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Understanding and governing global systemic crises in the 21st century: A complexity perspective

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Abstract

The growing interconnections among societies have facilitated the emergence of systemic crises, i.e., shocks that rapidly spread around the world and cause major disruptions. Advances in the interdisciplinary field of complexity can help understand the mechanisms underpinning systemic crises. This article reviews the most important concepts and findings from the pertinent literature. It demonstrates that an understanding of the nature of disruptions of globally interconnected systems and their implications is critical to prevent, react to, and recover from systemic crises. The resulting analytical framework is applied to two prominent examples of global systemic crises: the 2008 global financial crisis and the COVID-19 pandemic. The article provides evidence that relying on reactive and recovery capacities to face systemic crises is not sustainable because of the extraordinary costs they impose on societies. Efforts are needed to develop a multipronged strategy to strengthen our capacities to face systemic crises and address fundamental mismatches between the nature of global challenges and the necessary collective action to address these challenges.

1 | GLOBALIZATION AND THE ARCHITECTURE OF FRAGILITY

Contemporary globalization has fostered human development but growing interconnectivity between societies has increased systemic risks (Goldin & Mariathasan, 2014; Goldin & Vogel, 2010). Systemic risks are risks associated with large-scale failures or changes of a system (Helbing, 2013). Disruptions originating in one country can quickly spread beyond national borders and affect large parts of the human population. Addressing such threats is considered a global public good, i.e., goods with benefits that extend to all countries (Kaul et al., 1999). In the study of risks with large-scale impacts, research has often focused on wars, natural disasters, and existential risks (Ord, 2020). However, crises affecting human societies are also related to economic and social issues, or the co-occurrence of social and ecological phenomena (Folke et al., 2021). In the early 21st century, the world has experienced several systemic events with global repercussions, including jihadist terrorism and the war on terror (2001), the global financial and economic crisis (2008), the COVID-19 pandemic (2020), and the current broader impact of the Russian aggression against Ukraine on energy, food, and security (2022).

These events have provided an empirical basis to study systemic crises. This article aims at providing a broader understanding of the nature, causes, mechanisms, and impact of global systemic crises and their implications for global policymaking and governance. Such understanding is essential for the provision of global public goods to prevent, react to, and recover from shocks. The article reviews developments in complexity science and related fields to understand the nature and dynamics of systemic crises. Complexity science is not a unified theory but a collection of concepts, theories, and methods that are influencing a range of scholarly disciplines. Many insights come from the study of physical, biological, and ecological systems but complexity science is increasingly used to improve our understanding of social and intertwined social-ecological systems (Arthur, 2021; Biggs, De Vos, et al., 2021; May et al., 2008; Scholl et al., 2021).

The second section of this article covers the various determinants of a systemic crisis. The third section discusses connections between the study of non-linear dynamics and the unfolding of crises. The fourth section focuses on the capacities that underpin a system's reaction to a crisis. The fifth and sixth sections cover the associated implications for global policymaking and governance. Overall, this article demonstrates the relevance of complexity science to understand important features of systemic crises. The resulting analytical framework is applied to the 2008 global financial crisis and the COVID-19 pandemic, two of the most prominent examples of contemporary global systemic crises. This paper draws our attention to the lack of capacity of current global institutions to address systemic risks, emphasizing the need for governance systems that match the key features of contemporary global challenges.

Policy implications

- Relying exclusively on the reactive and recovery capacities of individual countries to face systemic crises is not sustainable because of the extraordinary costs they impose on societies. Efforts are needed at the local, national, regional, and international levels to develop a multipronged strategy to strengthen our capacities to face systemic crises and address fundamental mismatches between the nature of global challenges and the collective action that human societies can achieve.
- The most effective long-term strategy to prevent systemic crises is to address their root causes and thereby reduce global vulnerabilities while accelerating global change towards the achievement of the sustainable development goals. A high-level United Nations panel supported by a transdisciplinary scientific commission is needed to (i) evaluate systemic risks and (ii) develop transformative actions aiming at minimizing such risks. Trade-offs between goals and actions in different sectors need to be transparently assessed, communicated, and addressed.
- The second most effective line of defense against systemic crises is to prepare for a timely implementation of interventions before localized events spiral out of control and develop into systemic crises. A United Nations global action plan for preventing, reacting to, and recovering from systemic crises is needed as a common foundation that informs actions across different sectors of the economy. A first step would be the adoption of a resolution at the United Nations General Assembly in 2023.
- Governments should work together to improve systemic risks monitoring, timely information sharing, and the provision of rapid guidance in case of a developing systemic crisis. As multiple binding and non-binding international institutions already exist in several sectors, reforming existing institutions to make them both more effective and agile should be preferred. Proper human and financial resources are needed to accomplish these objectives.
- More attention should be given to the study of complex systems in education and research but also in policy circles. All higher education institutions worldwide should introduce teaching modules on global systems science to improve literacy in resilience and sustainability. Policymakers and researchers need to

