading to his becoming a khagan, his campaigns to expand and expand his country, and the events that took place during these campaigns are discussed. Oğuz had two extraordinary marriages and three children were born from each marriage. These children, named Day, Moon, Star and Sky, Mountain, Sea, are the source of the emergence of 24 Oghuz tribes as Bozoklar and Üçoklar.

Ergenekon Epic: It is a Göktürk epic. The struggles between Göktürk Khan Il-Khan and Tatar Khan Sevinç Khan are featured. As a result of these struggles, the Gokturks were massacred. Il-Han's youngest son Kayan and his nephew Tukuz, who was the same age as him, escaped from captivity with their wives and settled in a place they called Ergenekon. Göktürks lived and multiplied here for 400 years. Then they leave here and come to the place where their ancestors lived and regain their homeland. The epic deals with these processes.

Migration Epic: In this epic, which is a Uyghur epic, attention is drawn to the struggles of the Uyghurs with the Chinese. To put an end to these struggles, the kagan of the time decides to marry his son to a Chinese princess. There is a rock that Uyghurs call Kutlu Mountain. The Chinese wanted to buy this rock in exchange for the princess and they did. The epic then tells about the disasters that befell the Uyghurs and their forced migration as a nation.

5 Turkish Epics from the Framework of Metaphoric Complexity

This section includes the evaluation of Turkish epics based on the metaphorical complexity framework in line with their genre, structure, and content characteristics. In this context, first of all, it can be said that Turkish epics, a literary genre, are an ontologically complex phenomenon. It was stated in previous sections that complexity refers to objects and situations that contain many elements of the same type. Turkish epics are composed of many similar epics that emerged in different Turkish communities and in different time periods. Each of the individual epics that make up Turkish epics as a literary genre corresponds to an actor in the language of complexity. In this context, it can be said that Turkish epics have a multi-actor structure. However, the multi-actor structure is not sufficient for pure complexity. Actors must also have a feature that is independent in their positions but interdependent on a large scale.

Since the emergence or existence of an epic does not necessitate the emergence or existence of other epics, it can be said that each of the epics as actors is independent in their local positions. However, each of the epics has a dependent feature on each other in the emergence of Turkish epics as a literary genre. Therefore, the existence of a whole in the form of Turkish epics has naturally made the parts that make up that whole interconnected.

The existence of Turkish epics as a genre can also be evaluated as an emergence through the language of complexity. As seen in Fig. 3, the coming together of many different epics, each with an independent character in its own position, has revealed Turkish epics as a literary genre. These epics reveal the entire feeling and thought structure of the Turkish nation, from their understanding of cosmogony to their pain, sorrow, joy and enthusiasm. And these features are in fact a product of emergence. Therefore, generalizations about the Turkish nation from ancient times to today can only be obtained with a holistic view of Turkish epics. In other words, it is not possible to understand the knowledge revealed by Turkish epics that emerged as a whole by reducing them to any epic that is a part of that whole or starting from a single epic. In this sense, it can be said that it is an example of the emergence of Turkish epics as a literary genre.

Many different studies have been conducted on Turkish epics. The data obtained in these studies are actually closely related to the "emergence" feature of Turkish epics. For example, in a study on the linguistic structure of the Turkish nation, richness of data can only be obtained by examining Turkish epics in a holistic manner. Although some data can be obtained when each epic is examined separately as the parts that make up the whole, seeing how they follow a course in the historical process necessitates a holistic view of the epics. The phenomenon that cannot be obtained by examining the parts separately and that requires a holistic view is the emergence that expresses more than the sum of the parts in the language of complexity.

When Turkish epics are examined in terms of their structural features, it is seen that each epic has a multi-actor structure. And while each of these actors has independence, that is, unlimited choice opportunities in their own local positions, as a natural result of the social structure, they exhibit a dependent feature on each other in terms of the whole social structure. The plots in epics are essentially manifestations of interactions between multiple actors who are independent and interdependent in their local situations. For example, Shu Epic has a multi-actor structure, including the ruler Shu, Alexander the Great of Macedon, Shu's Vizier, Shu's soldiers, Turkmens and Kalaç, each as an actor in their own right. Similarly, the Epic of Oghuz Khagan displays an example of a structure with multiple actors, each of whom is an actor in his own right, including Oghuz Khagan and the monster in the forest. Perhaps the shortest text among the Turkish epics is the Epic of Genesis, but even in this epic there are many actors, including the Great Hun Khan, Hakan's two daughters, other people from whom the Khan tried to keep his daughters away, and Bozkurt who came to marry the Khan's daughters.

In epics with a multi-actor structure, each actor has the potential to influence and change other actors or the whole system with their individual actions. An actor's influence or change on others often occurs in a non-linear manner. Oguz Khagan's desire to enlarge his state and expand its territory can be considered as an example of this situation. For this reason, Oguz Khagan gathered his people under a flag, armed them, and sent orders and declarations to all four corners. He said that he would be friends with those who obeyed the order and that he would march against those who did not obey the order with his army. This decision taken by Oghuz Khagan had non-linear consequences for all other actors, including his own state. While the khaganates that did not comply with the order perished along with their people, those who followed the order had to pay some taxes to gain the friendship of Oghuz Khagan. As a result, this decision, which Oghuz Khagan took independently in his own local position, affected all actors in the system in a non-linear way due to the interdependent characteristics of the actors forming the social structure.

When epics are considered in the context of the social facts they contain, it is possible to say that the dominant paradigm for social life in epics is the "edge of chaos". In this context, epics include social situations that lie between order and chaos, drifting into disorder from time to time, but giving rise to a more developed order as a result of some adaptive processes. The situation of being on the edge of chaos, also expressed as a limited area of instability (Kelly & Allison, 1999; 4), can also be understood from some of the precautions of the heroes in the epics. In the Shu Epic, Ruler Shu's placement of his most distinguished commanders as watchmen on the banks of the Hucend River can be given as an example of this. In addition, the inclusion of sayings such as "water sleeps but the enemy does not" are actually strong conceptualizations of living a life on the edge of chaos. In addition, the fact that the groups that are crowded in the regions they are in (such as the Uyghurs and the Chinese in the Migration Epic) are in constant conflict with each other is also a sign of the situation on the edge of chaos.

A life on the edge of chaos requires the system to be dynamic at all times. This dynamism comes to light in two ways in epics. The first is that unpredictability and

uncertainty are seen as natural by epic heroes. The thought of Kayan and Tukuz, who escaped from the Tatars in the Ergenekon Epic, is a good example of this situation. Kayan and Tukuz, who escaped from the enemy when the Göktürks were almost extinct as a result of the raid they were raided, try to reach places in the inner parts of the mountains where there are no human roads. Because everyone everywhere is an enemy to them. Meanwhile, they occasionally wander into the past, but the situation they are in brings them back to themselves. In the end, they come to the conclusion that there is no point in thinking about what happened or getting upset by thinking about it. Let's see what the future will bring for them. By saying so, they support each other and vow to drown despair in their hearts and keep hope alive. Their greatest strength is that they join hands and unite and use collective effort.

In addition to collective effort, the second condition for dynamism is to be as prepared as possible against uncertain future situations, rather than controlling the unpredictable future. In the Shu Epic, Ruler Shu always keeps his soldiers alive and fit for this reason. For this reason, in the Ergenekon Epic, the Göktürks act in a state of readiness for war for peace. In the Epic of Oghuz Khagan, it is also in line with this purpose that Oghuz Khagan equips his army with equipment such as iron spears and copper arrows. Therefore, being on the edge of chaos in epics emphasizes the fact that unpredictability and uncertainty are inherent in the nature of life. What is done in this direction consists of being at peace with this reality and being as prepared as possible against the uncertainty of the future.

Another aspect of social events in epics is that they have a non-linear feature, in the language of complexity. Non-linearity can be expressed as any change in any situation causing disproportionate results. Most of the social events narrated in epics actually lead to results like this. In the Epic of Migration, the Uyghur Khan's marriage of his son Galı Tigin to a Chinese princess in order to put an end to the wars with the Chinese is a good example of non-linearity. As a matter of fact, Hakan did not care about what was said and did what he knew, even though the old men with gray beards considered this as bad luck. The Chinese princess is beautiful, but ultimately, she was raised to serve the happiness of her people. Uyghurs have a sacred rock, and it is believed that the happiness of the people depends on this rock. Since the Chinese know this, they want the sacred rock to be given to them in return for the princess. The Chinese princess insists on this to her husband. Gali Tigin could not resist his wife's insistence and gave the sacred rock to the Chinese. The Chinese break the rock into pieces and take it away. Whatever happens happens after that. Rivers dry up, trees turn dark, grass turns yellow, not a single drop of rain falls and the soil cracks from thirst. Seven days later, Gali Tigin dies. One night, birds, insects and inanimate objects speak out and scream "Migration, Migration, Migration". Uyghurs consider this a divine command and begin to migrate. As a result, Hakan marrying his son to a Chinese princess had non-linear consequences that caused an entire nation to leave their homeland and migrate.

Similarly, in the Ergenekon Epic, a small heedlessness of the Göktürks produced non-linear consequences that would be the end of the entire nation. Realizing that they could not defeat the Göktürks without cheating, the Tatars set a trap to drive the Göktürks out of their trenches. Accordingly, one morning, they left their heavy loads

and useless goods on the battlefield and started to run away as if they had been raided. The Göktürks, who were watching what was happening from a distance, thought they were running away because they had no fighting strength left and caught up with them. At that moment, the Tatars suddenly returned and put their plans into action. The Göktürks, who did not expect this, realized that they had been tricked, but it was too late. The Tatars came to the tents of the Göktürks, killing them, setting everything on fire and plundering their goods. Not even a single tent can survive this raid. The elders were put to the sword and the younger ones were captured as slaves. Therefore, a small heedlessness on the battlefield led to the disaster of an entire nation and was the beginning of a life of exile for the Göktürks that would last 400 years.

Another point that draws attention in epics is that individual behaviors have consequences that affect the whole system. Sometimes the action of one person binds the fate of an entire nation to itself. Oguz Khagan's desire to kill the big monster in the forest and save his people from the cruelty of this monster is a good example. As a matter of fact, Oguz Khagan's killing of the monster and his realization that all kinds of difficulties could be overcome with man's mind, labor and the weapons that are their products, became the source of his development along with the nation of which he was a part. In this way, he became the Khagan of the Oghuzs, and in the following period, he expanded the borders of his country and increased the welfare of his people with the spoils he obtained. This development is an example of coevolution in the language of complexity. While there is development as a result of coevolution in epics, the negative consequences of individual decisions also create a situation that affects everyone. This can actually be read as a natural result of coevolution, albeit in the opposite direction. Therefore, as a natural result of coevolution, the skill and happiness of the Khagans become the happiness of the people, and the helplessness and incompetence of the Khagans become the torment of the people.

Another striking point about the coevolution process in epics is that the people and communities that make up the social structure unite for their mutual benefit and form new "symbiotic" organisms, as Erçetin (2001: 11) puts it. Symbiotic organisms give rise to collective intelligence. Irregularities and complex problems encountered in epics are often overcome thanks to collective intelligence, which is the product of "organizational intelligence". In this sense, the culture of consultation is frequently emphasized in epics. For example, in the Epic of Shu, the Ruler is warned by his Vizier because all of the vanguard troops he sent against Alexander the Great were young. The vizier says that the youth should be led by an old and experienced person. Thereupon, Ruler Shu sends an old and experienced commander at the head of the young people. In the Ergenekon Epic, the formula for getting out of Ergenekon is given by a blacksmith living among the people. Everyone, including the Khagans, adopts the blacksmith's idea and they come out of Ergenekon by joining hands and working in unity. Again, the complex problems encountered during the campaigns launched by Oghuz Kaghan to all four corners were resolved with the participation of others in line with the advice and talents of the skilled people in the army.

The coevolution process that revealed collective intelligence and organizational intelligence also led to the emergence of order from disorder in epics. In epics that emphasize daily life in conditions far from balance, on the edge of chaos with the

language of complexity, some changes push the system into disorder. In case of disorder, the system constantly exchanges energy, materials, and information with its environment to reveal new order. This energy, material and information taken from the environment to create and adapt to the new order is consumed by the system. And this process is done by activating internal dynamics without any dominant intervention from outside. As a result of this process, which is expressed as self-organization (Erçetin, 2001: 42), the system reveals a new order from disorder. The events in the epics are generally based on this principle. The fact that the Göktürks made Ergenekon their homeland and lived and multiplied here for four hundred years is essentially an attempt to create order out of disorder. As a matter of fact, after leaving Ergenekon, they found their old homeland, which they had heard from their ancestors, set up their tents and sent ambassadors to all provinces to announce that they had established their new order. Similarly, in the Epic of Migration, the migration of the Uyghurs, leaving their homeland, resulted in a new order in which they founded five cities and named them Five Fish.

Sometimes it is also possible to consciously push the system into a state of disorder in order to achieve a more developed state of order. Oguz Khagan's desire to expand his borders and establish a single and powerful state essentially means deliberately pushing the system into disorder. Here, Oguz Khagan's preparations for this purpose should not be ignored. Oguz Khagan is pushing the system into disorder, but he is making as much preparation as possible despite the uncertainty of the future. However, no matter what preparations are made, how the expeditions to all four directions will turn out and what will be encountered during these expeditions cannot be predicted at the beginning. Therefore, this unpredictability essentially means pushing the system into disorder. As the process progresses, it is seen that Oguz Khagan went through many troubles with his army. Difficulties are overcome, sometimes with the guidance of Gray Wolf, who marches in front of the army, and sometimes with the knowledge and experience of the smart and skillful people in his army (in a sense, by consuming these). As a result, Oguz Khagan returns home after gaining countless spoils and expanding the borders of his country. The source of the order, which expresses a new and more developed situation that emerged in this context, is the state of disorder consciously created by Oghuz Khagan. This process resulted in coevolution as a result of the self-organization of Oghuz Khagan and his army. At the same time, the new order that emerged for the Oghuzs brought about an evolution in line with the new order for all other states. In this sense, it can be said that coevolution is a general rule in epics and no social structure is isolated from each other.