2 | UNDERSTANDING SYSTEMIC CRISES UNDER A COMPLEXITY LENS

Complex systems are "*systems in which the interactions of large numbers of entities may give rise to qualitatively new kinds of behavior different from that displayed by small number of them*" (Ladyman & Wiesner, 2020). Examples of complex systems include living organisms, an organization, an ecosystem, the economy, society as a whole, and the biosphere (Mitchell, 2009; Ruhl, 1996). Many complex systems can be described as co-evolving multi-layered networks (Artime et al., 2022; Kivelä et al., 2014; Thurner et al., 2018). Their overall behaviour crucially depends on structural details and usually cannot be described by reductionist approaches (Parisi, 1999). Complex systems typically exhibit an emergent behaviour where stability tends to prevail, but they can be disrupted and their functions impaired. A 'crisis' is an acute event that threatens the stability and persistence of a complex system.

2.1 | From systemic risks to systemic crises

The literature on crises has classically focused on disaster management caused by natural 'exogenous' work more closely together to strengthen the capacities to face global systemic crises, increase learning from past and current events, and improve complexity-informed governance design.

- To make resilience and the broader capacities to prevent and mitigate systemic crises a core concern of societies, a multistakeholder approach is needed. Many public and private actors have knowledge and capacities that can enhance societal resilience while contributing to the sustainability transformation. Participatory processes are needed at all governance levels to allow different actors both to prepare themselves for systemic crises and contribute to a reduction of global vulnerabilities.

events (Comfort et al., 2010). In international relations, the word 'crisis' has been used to describe the confrontation between major powers and the risk of escalation towards nuclear war (e.g., Cuban missile crisis in 1962). In the 21st century, the word 'crisis' has taken a new meaning due to the consequences of growing interconnectivity in social, economic, and political systems. As growing interconnectivity has not been accompanied by a fundamental reform of global governance (Gill, 2015; Held & Young, 2013; Pierre & Peters, 2019; Rosenau, 1995), it has favoured the emergence of systemic risks (Frank et al., 2014; Galaz et al., 2017; Goldin & Mariathasan, 2014; Helbing, 2012; Kaufman & Scott, 2003). While the world has experienced several systemic events with global repercussions, the concept of 'systemic crisis' has been mainly used in the context of financial and economic crises, particularly in the wake of the 2008 global financial crisis. We define a global systemic crisis as the result of an event originating in one area cascading into a wider macro-shock in areas that are not directly related to the origin of the crisis. A global systemic crisis affects many actors and implies the participation, interactions, and reactions of these actors within the global system. While the onset of a typical crisis is acute and rapid in its progression, it can have wave-like behaviour (e.g., the COVID-19 pandemic) and long-lasting impacts (e.g., the 2008 global financial crisis). Without a timely reaction, a systemic crisis might trigger irreversible change, as illustrated by the collapse of the Soviet Union in the early 1990s. However, it can also create the possibility of transformation of a system incurring fundamental change in its structure and goals (Folke et al., 2005; Herrfahrdt-Pähle et al., 2020). In other words, systemic crises are both one of the main threats facing humanity and an opportunity for change.

2.2 | The complex causality that leads to a systemic crisis

Systemic crises are shaped by emergent, multiple co-occurring and path-dependent causal processes in complex networks (Artime & De Domenico, 2022; Kivelä et al., 2014). A key issue is to understand how macro-dynamics emerge from micro-interactions. The classical pressure and release model provides a simplified yet relevant framework to understand the emergence of systemic events (Turner 2nd et al., 2003). These events result from interactions among hazards, exposure, broader vulnerabilities of the system, and the responses of the system (Simpson et al., 2021). Hazard events are stresses or stressors that can trigger a chain of events while vulnerabilities are pre-conditions that make systems more likely to be affected by a hazard. Interactions between hazards, exposure and broader vulnerabilities are further mediated by contextual factors (e.g., a country-specific population characteristics and institutional strengths) (Duan et al., 2022; Valdez et al., 2020). These interactions typically result in evolving interdependencies among many elements of the underlying network (Bodin et al., 2019; Stavroglou et al., 2020). Such complexity explains why vulnerabilities are sometimes hard to detect or to act upon before a systemic crisis occurs (Sugihara et al., 2012). Identifying relevant weaker or less visible interactions is particularly challenging (Granovetter, 1973). Furthermore, vulnerabilities to shocks relate to the capacities of different actors to cope with them (further discussed in Section 6). Factors that may negatively influence national capacities include low trust in public institutions (Dryzek et al., 2019), the absence of rule of law (Wiesner et al., 2018), the existence of an extractive economic and political systems (Acemoglu & Robinson, 2012), and the lack of institutional fitness (Clemens, 2013).