6 Conclusion

This study was conducted to concretize the idea of complexity and to explain the key concepts related to complexity through Turkish epics. In this regard, first, a "metaphorical complexity framework" containing key concepts was created based on the basic characteristics of complexity. The framework is shaped by the concepts of

multi-actor structure, non-linearity, emergence, edge of chaos and coevolution, which reflect the basic characteristics of complexity. Afterwards, Turkish epics have been evaluated from the perspective of these concepts in terms of their genre, structure and content characteristics, and the concepts related to complexity have been explained through epics. In this context, it can be said that Turkish epics provide a strong basis for explaining the metaphorical complexity framework. In addition, thanks to the social facts and events in the content, the relationship between complexity and the social world has been established.

The fact that Turkish epics provide a strong basis for concretizing the concepts of complexity can be attributed to two main reasons. One of these stems from the characteristics of epics and the other stems from the complexity itself. The reason for Turkish epics is that epics have diversity in terms of genre and structure and are also rich in terms of social events in their content. Another reason arising from the complexity itself is that this idea provides a realistic framework for explaining social phenomena. Therefore, the study not only explains the key concepts of complexity but also strongly reveals the relationship of complexity with the social world. In this context, the social world depicted in epics; It is a complex world with multiple actors, interactions between actors produce non-linear results, and life is lived on the edge of chaos. Individual behaviors that are thought to be small produce social consequences. And this reveals how important the role of every individual that makes up the society is for the well-being of the society.

The study is also important in that it gives some clues about the way of acting in such a complex world. In epics where life is lived on the edge of chaos, individual behavior sometimes drags the society into disorder. The attitude of the society in the process of emergence of order from this disorder is actually strong clues about how to act in complex processes. First, society has embraced the uncertainty of social life. In other words, uncertainty is considered natural. For this reason, instead of controlling the future, we try to be as prepared for the future as possible. Individual competencies are developed, and necessary equipment is provided. In this way, the ability to react to uncertain situations is kept alive. Then, collective intelligence is revealed, and organizational intelligence is put to work. Consultation is important in this sense. Thirdly, there is the existence of team spirit and teamwork. The solution, which is the product of the collective mind, is implemented by joining hands and uniting our hearts. As a result of all these, society is dragged into disorder and emerges from this disorder into a new and more developed state of order. These are the modes of action that epics reveal regarding complex processes.

As a result, Turkish epics have provided a strong basis for explaining the idea of complexity together with its relevant concepts. However, it has also provided important practices on how to act in complex situations, especially in social organizations. One situation needs to be emphasized here. The conclusion reached in the study should not be perceived as the existence of complexity as a paradigm in Turkish epics. Since the emergence of complexity as a scientific idea dates back to recent times, such a situation cannot be the case. Only from this point can the fact that the idea of complexity co-exists with the human phenomenon be revealed. And this also means that complexity will always exist with human phenomena. Then, it seems

appropriate to re-ask the question of Erçetin (2001: 18), who describes complexity as a philosophical and sociological call to the people of the third millennium; "Is it possible not to heed this call and not take it seriously?".

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Wavelet-Based Entropy Methods in the Analysis of Chaotic and Complex Systems

Nazmi Yılmaz, Mahmut Akıllı, and Kamil Gediz Akdeniz

Abstract Social systems, characterized by human interaction, inherently exhibit disorder, unpredictability, and complexity traits. The application of entropy measures has become crucial in the data analysis of these chaotic and complex systems. This work focuses explicitly on using wavelet-based entropy methods within such systems, drawing upon examples from our previous research. These examples include evaluating cardiorespiratory dynamics through pneumocardiogram signal analysis, characterizing tumour and normal cell behaviour using entropy-based methods, analyzing low-amplitude seismic wave data for earthquake forecasting, and examining quantum fluctuations of fermionic instantons. These studies demonstrate the effectiveness of wavelet-based entropy methods in comprehending chaotic and complex systems. Furthermore, such approaches could enhance the predictability in seemingly disordered and complex social and economic interactions and international relations.

Keywords Social systems · Complexity · Chaotic systems · Wavelet entropy

1 Introduction

In the dynamic realm of social and economic systems shaped by human interactions, we encounter a mix of disorder, unpredictability, and complexity. By quantifying levels of disorder and unpredictability, entropy offers a novel vantage point into the inner workings of such intricate systems. Specifically, wavelet-based entropy methods play a pivotal role in unraveling the dynamics of social and economic

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systems and the complexities inherent in international relations. Their ability to discern patterns amidst disorder equips researchers with valuable tools to enhance predictability, laying the foundation for more informed decision-making and effective management of intricate social and economic interactions on both national and global scales.

Researchers across diverse disciplines have long endeavored to unveil the underlying patterns governing social and economic systems (Holling, 2001). Among the approaches, entropy has emerged as a valuable tool to delve into the landscape of chaos and complexity (Baranger, 2000). Recent works have been performed using chaotic theory metaphors in social movements and political behaviours. (Akdeniz, 2014, 2019; Akdeniz & Anastasopoulos, 2016; Açıkalın & Artun, 2019; Yılmaz et al., 2020). This paper focuses on wavelet-based entropy methods—an increasingly popular technique. We dive into how these methods can be applied in social and economic systems, using real examples from our past research. These examples span a range of areas, including evaluating cardiorespiratory dynamics through analyzing pneumocardiogram signals (Yılmaz et al., 2020), understanding cell behaviour through entropy-based techniques (Akıllı, 2022), predicting earthquakes with seismic wave data (Yılmaz et al., 2023), and exploring quantum fluctuations of fermionic instantons (Akıllı & Yılmaz, 2022).

Through wavelet-based entropy methods, these studies effectively showcase how this approach uncovers hidden patterns, deciphers complexities, and deepens our grasp of chaotic and complex systems. These methods can potentially increase predictability within the complex world of social and economic interactions and in the arena of international relations. As we explore chaos and complexity, wavelet-based entropy methods lead us toward a richer understanding of the complex networks that define our surroundings.

2 Entropy

The entropy concept was first used by Shannon to describe the information theory which provides mathematical tools and approaches to measure the amount of information in a system and has wide-ranging applications in telecommunications, cryptography, data science, linguistics, and the study of complex systems.

The concept of the change in a system's total entropy (ΔS) was defined by Rudolf Clausius in the year 1865.

$$\Delta S = \frac{\Delta Q}{T} \tag{1}$$

Here, ΔQ represents the change in heat energy of the system, and T denotes the temperature of the system. Boltzmann demonstrated that entropy is related to the probability distribution of microstates within the system. The Boltzmann equation is as follows:

$$S = k_B \ln(W) \tag{2}$$

Entropy provides a statistical measure of energy distributions for systems at a certain temperature. Thus, calculating entropy measures fundamentally rely on the probability distributions.

$$S_{BGS}(p) = -k \sum_{i=1}^{W} p_i \ln p_i \tag{3}$$

Here, k is the Boltzmann constant, representing the unit of entropy measurement. W denotes the number of states or microstates of a system. The probability of the i-th microstate of a system is p_i. The Boltzmann equation expresses the maximum entropy of a system in equilibrium. In equilibrium, the probability of microstates occurring (or being realized) in a system is equal (see Fig. 1).

3 Wavelet—Based Scalogram Entropy

Wavelet-based entropy determines the disordered characteristics of the signal using the wavelet theory. It unveils supplementary insights into the latent dynamic processes linked with the signal. The scalogram represents the energy of the continuous wavelet transform obtained at each signal scale. Scalogram Entropy (Akıllı et al., 2019) calculates the average entropy where the inner scalogram is normalized to identify the contributions of all scales, hence frequencies to the combined energy of the signal over time.

The probability distribution is obtained by dividing the normalized inner scalogram at each scale by the total energy. Boltzmann–Gibbs–Shannon (BGS) entropy is calculated using the probability distribution, and the discrete BGS entropy of a signal can be defined as follows:

$$S_{BGS}(p) = -k \sum_{s=s_0}^{s_1} p_s \ln p_s \tag{4}$$

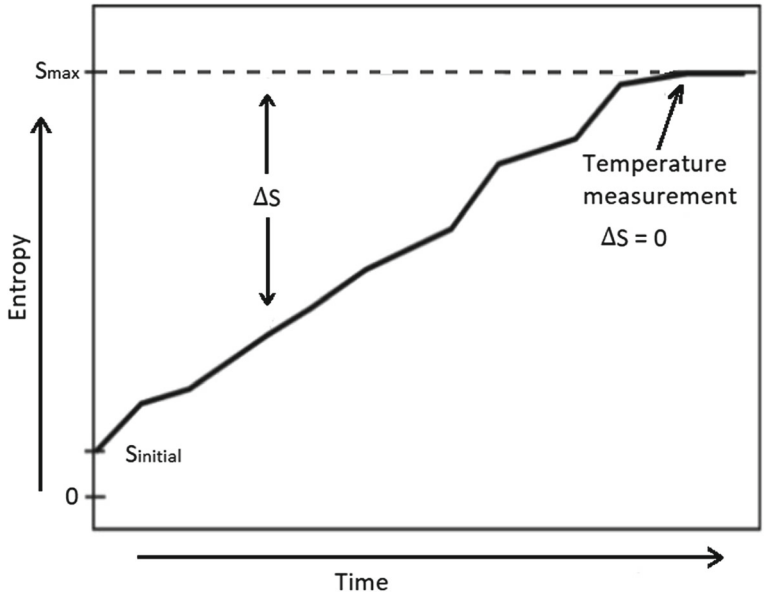

Fig. 1 Entropy as a function of time. As a system reaches equilibrium, entropy becomes maximum ($S_{\max}$), and there is no longer a change in entropy ($\Delta S = 0$) (Lineweaver, 2014)

4 Windowed Scalogram Entropy

Wavelet-based entropy determines the disordered characteristics of the signal using the wavelet theory. It unveils supplementary insights into the latent dynamic processes linked with the signal. The scalogram represents the energy of the continuous wavelet transform obtained at each signal scale. Scalogram Entropy (Akıllı et al., 2019) calculates the average entropy where the inner scalogram is normalized to identify the contributions of all scales, hence frequencies to the combined energy of the signal over time.

The scalogram entropy provides only the mean entropy of a signal. However, the behaviour of nonlinear dynamic systems can significantly change. As a result, entropy does not remain constant over time. For this, we utilize the method of 'windowed scalogram entropy' to measure the temporal variations in the entropy of a signal that undergoes substantial changes in behaviour over time. This adaptable technique effectively captures the relative contributions of distinct scales proximate to a designated time point, unveiling the intricate dynamics hidden within the signal's temporal landscape (Blanco et al., 1998; Rosso et al., 2001, Xu et al., 2013).

The scalogram limited to a time interval of $[t - \tau, t + \tau]$ is called windowed scalogram. In other words, the windowed scalogram represents a time series's 'normalized windowed scalograms' in a scale interval. Technically, a time window centred at the time t with a time radius τ is determined, and then the windowed scalogram is computed using time windows obtained by increments of Δt (Bolós et al., 2017,

2020). Therefore, for each time window, the BGS entropy can be written as follows (Akıllı & Yılmaz, 2021):

$$WS_{BGS}(p) = -k\sum_{s_0}^{s_1} p_{s,\tau}(\mathrm{t}) \ln p_{s,\tau}(\mathrm{t}) \tag{5}$$

This method enables to analyse Time-dependent entropy changes of a dynamical system.

5 Application of Scalogram Entropy in Cardiorespiratory Dynamics

This study analysed airflow and pressure changes in the respiratory system using scalogram entropy alongside other nonlinear analysis methods (Yılmaz et al., 2020). The measurement of airflow and pressure changes in respiratory airways indicates variations in lung and heart volumes. These fluctuations are observable externally and mirror the movements of the lungs and heart, providing valuable insights into the dynamics of volume changes driven by these organs. Exploring interactions between the cardiovascular and respiratory systems has yielded valuable information about various pathological conditions (Schulz et al., 2013; Yoon et al., 2018) (see Fig. 2).

In this study, wavelet-based scalogram entropy emerges as a promising approach for uncovering nonlinear patterns within physiological signals. The study's findings emphasize the responsiveness of the analyzed signals to initial conditions, attributing irregular behaviour to the system's inherent nonlinearity rather than external noise sources. Notably, the study suggests that a comparative analysis employing scalogram entropy has the potential to distinguish levels of chaos, providing an additional viewpoint alongside an established chaos analysis method of Maximum Lyapunov Exponents (Wolf et al., 1985) for examining a range of physiological data.

6 Application of Scalogram Entropy and Windowed Scalogram Entropy in Understanding Cell Behavior

Nobel laureate Schrödinger (1967) pondered how living cells -by growing and forming complex organisms- appear to challenge the second law of thermodynamics, which is the basis of entropy. Creating order by living cells through growth and forming intricate organisms might contradict this law. According to Erwin Schrödinger, living cells are open systems that can receive energy from their surroundings, such as nutrients or photons from the sun. In a closed system where no external energy is provided, entropy tends to increase or remain constant. However, living cells operate as open systems, absorbing energy from their environment and utilizing it to create internal order. Living organisms have lower entropy compared to

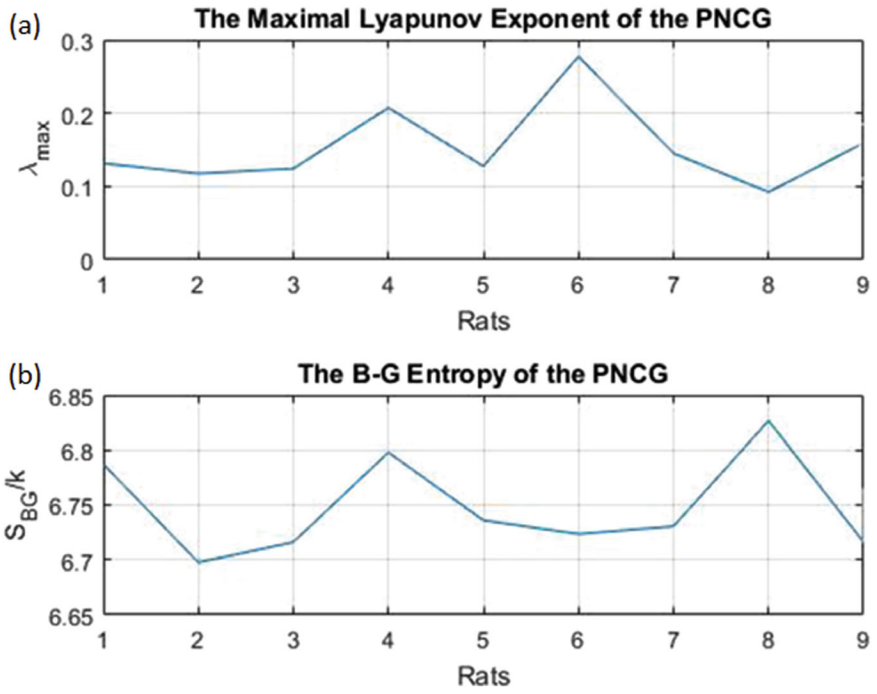

Fig. 2 **a** Maximum Lyapunov exponents, **b** B-G entropy calculated by normalized inner scalogram for the airflow and pressure signals in the respiratory system (PNCG) of the nine rats (Yılmaz et al., 2020)