The study of complex networks from physical to social sciences has supported progress in our understanding of vulnerabilities in complex systems (Vespignani, 2010), including how properties such as connectivity, diversity, modularity and redundancies influence systems' behaviours (Biggs et al., 2015; Levin et al., 2013). In many areas, an increase in connectivity fosters systemic risks. However, this is not always the case as exemplified by risk sharing in financial markets (Schweitzer et al., 2009). Homogeneity and lack of redundancies, can also render the system more susceptible to disruptions, as a large proportion of elements are likely to be affected by a specific disruption (Goldin & Vogel, 2010). Typically, some weak and short perturbations can cause slight and temporary fluctuations in system performance while stronger and/or longer disruptions self-sustain a chain of events that tend to increase disruption over time. On the one hand, certain disasters are the results of natural catastrophes such as earthquakes or tsunamis (Young, 2017b). On the other hand, systemic crises are typically caused by a mild trigger event with disproportionate effects on the system. How a disruption affects the system depends not only on the nature of disruption but also on the intrinsic resilience of the system (further discussed in Section 4). The more fragile a system, the less intensity is needed for an event to trigger a chain of events that eventually leads to marked damage. In international relations, the outbreak of World War I and its subsequent devastation was triggered by a 'mild event' within an extremely fragile system (Young, 2017b). A trigger within one system can lead to synchronous failure of other interconnected systems (Homer-Dixon et al., 2015).

2.3 | Application to the COVID-19 pandemic and the 2008 global financial crisis

Both the global financial crisis of 2008 and the COVID-19 pandemic are manifestations of interactions in complex systems. The increased connectivity and density of financial networks were largely driven by the liberalization of capital markets and the development of information and communication technologies (Goldin & Vogel, 2010). The rapid spread of emerging infectious diseases such as the SARS-CoV-2 virus can also be attributed to increased connectivity (e.g., travel and trade) (Farzanegan et al., 2021; Shrestha et al., 2020). Furthermore, global environmental change and agricultural intensification have been associated with the emergence of zoonoses (Jones et al., 2013). Both systemic crises had an identifiable trigger that was localized in one place. Regarding the 2008 global financial crisis, the combination of a housing boom with a low interest rate led to increased accessibility to loans by individuals with a high default risk. The bursting of a real-estate bubble in the USA resulted in a mortgage crisis. Regarding the COVID-19 pandemic, a localized outbreak in Wuhan in China is considered as the origin of the pandemic. However, the exact origin has not been established yet.

Both crises were enabled by an accumulation of vulnerabilities. The absence of prior immunity to SARS-CoV-2 in the population was a proximal vulnerability to the COVID-19 pandemic which was compounded by aging population and high prevalence of obesity and diabetes in many parts of the world (Booth et al., 2021; Dessie & Zewotir, 2021). Unpreparedness and limited health systems capacities also made countries vulnerable to the pandemic. Regarding the 2008 global financial crisis, the lack of regulations of the market for subprime mortgage in the United States was a proximal vulnerability. Furthermore, the development of complex financial instruments (e.g., derivatives, credit default swap) led to uncertainty regarding the exposure to bad assets (Battiston, Caldarelli, et al., 2016; Haldane & May, 2011). Broader vulnerabilities were also present in both crises. Greater integration of global financial markets increased the risk that a failure of a core bank led to the default of other banks (Battiston, Farmer, et al., 2016c; Goldin & Vogel, 2010). Models did not capture these elevated risks. Regarding the COVID-19 pandemic, vulnerabilities included the social determinants of health, particularly ethnicity and socioeconomic deprivation (Upshaw et al., 2021). Finally, cultural tightness/looseness, and trust in public institutions also affected the capacity for effective response (Gelfand et al., 2021; Lenton et al., 2022).

3 | WHEN THE CRISIS UNFOLDS: THE CONSEQUENCES OF INTER CONNECTEDNESS

Complex systems can be affected by a wide range of disturbances, ranging from short-term and high intensity to long-term and mild ones. However, not every fluctuation entails a new crisis. Some sort of variability, which can take the form of oscillations, is a frequently observed behaviour of dynamical systems including social systems (e.g., economic cycles) (Turchin, 2003; Wangersky, 1978). When the system is not fragile, small disturbances do not alter its identity, and the system can recover quickly from the loss of performance (further discussed in Section 4). By contrast, major events can result in a more marked loss of performance that can be brutal and affect the stability of the system. Catastrophic failures in complex networks are due to the destruction or malfunction of a major part of its constituents (Albert et al., 2000; Cohen et al., 2001). Some powerful shocks to a complex system can even lead to a permanent loss of structure, identity, and functions (Abel et al., 2006).

3.1 | Diffusion, contagion, and cascades

Most disruptions in complex systems are driven by diffusion-like and feedback dynamics within strongly coupled networks (Böttcher, Nagler, & Herrmann, 2017; Gai & Kapadia, 2010; Haldane & May, 2011; Valdez et al., 2020). Contagion processes can be broadly classified into simple and complex contagions. In a simple contagion, a transmission process can occur if a susceptible entity is in contact with at least one contagious entity, while complex contagions require the contact to multiple 'infectious' agents (Centola, 2018). For simple contagions, the transition from a disease-free state to an endemic state is continuous (Figure 1a), meaning that small changes in the control parameter entail small

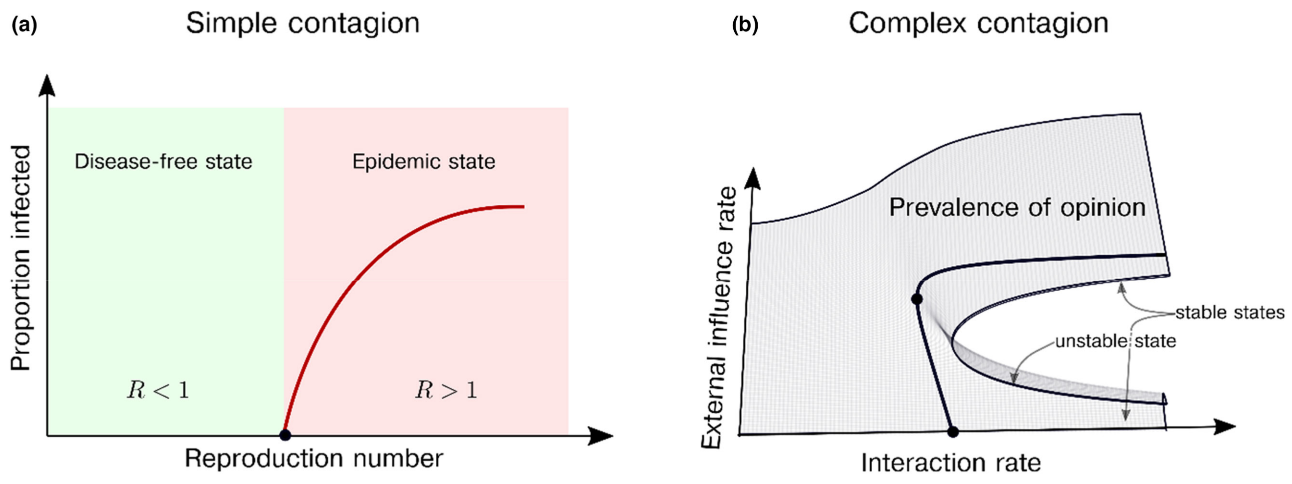

FIGURE 1 Bifurcation diagrams of simple and complex contagions.

changes in the system state. By contrast, for complex contagion processes, the bifurcation diagram is a cusp catastrophe (Figure 1b), an elementary bifurcation associated with the existence of two stable states (Zeeman, 1979). For example, the two stable states may represent populations in which one or a second, alternative, opinion is prevailing. Perturbations can lead to switching dynamics in which systems stochastically jump from one state to another one (further discussed in Section 3.2).

Certain interaction structures are prone to cascading behaviours which are large and strong amplifications of an initial perturbation. Models of cascading behaviour found that both the size of a cascade and the elapsed time between events associated with one cascade follow a power-law distribution and are difficult to predict and contain (Bak et al., 1987; Watts, 2002). Cascading behaviour has been observed in different contexts, including power-grid failures (Buldyrev et al., 2010; Yang et al., 2017), ecological disruptions (Kinzig et al., 2006), flash crashes in financial markets, and the rapid formation of political or ideological movements (Hale, 2013). In online social networks, information cascades are connected to viral social media posts and the spread of trending topics. The misuse of online media platforms to spread misinformation and potentially to manipulate the electorate can undermine public discourse and democracy (Aral & Eckles, 2019; Morgan, 2018). The topology (i.e., the network structure) and strength of interactions of an interdependent network are major factors that make cascades possible (Barrat et al., 2008; Vespignani, 2012). In multi-layered networks, the failure of a small proportion of nodes in one network may lead to its complete fragmentation (Buldyrev et al., 2010) with major implications for highly connected international systems such as the power grid, internet (Tu, 2000), trade (Wang et al., 2016), and transportation (Barrett et al., 2012).

3.2 | Regime shift and collapse

Being in a state of dynamic equilibrium, complex systems may be able to withstand perturbations and revert to their initial 'normal' state. However, some perturbations may lead to a new state (Gunderson & Holling, 2001; Holling, 1973). In physics, cooling down water below zero degrees Celsius at atmospheric pressure does not result in cooler water, but in a new phase, ice, which has completely different properties than water. Similarly, systemic crises can trigger regime shifts in social systems which portray a major change in a system's feedback dynamics and behaviour resulting in a 'new normal'. Historical evidence suggests that crises can precipitate an abrupt transition from democracy to authoritarianism and vice versa (Hale, 2013). Tipping points describe how a relatively small event can precipitate disproportionate change in the system itself. A tipping point is generally associated with some forms of irreversibility in the underlying dynamics which is often referred to as 'hysteresis' or 'path-dependence'. Tipping points have been identified in the change of social convention and other social phenomena (Centola et al., 2018; Scheffer, 2010) suggesting that minority groups within a population can foster social change dynamics. An understanding of these dynamics may help policymakers communicate more effectively in times of crisis (Centola, 2010).