their surroundings, and they use external energy sources to sustain their low entropy states. This is essential because the emergence of life and the sustenance of living organisms in a high-entropy equilibrium state would be implausible (Himeoka & Kaneko, 2014).

This work (Akıllı, 2022) demonstrates that both tumour and normal cell structures are chaotic, and therefore, predicting cell behaviours is highly challenging. In this analysis, the wavelet-based windowed scalogram entropy method is observed to outperform another entropy method—sample entropy (Richman & Moorman, 2000). Furthermore, results obtained from the scalogram entropy method are comparable to maximum entropy. As known, living organisms have lower entropy compared to their surroundings. The graphical results compared to maximum entropy in Fig. 3 confirm this general assumption.

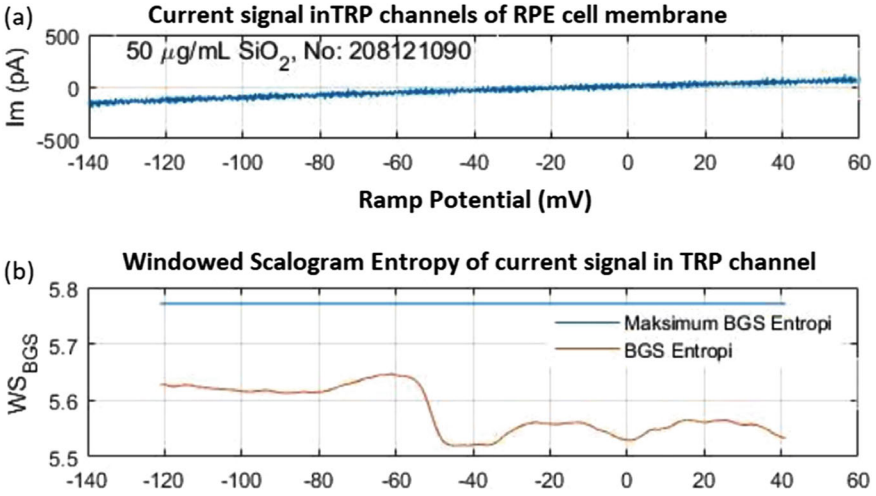

Fig. 3 In a stimulated RPE (Retinal Pigment Epithelial) cell. **a** Current recorded in the TRP (Transient Receptor Potential) ion channels in a RPE cell membrane. **b** Windowed scalogram entropy of the TRP cell current signal. The entropy spectrum illustrates the complexity and irregularity of the signal based on voltage changes over time (Akıllı, 2022)

7 Application of Wavelet-Based Entropy Methods in Seismic Waves

This study employed four distinct methodologies to investigate the dynamic changes in chaotic attributes, entropy over time, and aperiodic characteristics inherent in seismic waves that precede earthquakes. The selected techniques encompassed Windowed Scalogram Entropy, Sample Entropy, Maximum Lyapunov exponents and Windowed Scale Index. The seismic events under scrutiny occurred on 26-09-2019 in Istanbul, M = 5.7, and on 17-11-2021 in Duzce, M = 5.2 (see Fig. 4).

Significantly, our investigation underscored the high sensitivity of Windowed Scalogram Entropy for the frequency changes within continuous seismic waves with low amplitude, enabling the identification of entropy fluctuations in signal sections where amplitude changes were either minimal or absent. This particular outcome exemplifies the unique prowess of the Windowed Scalogram Entropy method, enabling intricate analysis within constrained timeframes in the temporal sequence. The profound insights derived from this approach have the potential to contribute substantially to the advancement of earthquake forecasting methodologies.

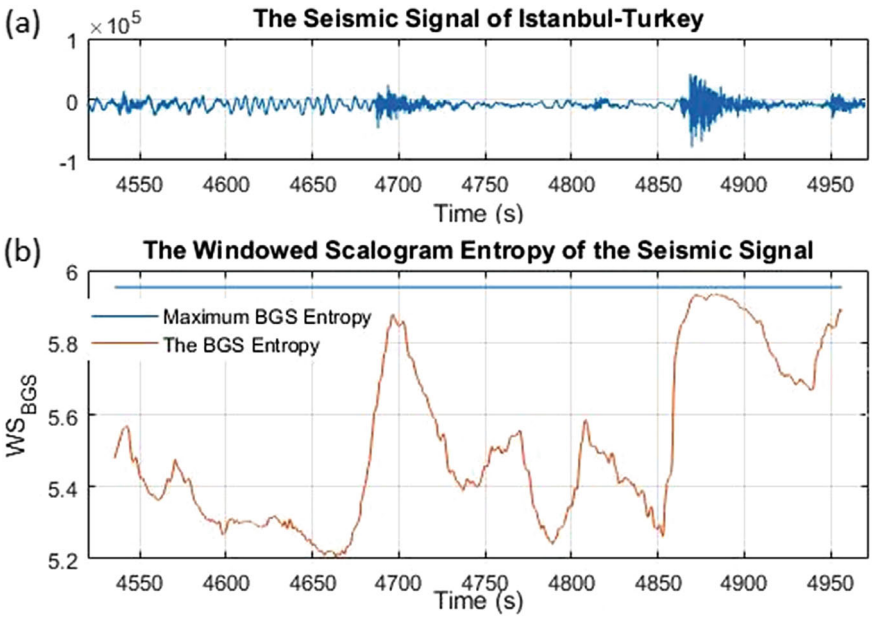

Fig. 4 **a** The seismic data, recorded on 26-09-2019, in Istanbul, Turkey, just before the earthquakle of M = 5.7 **b** The entropy change in the seismic waves displayed by the windowed scalogram entropy (Yılmaz et al., 2023)

8 Application of Wavelet-Based Entropy Methods in Analysing the Beginning of the Universe

This study delves into the phenomenon of fermion emergence following the Big Bang, calculating the wavelet entropy of of fermionic instantons' quantum fluctuations. In pursuit of this objective, Boltzmann–Gibbs–Shannon entropy was computed for quantized orbits derived from the Thirring model, employing the wavelet-based normalized inner scalogram technique. The investigation centred on the massless Thirring equation, explicitly exploring the point at which quantum fluctuations of the instantons assume the form of fermionic instantons (see Fig. 5).

The insights gleaned from this research hold significance in estimating entropy in the beginning of the Universe. Conventionally, the genesis of the Universe is posited to involve a quantum state. Operating under the premise that the Universe began in low entropy conditions, it is proposed in this work that the entropy of fermions during their genesis plays a pivotal part in shaping the overall entropy of the Universe following the cataclysmic event of the Big Bang. Remarkably, the emergence of the observable Universe is attributed to its fundamental role in the fabric of existence. This outcome would be improbable if it had emerged from a state of high-entropy equilibrium. As such, the findings conclusively affirm the notion that a state of low entropy marked the Universe's inception.

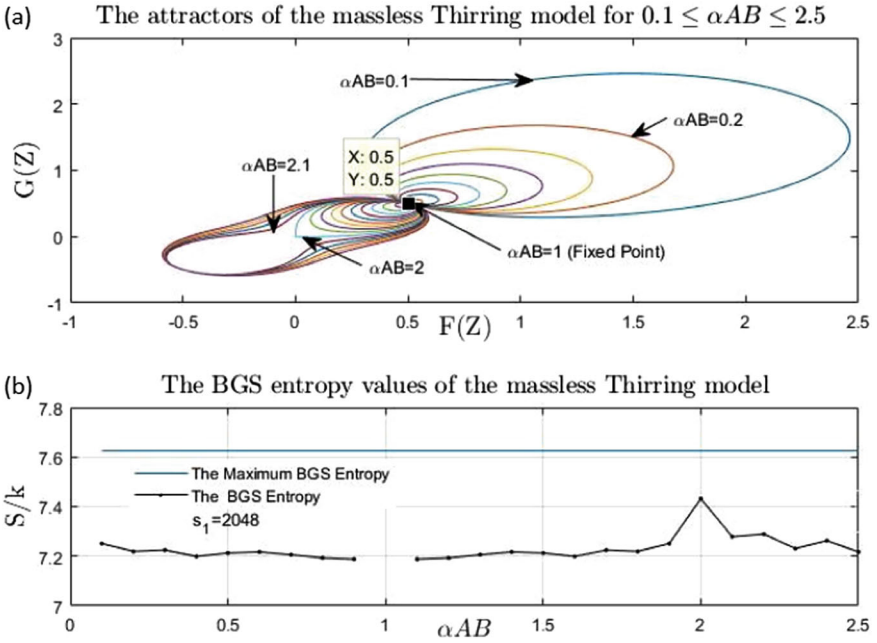

Fig. 5 **a** Thirring model for the instanton solution of αAB = 1, the initial conditions are G(0) = +0.5, F(0) = +0.5. The phase space is displayed for 0.1 ≤ αAB ≤ 2.5. **b** The BGS entropy of the F(Z) for 0.1 ≤ αAB ≤ 2.5 (Akıllı & Yılmaz, 2022)

9 Discussion

In international relations, where the interactions between countries and entities are multifaceted and nonlinear, wavelet-based entropy methods offer a new dimension to understanding the factors driving these complex interactions. By shedding light on the hidden dynamics and interdependencies, these methods can contribute to more accurate modelling, forecasting, and policy formulation, ultimately fostering more excellent stability and cooperation in the global arena.

The findings presented in this study shed light on various facets of chaotic and complex systems through the lens of wavelet-based entropy methods. The application of these methods has revealed insights that contribute to our understanding of diverse phenomena, ranging from cardiorespiratory dynamics and cell behaviour to seismic wave analysis and the emergence of fermionic particles after the Big Bang.

The diverse applications of wavelet-based entropy methods underscore their significance as tools for deciphering complexity and disorder across a range of domains. The ability of these methods to capture subtle shifts, transitions, and patterns within chaotic systems opens avenues for further research and practical applications. These insights not only deepen our understanding of fundamental

phenomena but also potentially drive advancements in fields such as medical diagnostics, disaster prediction, cosmology and social sciences. As we continue our quest to unravel the mysteries of chaotic and complex systems, wavelet-based entropy methods are valuable tools, guiding us through the intricate landscapes of disorder and unpredictability.

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The Nature of Chaotic Research and New Science

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Abstract This research provides information about the nature of scientific discovery and progress by addressing the connections between the new concept of science, chaos theory, and research methods. New science is an important concept that examines unexplored or little-known research areas and topics and introduces new methods needed in new situations. Chaos theory stands out as an exciting field for the study of complex and disordered systems observed in nature and science. This theory aims to understand the behavior of systems characterized by uncertainty and unpredictability using mathematical models and graphs. Chaos theory has important applications in physics, economics, biology, and other disciplines. Various research methods such as system dynamics, fractals, and scaling analysis are considered important tools for applying the principles of chaos theory. The connections between new science, chaos theory, and research methods provide important ground for scientific discoveries and advances. New fields of science can combine different research methods and expand existing knowledge using the principles of chaos theory. These concepts play an important role in explaining complex natural phenomena and providing important foundations for future research. In particular, these approaches can contribute to the understanding and analysis of complex systems that are vital to technology, health, and many other fields.

Keywords New science · Nature of research · Chaos theory

1 Introduction

Chaos theory is an exciting field of research for the study of complex and disordered systems observed in nature and science (Boccaletti et al., 2000). This theory aims to understand the behavior of systems characterized by uncertainty and unpredictability using mathematical models and graphs (Thıetart & Forgues, 1995). The discovery of chaos theory has brought new perspectives and understandings in many

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fields from physics to economics, from biology to social sciences (Skinner et al., 1992). Likewise, research methods are also important elements that form the basis of scientific studies (Williams et al., 2007). The selection and use of appropriate research methods are vital to reaching accurate and reliable results (Walliman & Nicholas, 2015). Natural observation, experimental studies, surveys, interviews, and other methods enable researchers to test specific hypotheses, collect and analyze data (Coe et al., 2017). In this article, we examine how chaos theory and research methods can be combined and how complex systems can be studied. We will consider how we can apply various research methods using the principles of chaos theory and how these approaches contribute to the understanding of complex systems. We will also explore the applications and important implications of chaos theory and research methods in different disciplines and explore what opportunities advances in this field can offer. As a result, chaos theory and research methods play an important role in scientific discoveries and contribute to a better understanding of complex systems. To better understand the current situation, we need to examine the new concept of science.

2 The New Science

As nature, the human brain is a complex system. The human mind felt the need to develop scientific methods to objectively perform the effort to create a sense-relationship between complex systems. Thanks to the developing technologies, scientific research methods have also developed and the process of the formation of new science has accelerated (Watts, 2004).

Our effort to explain natural events started with stories developed by people with an unknown explanation and passed on by the word of mouth. This period, in which the descriptor is anonymous and validity lasts for a very long time, can be called the Science 1.0 period. The next stage is what we can call Science 2.0, where there are only the explanations of the great people who are thought to be chosen. At this stage, some periodic events in the sacred sky and some events on the ground were associated with future predictions and explanations of natural events and tried to be developed with controls. As in other scientific stages, some people continue to live in this period. After Science 3.0, Science 2.0, and Science 1.0 were not completely extinguished, they continue to develop and evolve today. Science 3.0 is a positivist process in which variables are defined and other variables are ignored by controlled experiments. The Science 3.0 period, which has linear relations with isolated systems, has a structure that maintains its validity even today. Many books and research are always fed by the understanding of this period. The new science, Science 4.0, is the process in which we obtain graphics that people can understand using big data and some artificial intelligence-assisted data mining methods (Fig. 1).