If not managed appropriately, systemic crises may have long-term impacts and even lead to the collapse of some parts of the economy, social systems, and society. Collapse can be considered as an abrupt regime shift at which point the identity of a system is lost (Abel et al., 2006; Sato & Lindenmayer, 2018). Along with a loss of identity and capital, the notion of collapse emphasizes a breakdown that occurs relatively rapidly and is accompanied by a series of undesirable or destructive events (Cumming & Peterson, 2017). In history, societal collapse has often been the result of a powerful external shock to a system (e.g., the collapse of the Maya civilization) (Toynbee & Somervell, 1987a, 1987b), but more complex mechanisms may be at play. For example, the disintegration of the Roman empire is often related to barbaric invasions from other parts of Europe or the East, but environmental challenges and diseases may also have played a fundamental role (Harper, 2017). Collapse can derive from the incapacity of a given civilization to tackle the challenges that it creates itself. By becoming more complex, societies create new risks, requiring an ever-increasing need for 'energy' to address associated side-effects (Tainter, 1988). The Wall Street Crash of 1929 and the Great Depression that ensued (Young, 2017b) are striking examples of the inability of societies to manage these side-effects. From a global sustainability perspective, collapse can result from the failure of a society to manage its ever-increasing complexity while preserving the natural resources it needs to persist. In 1972, 'limits to growth' theory predicted that humanity would surpass the planetary boundaries and end up in a dangerous societal crisis in the next 100 years (Meadows et al., 1972). The crossing of planetary boundaries (Rockström et al., 2009; Steffen et al., 2015) increases the risk of interdependent regimes shift in social ecological systems (Rocha et al., 2018). Globally, it has been suggested that the Earth system may be approaching a planetary threshold that could facilitate rapid pathways towards much hotter conditions and extreme climate risks (Armstrong McKay et al., 2022; Kemp et al., 2022; Steffen et al., 2018).

3.3 | Application to the COVID-19 pandemic and the 2008 global financial crisis

Both the 2008 global financial crisis and the COVID-19 pandemic are associated with non-linear dynamics. Direct contagion is the primary diffusion mechanism of viruses. Superspreading events accelerated the spread of the COVID-19 pandemic (Nielsen et al., 2021). In addition, complex social contagion of infodemics and disinformation also amplified the COVID-19 pandemic, leading to duelling contagion processes (Cinelli et al., 2020; Fu et al., 2017), but it remains debated whether infodemics have reduced adherence to public health measures and increased vaccine hesitancy (Loomba et al., 2021; Valensise et al., 2021). In the case of the 2008 global financial crisis, the collapse of Lehman Brothers led to a rapid contagion of uncertainty in interbank markets due to financial liabilities (Schweitzer et al., 2009). Limited available information about exposure of different banks amplified fear among investors. As a result, financial institutions stopped lending money to each other, causing a massive liquidity crisis in the interbank market.

The high network connectivity during both the 2008 global financial crisis and the COVID-19 pandemic allowed for rapid cascading societal effects. During the 2008 global financial crisis, cascading failures resulted from discontinuous changes in asset values which in turn triggered further failures (Elliott et al., 2014). The initial default of a banking institution reduced the 'credit worthiness' of all institutions in the interbank market (Sieczka et al., 2011). Cascade insolvencies amplified uncertainty about the financial health of different firms in the real economy. High uncertainty severely impacted the capacity of firms to borrow money and led to panic selling in stock markets (Jackson & Pernoud, 2021). National economies were impacted in various ways, including a surging level of both unemployment and household debt (Romer & Romer, 2017). Regarding COVID-19, the nature of the pandemic and the associated responses generated cascading effects across health, economic, social, environmental and governance systems. As of January 2023, the number of reported COVID-19 fatalities is approaching 7 million. Furthermore, many more people have been affected by the disease, experiencing short as well as longer-term effects (Michelen et al., 2021). The COVID-19 pandemic and associated responses have also decreased the provision of essential health services and quality of care and have strongly impacted mental health (Arsenault et al., 2022; Pai et al., 2022). After an acute phase at its onset in 2020, the COVID-19 pandemic has morphed into a more slowly developing health, social and economic crisis punctuated by several epidemic waves in different countries (Peleg et al., 2021).

A threshold was crossed when the initially localized epidemic of COVID-19 became a pandemic through an exponential surge of cases worldwide. Controlling the outbreak usually came at the price of closing national borders (Lee et al., 2021) and shifting to an altered mode of societal functioning, implying limited in-person interactions (Wernli, Tediosi, et al., 2021). Financial crises can also be considered as a (transitory) regime shift (Hamilton, 2016), where investors behave in a different ways than in normal times (Hubrich & Tetlow, 2015). Both crises were followed by a return to more normal conditions. Regarding the COVID-19 pandemic, effective vaccines helped return to 'normal life' in many countries by 2022. However, the long-term impact of the COVID-19 pandemic and associated responses on the economy, education, fundamental rights, and democratic functioning is not yet fully understood (The British Academy, 2021). Regarding the global financial crisis of 2008, many countries recovered but some did not find themselves on the same trajectory of pre-crisis growth several years after its onset (Fatás & Summers, 2016; Furlanetto et al., 2021; Romer & Romer, 2017). Furthermore, the economic crisis and austerity policy that followed the global financial crisis of 2008 had long-term social and health impacts across

Europe (Mckee & Stuckler, 2016; Stuckler et al., 2017; Suhrcke et al., 2011).

Finally, although several sectors encountered strong disruptions, neither crisis resulted in a complete system collapse due to the capacities of societies to face disruptions (see Sections 4–6 below). Some banking institutions and firms (e.g., Lehman Brothers, American International Group) collapsed (Johnson & Mamun, 2012), showing the fragility of the global financial network (Battiston, Delli Gatti, et al., 2012). However, this did not cause the collapse of the entire system thanks to timely bailout of financial institutions that were deemed too big to fail and further interventions from governments and central banks (Battiston, Puliga, et al., 2012). In the case of COVID-19, health systems have faced increased pressure and, in some countries, failed both to respond to COVID-19 patients' needs and to maintain the provision of essential health services (Arsenault et al., 2022; Silva & Pena, 2021). Some health systems continue to be strongly impacted by the COVID-19 pandemic but the question of whether the pandemic will have a long-term impact on their performance remains open.

4 | HOW COMPLEX SYSTEMS FACE DISRUPTIONS

Societies usually exhibit capacities, either as an actual ability or as a potential one, to face shocks. Many small-scale disruptions are absorbed by the system and require limited governmental interventions. By contrast, larger disruptions may require more deliberate and coordinated responses. Resilience has been used as an umbrella concept that captures systems' capacities to absorb, adapt and transform (Fraccascia et al., 2018; Quinlan et al., 2015). These three core capacities refer to the increasing level of change that a system undergoes because of a disturbance. While absorbability aims at maintaining existing processes and functions, adaptivity and transformability may imply more extensive systems change. Enhancing absorptive capacities may come at the price of reduced adaptive and transformative capacities and vice-versa. Balancing these capacities is a critical challenge in the design of complex systems (Alderson & Doyle, 2010; Levin et al., 2013).

4.1 | From resilience capacities to the properties of complex systems

A recent review found adaptability, agility, reliability, resilience, resistance, robustness, safety, security, and sustainability to be concepts that are often used to characterize systems facing threats (Galaitsi et al., 2021). These concepts are best understood in terms of the temporal evolution of system performance in the face of disturbances (Grafton et al., 2019). At the onset of a disruption, a robust system is likely to continue working at its original level of performance. By contrast, 'resistance' determines the peak value of the disruption on the system. The performance of a highly resistant system will be less affected than that of a system with low resistance. Another important resilience measure is the extent and the speed of recovery. The dynamic character of these capacities means that "*past failures are due to fragilities that were direct side effects of mechanisms that promised to provide great benefits, including robustness*" (Alderson & Doyle, 2010).

What makes complex systems resilient to cascading failures depends on the topology of the underlying network (Böttcher, Nagler, & Herrmann, 2017; Centola, 2010; Centola et al., 2018; Gao et al., 2016; Lorenz et al., 2009; Valdez et al., 2020). Network topology is especially important in situations where overload is the primary mechanism of cascading behaviour such as in many infrastructure systems (Motter & Lai, 2002; Ronellenfitsch & Katifori, 2016; Valdez et al., 2020). Robustness derives from key features of the network such as diversity, modularity and redundancy which in turn affect the emergence of difficult to control feedback loops (Levin, 1999). Increasing connectivity can provide more rapid diffusion of information flows within a network but it might also increase the risk of overload (as discussed in Section 3). Similarly, the 'robust yet fragile effect' describes situations where risk sharing increases the robustness of a system while the system remains fragile to rapid contagion (Gai & Kapadia, 2010; Jackson & Pernoud, 2021). There is a growing interest of using these insights to foster absorptive, adaptive and recovery capacities (Böttcher, Luković, et al., 2017; Di Muro et al., 2016; Gai & Kapadia, 2010; Korkali et al., 2017; Naqvi & Monasterolo, 2021; Smolyak et al., 2020; Yuan et al., 2017; Zhong et al., 2019) which are further discussed in Sections 5 and 6.

4.2 | Disentangling resilience capacities

Resilience is often considered as a positive attribute of a system. However, resilience may also imply challenges in moving away from a societally non-desirable situation. For example, the use of fossil fuels in transportation has so far proven resilient to the emergence of new technologies. Some situations are traps (or absorbing states) from which it is difficult to escape (Young, 2021). In global governance, this phenomenon is perhaps best known as gridlock (Hale et al., 2013; Hale & Held, 2017). Hence, there is a need for considering power relations and political agendas of different actors when studying resilience (Béné et al., 2014; Joseph, 2013; Mikulewicz, 2019). Because societies are composed of agents with different goals and interests, understanding resilience's capacities always requires examining: (1) the capacity of whom/what (e.g., stakeholders or existing regimes), (2) capacity to withstand what (e.g., disruption or phenomenon), and (3) capacity for whom (i.e., who benefits and loses from those capacities) (Carpenter et al., 2001; Topp, 2020).