The differences between new science and existing science are related to the changes and developments that occur due to the nature of scientific progress. Here,

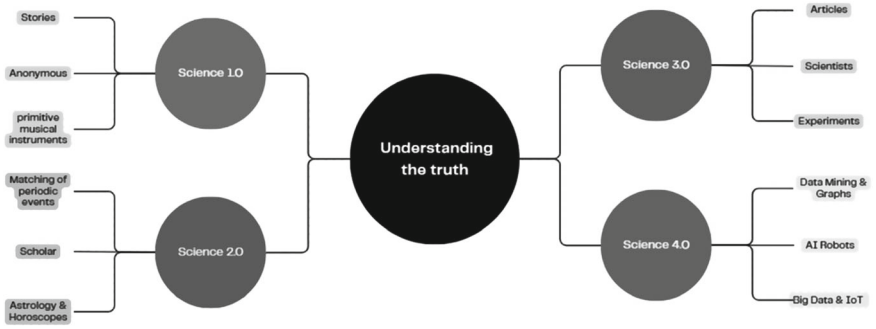

Fig. 1 Classification of science in terms of understanding truth processes

we consider some key points to summarize the important differences between new science and existing science:

Significance and Impact: New science can have a significant impact on scientific fields with discoveries and innovations. Such discoveries can lead to significant transformations in fields such as technology, health, environment, and social sciences. Current science, on the other hand, is of great importance in developing fundamental knowledge, validating theories, and using it in applied research. New science will also affect the revision of existing science. A single model used in the explanations will be replaced by a form of explanation that will be called the "ghost model" in which all the old and new models are evaluated holistically. Ghost models are multiple models created with old and new version models based on the fact that many models, like the formulas we use to explain events, will not be fixed (contain deviations).

Knowledge and Theories: New science often involves the development of new theories and concepts. These theories may not have been tested or widely accepted yet. In current science, however, basic theories have often been tested and accepted by the scientific community. Existing science continues to advance based on stronger and more validated information, but new science always retains the potential to create a paradigm shift in existing science. A single package of information or a set of explanations will give way to constantly moving fluid information and theories. The stagnant and holistic theories that will always explain everything will be replaced by fluid and instantaneous theories.

Related Researchers: Researchers working in new science often pioneers and leading all-around experts in AI-powered employe fields. They work to make discoveries and make important contributions to the scientific literature. Researchers working in current science are experts in the subject and scientists with long-term studies. While the theoretical knowledge of these researchers is isolated and idealized, their practical knowledge often far from their theoretical knowledge. These experts work to understand and develop the existing knowledge in science in depth, but they are

far from multifaceted studies because they have the judgment that the knowledge will be certain and absolute.

Research Area and Topic: New science deals with an unexplored or little-known research area or topic, or with systems that have previously been studied in one dimension but are essentially multidimensional. A new field of science can offer more opportunities for scientific discoveries and innovations and expand the boundaries of existing science. Current science, on the other hand, is a field studied for a long time and whose basic principles have been determined. The knowledge available in this area is often extensive and concentrated on a particular discipline.

Research Methods: New science can use original and innovative research methods and technologies. Traditional methods may be insufficient to obtain new information in areas that have not yet been discovered. In current science, research methods and protocols developed and validated over many years are widely used. The stagnant and unstable data, the biased values of the vibrations, and their drag into ghost models will validate the research methods by revealing the instant truth for the instant decisions of the new science. For example, while continuously flowing data is analyzed correlationally for a while, it can be analyzed for classification after a certain period. Decision-making processes for this method change will appear as a separate research area.

To a result, the differences between new science and existing science are related to changes due to the nature of scientific discovery and progress. Both fields contribute to the development of scientific knowledge and understanding and have complementary qualities, but the working method of the new science will not progress with completed articles but with large data sets that can change instantly. More than the journals in which the articles are published, we will encounter structures that work with artificial intelligence and that can collect processed data and create more meaningful ghost models. Studies on existing science will continue, but instead of studies that are not based on real data and require long processes, studies that can be checked and interpreted instantly and new science studies will make it easier for us to understand complex systems such as our brain and nature.

There is a relationship between chaos theory and research methods. Chaos theory is known as a scientific field that focuses on the study of complex and disordered systems (Thıetart & Forgues, 1995). This theory asserts that events in the natural world can be explained and predicted using complex mathematical models (Boccaletti et al., 2000). Research methods are systems used for planning scientific studies, organizing data collection and analysis processes, and interpreting results. Researchers use appropriate research methods to test a particular hypothesis, solve a problem, or understand a phenomenon (Skinner et al., 1992). Chaos theory may be relevant to some research methods, especially when used for the understanding and analysis of complex and uncertain natural processes.

3 Naturalistic Observations

Chaotic systems are often complex and irregular. To study such systems, researchers can use the natural observation method. For example, weather, environmental, and biological systems can be studied by natural observation in the context of chaos theory.

Natural observation is a research method that involves researchers watching an event or phenomenon in its natural environment without any intervention. This method is widely used to understand complex and real-world situations, observe behavior, and study complex systems. Researchers collect data by observing the behavior of participants or the natural flow of a process and analyze these data to make inferences. The human brain, which is an observer, actually concludes by conducting a complex analysis. Most of the time, these observations and the explanations created are also misleading because the observer can manipulate the data he collects with his prejudices in his mind. We have noticed this in current prescience versions. Current science has only helped us to develop more coherent explanations by making these natural observations systematic. The new science will provide the opportunity to collect and analyze data by eliminating the limitations of the observer; it will also collect data at frequencies beyond vision and present instant reality with continuous (without sleeping) controls.

The relationship between chaos theory and natural observation is based on the observation of chaotic systems in the natural world. Chaos theory is used to understand complex and disordered systems, while the naturalistic method of observation is used to observe and analyze these systems in a real-life context. For example, chaotic processes such as weather, water flow, ecosystems, and human behavior can be studied by natural observation. To adapting these natural observations to mathematical models and using fractal analysis techniques, researchers can relate the principles of chaos theory to these complex systems. In this way, they can observe how chaos theory is applied to understand the behavior of complex systems and how explanations are made.

Natural observation can contribute to the analysis of chaotic processes that cannot be done, especially under laboratory conditions, and that involve certain control deficiencies. However, the natural method of observation also comes with challenges in the nature and complexity of the data. Therefore, when making natural observations based on chaos theory, researchers need to collect and analyze data carefully and systematically. At this point, Science 4.0 appears. Natural observation can provide valuable information for determining the properties and behavior of complex systems and, when combined with chaos theory, can contribute to a better understanding of real-world events and phenomena. If taking a photo for natural observation and analyzing that photo is an approach suitable for Science 3.0, the instant truths that we have formed in the process of constantly taking data on the observed nature with cameras pointed at multiple and different angles and analyzing it with multiple artificial intelligence systems are the product of the Science 4.0 process.

4 System Dynamics

System dynamics allows us to understand the behavior of systems using mathematical models that represent a system (Martınez-Moyano & Rıchardson, 2013). Chaos theory can help analyze certain systems with mathematical models and understand how systems behave.