Societal resilience can result from both the inbuilt properties of the underlying network and from deliberate actions by agents to react to and recover from shocks (Hynes et al., 2022). Deliberate actions by governments are often the central interest of policy studies, but a complexity lens suggests that policies can have a limited impact if the context is particularly fragile (see the discussion about complex causality in Section 2.2). Conversely, many agents from an individual to an organization support the overall societal capacities to face a shock (Ungar, 2021). From a political philosophy perspective, one can ask who has the main responsibility for resilience (Welsh, 2014). For example, a neoliberal perspective may substantially shift the responsibility of being resilient from governments onto individuals and communities, and give more power to the private sector (Joseph, 2013).

The type of capacities also matters (Fraccascia et al., 2018). In times of crises, some stakeholders, who benefit from the system, may focus on the capacity to absorb the shock, and come back to the same state (recovery) which is often measured by a few indicators (e.g., GDP in the case of the economy). When the system is no longer viable due to marked changes in its operating condition, the capacity to persist after a shock can only derive from transformation of the system. Transformation is often underpinned by a fundamental change in mental models, actions, and resources (Herrfahrdt-Pähle et al., 2020; Westley et al., 2013). Inversely, a lack of transformability implies a reduced capacity to deal with change – especially dramatic, fast, and unexpected change. Focusing on the capacity to recover from shocks can neglect the capacity to prevent and to anticipate shocks leading to inaction. Furthermore, a narrow definition of recovery might prioritize a return to the 'normal conditions' (Martin & Sunley, 2014) to the detriment of adaptation or transformation, even when 'normal conditions' are suboptimal or not desirable for most of the population.

4.3 | Application to the COVID-19 pandemic and the 2008 global financial crisis

Both the COVID-19 pandemic and the 2008 global financial crisis tested the capacities of societies to face a shock. In both cases, a primary source of resilience was the capacity to manage connectivity. As one of the most important manifestations of the 2008 global financial crisis was a paralysis of financial flows, resilience originated from the capacity to restore trust and connectivity (Section 5 discusses the nature of interventions adopted). By contrast, resilience to the COVID-19 pandemic originated from the capacity to absorb increased demand for intensive care (Haldane et al., 2021). However, because public health and healthcare systems were not prepared to a shock of the magnitude of the COVID-19 pandemic, resilience came from the adoption of timely countermeasures that aimed at controlling in-person interactions.

While both crises underline the capacities of financial systems and health systems as the respective first line of defence, resilience ultimately depended on the capacities of different actors across systems. During the 2008 global financial crisis, governmental and central bank interventions kept the financial system and the economy afloat. Actions by governments were also critical during the COVID-19 pandemic. A 'zero COVID-19' strategy allowed some countries (e.g., China and Australia) to continue live in a 'normal' state while vaccines were not readily available in 2020–2021. This strategy was effective in countries where connectivity to other countries was more easily controlled than other countries. In contrast, a 'living with COVID-19' suppression strategy resulted in an altered state characterized by societal disruptions, limited social interactions, and reduced individual freedom (Wernli, Tediosi, et al., 2021). In both systemic crises, resilience was expressed in different systems (e.g., food, trade) and the source of resilience in these different systems were multiple and included innovation, technologies, and financial capacities (Wernli, Clausin, et al., 2021). The expression of capacities by interventions also depended much on politics and political will as it was clear during the COVID-19 pandemic.

Both the COVID-19 pandemic and the 2008 global financial crisis demonstrated the tension between the resilience of the current institutional arrangements (going back to 'normal' quickly) versus the narrative of transformation that addresses the root causes of both crises. Assessment of the origin of the 2008 global financial crisis identified the fact that financial institutions' investment decisions have externalities that they do not internalize. As banking institutions are 'too connected to fail', they can be expected to be bailed out (Goldin & Vogel, 2010), This situation increases the risk of moral hazard (Battiston, Farmer, et al., 2016c; Battiston, Puliga, et al., 2012). Despite the adoption of micro- and macroprudential policies and regional change (e.g., in the framework of the European Union Banking Union), the global financial architecture has not been fundamentally reformed (Schwarcz, 2019). A similar situation prevails regarding the COVID-19 pandemic. The pandemic has accelerated pre-existing societal trends such as remote working and green transportation as well as reforms of health systems (Bali et al., 2022).

Several calls have been issued for 'building back better' that would encompass both a broad political economy shift in the context of rising environmental risks (Singh et al., 2021) but they have not materialized. While transformation crucially depends on multilateralism (Sachs et al., 2022), international collaboration is hampered by major geopolitical tensions (Jones & Hameiri, 2022).