System dynamics is a research method used to understand and analyze the behavior of complex systems (Wolstenholme & Coyle, 1983). In this method, the variables affecting the system and the relationships between these variables are represented by mathematical models. System dynamics is used to understand how the system changes over time, how different variables affect each other, and how the system may behave in the future.

The relationship between chaos theory and system dynamics focuses on the mathematical modeling and analysis of complex systems. Both methods use mathematical and graphical tools to understand the complexity of the system and explore its behavior over time. However, there are also some differences between chaos theory and system dynamics. While chaos theory examines complex systems with disorderly and unpredictable behavior, system dynamics is used in the analysis of more stable and balanced systems. System dynamics is used to understand the transitions between equilibrium and non-equilibrium states of the system and how these transitions occur. At the same time, system dynamics include simulation and modeling techniques to study the interactions of different components of the system and the effects of these interactions on the system.

Chaos theory and system dynamics can also be considered complementary methods. While chaos theory focuses on the study of disordered and uncertain events, system dynamics deals with more stable and predictable systems. However, in some cases, chaos theory principles can also be important in system dynamics analysis, where small changes within the system can have big consequences. For this reason, some researchers may combine chaos theory and system dynamics approaches to work toward a more comprehensive understanding and analysis of complex systems (Ayers, 1997).

While system dynamics is modeling the stable structure based on mainstream data, it will be possible only with the new science approach to make sense of the turbulence data that will occur and put the unstable holistic model (ghost model) into it.

5 Fractal and Scaling Analysis

Rely on the geometry of nature, namely fractals because they know that the relationship between the data will not be linear or unidirectional. Using fractal geometry, chaos theory can lead us to study complex structures observed in nature. Fractals

are defined as structures that similarly repeat themselves and are frequently found in chaotic processes (Chua et al., 2005).

Fractal and scaling analysis is a research method that studies the mathematical representation of complex structures and patterns. Fractals are mathematical objects that express complex geometric structures. In particular, an important feature of fractals is that self-similarity persists at different scales. That is, a smaller portion of a fractal structure contains a pattern similar to the overall structure. Fractals and scaling analysis contribute to the understanding of many complex systems observed in nature and science (Lam, 2004).

Chaos theory, fractals, and scaling analysis are based on similar approaches to the study of complex systems. While chaos theory focuses on studying the disordered and unpredictable behavior of complex systems in the natural world, fractals and scaling analysis aim to create and analyze mathematical models of these complex structures. Fractal structures are commonly found in chaotic systems and can also be associated with chaos theory principles (Potapov, 2015).

Scaling analysis aims to determine how the patterns in a system are repeated and self-similar by examining how the behavior of a system changes at different scales (Cheng & Cheng, 2004). This analysis is particularly useful for understanding the behavior of large systems because some systems tend to show similar patterns at different scales. Therefore, scaling analysis helps to identify fractal structures and patterns and to understand how the behavior of the system responds to scale change (Brethouwer et al., 2007).

Fractals and scaling analysis run parallel to chaos theory when used to understand the structural and behavioral properties of complex systems. Both contribute to an understanding of the complexity observed in the natural world and to the determination of the internal regularities of systems. Using the mathematical properties of fractals, researchers can use scaling analysis to model and analyze chaos theory-based systems (Klonowskı, 2000). The combination of these methods allows for a more comprehensive understanding and prediction of complex systems.

6 Cognitive Science and Neuropsychology

Chaos theory can contribute to neuropsychology and cognitive science on the complexity and regularity of the human brain (Ayers, 1997). In studies in this field, chaos theory principles can be used in data analysis.

Cognitive science and neuropsychology are research methods used to understand the human mind and brain functions (Ayers, 1997). Cognitive science aims to understand how mental activities work and affect human behavior by examining cognitive processes such as perception, attention, memory, language, thought and problem-solving (Perry, 2009). Neuropsychology, on the other hand, explores the relationships between the brain and mental processes through methods such as examining patients with brain damage and measuring the brain activity. These fields lie at the intersection of psychology, neurology, neuroscience, and computer science (Iwakabe, 1999).

The relationship between chaos theory and cognitive science and neuropsychology comes from similar approaches to the study of complex mental processes and brain activity. Cognitive science and neuropsychology can use chaos theory principles to understand and explain the complexity of the human mind and brain functions. In particular, when chaos theory is used to understand the disordered and uncertain behavior of complex systems, it is observed that cognitive processes and brain activities have similar properties (Mccown et al., 2016).

In cognitive science, for example, topics such as memory processes, learning, and cognitive decision-making can be viewed as complex and dynamic constructs (Goel, 2005). Chaos theory can be used to explain and model disordered and unpredictable behavior in such cognitive processes. In neuropsychology, brain activities and neural networks can be considered complex structures and dynamic systems (Harley, 2004). Chaos theory can help analyze neuropsychological data and understand the complexity of the brain activity.

Cognitive science and neuropsychology, combined with chaos theory, offer a more comprehensive approach to better understanding and explaining the complexity of the human mind and brain functions (Prıtchard & Duke, 1992). Research in these areas can apply the principles of chaos theory in a broader context to understanding complex systems and disordered behavior and reveal new insights into the human mind and brain activity. Thus, cognitive science and neuropsychology can continue to better understand the fundamental mechanisms of complex mental processes and brain activity and make important contributions to the understanding and treatment of various psychological and neurological diseases. With machine learning systems developed in an artificial intelligence-supported way, the new science will change not only our thoughts and beliefs but also our view of science and life.

7 Conclusion

The nature of chaotic systems may in some cases complicate or limit the use of traditional research methods. Therefore, it may be important to develop more flexible and customized research methods in specialized fields such as chaos theory. However, the relationship between chaos theory and research methods may vary depending on the requirements of a particular field of research and how chaos theory is used.

We focused on chaos theory and various research methods used in the understanding and analysis of complex systems. Chaos theory explains the patterns and orders within complex systems by examining the irregular and uncertain behaviors observed in nature. This theory is especially useful when explaining natural events and phenomena, where traditional mathematical modeling fails. The findings show that chaos theory is a valuable tool for understanding complex systems and predicting their future behavior.

Research methods were also an important focus of this study. Various research methods such as natural observation, systems dynamics, fractals and scaling analysis, cognitive science, and neuropsychology are important tools used to apply

the principles of chaos theory. These methods can be used in combination from different perspectives to examine and analyze complex systems. In particular, fractals and scaling analysis provide important information for the modeling of chaos theory-based systems by providing a deeper look at complex structures and patterns.

In conclusion, in this article, we focused on the contributions of chaos theory and research methods to the understanding and analysis of complex systems. It has been seen that chaos theory is a strong alternative in cases where traditional methods are limited in explaining complex natural events and phenomena. In addition, research methods such as natural observation, systems dynamics, fractals and scaling analysis, cognitive science, and neuropsychology can be used as important tools in applying chaos theory. The combined use of these methods can contribute to a more comprehensive and holistic understanding of complex systems and provide an important basis for future research. Even if humans are not ready for the new science of connective reality, in which scientific articles will be replaced by sentences/codes containing scientific information, humanity is ready.

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