5 | IMPLICATIONS FOR GLOBAL POLICYMAKING

Systemic crises are difficult to manage, let alone to control. Once they have been triggered, disproportionate efforts are needed to tame their effects. Conventional policy approaches focusing on stability and/or efficiency are not designed to respond to systemic crises (Peters et al., 2019). Global policymaking to prevent, react to and recover from systemic crises relates to the capacity to understand and address key characteristics of complex systems (Biggs et al., 2012; Galaz, 2019; Linkov & Trump, 2019). The insights gained in the study of systemic risks/crises in different areas not only emphasize the relevance of different tools and strategies from regulations to incentives, but also show the importance of adopting a multi-stage response approach.

5.1 | Preventing capacities

When it comes to preventing systemic crises, a first aspect is risk assessment. Conventional approaches to risk assessment often fail to identify systemic risks because they do not integrate the behaviour of complex systems and the mechanisms that can generate vulnerabilities and cascading effects (Frank et al., 2014; Linkov & Trump, 2019; Schweitzer et al., 2009). Risk assessment should be coupled with resilience assessment using a tiered approach to increase resource, data collection and model complexity (Linkov et al., 2018). An important challenge is the integration of meaningful assessments of vulnerabilities at the country, regional, and global levels. The second aspect is risk management. One can distinguish two types of preventive actions. The first comprises all actions that seek to achieve a reduction in the emergence of systemic risks. 'Primary prevention' is challenging because some vulnerabilities derive from the very way the world is interconnected. In other words, addressing the root causes of systemic crises is likely to require transformation in socio-technical systems (e.g., more sustainable food production systems in the case of emerging infectious diseases). While recognizing that root causes can be challenging to address, the second kind of preventive measures are those policies that make individual nodes and the overall network less vulnerable to shocks (see Section 4.2) (Guillén, 2015). In many areas of society, reserve capacities such as buffers, redundancies, and insurances can improve a system's capacity to face disruptions. The critical question is then the short-term versus long-term cost/effectiveness of providing a higher level of reserve capacities in systems that have primarily been designed to maximize short-term efficiency.

5.2 | Reactive capacities

The dynamic behaviour of complex social systems, including the fact that agents constantly adapt to new situations (Ruhl, 2019), creates multiple ways for systemic risks to emerge. An understanding of complex systems draws attention to the fact that is not possible to anticipate every possible threat. Moreover, it may be prohibitively costly and not efficient to seek to prevent all potential threats. At the same time, delayed reaction to emerging cascades can be also excessively costly. These two constraints create an early and short window of opportunity for rapid and bold actions where cost-effectiveness is the highest. This window of opportunity translates into the goal of preventing a disruptive event from spiralling out of control at the stage when it is still localized. The capacity to react quickly is even more important when an irreversible tipping point may be crossed.

As time is the essence, the main issue is the ability to identify a developing systemic crisis in the first place. Improving detection of early warning signals of a looming crisis can help respond in a timely manner (Battiston, Caldarelli, et al., 2016; Dakos et al., 2015; Scheffer et al., 2009, 2012), but the lack of timely accessible information is a major obstacle (Battiston, Farmer, et al., 2016b). In the global arena, states may have disincentives to reporting of health events, as already observed during outbreaks of emerging infectious diseases (Gostin et al., 2017). The identification of a threat should, in turn, trigger rapid countermeasures. Preparedness is a well-known step in disaster management that involves building the capacity for rapid mobilization of resources such as an 'emergency workforce'. A good example of current efforts is the Public Health and Emergency Workforce Roadmap developed by the World Health Organization and partners (Mosam et al., 2022). Because the most urgent issue is connectivity, countermeasures may result in the activation of 'circuit breakers' that reduce contagion (e.g., a lockdown that buys some time in case of a pandemic or temporary measures that halt trading to curb panic selling in financial markets) (Ren et al., 2019).

In absence of effective responses in the early phase of a developing systemic crisis, cascading effects are likely to emerge and crisis management shifts to costly mitigation strategies. Classically, crisis management has focused on bringing the situation under control whatever the costs (this was the strategy of most countries during the first wave of the COVID-19 pandemic). However mitigation strategies usually affect many economic sectors and amplify the risk of unintended consequences of purposive action (Merton, 1936). Evaluating trade-off between the intended effects of a policy and its unintended consequences becomes a core concern (see Section 6). It may also be in this phase that (in-)actions and communication about a problem can result in path-dependence where the costs of taking one action reinforce the need for further actions or make a change of trajectory costly (e.g., changing mask mandate policies after the first wave of the COVID-19 pandemic) (Bardosh et al., 2022).

5.3 | Recovery capacities

Contagion and diffusion in complex systems means that a disruption can exhibit exponential growth and can rapidly reach a peak. This is usually followed by a phase of recovery which can be quick or slow, partial, or complete. The recovery of complex systems is associated with processes of reconstruction such as restoring connectivity, reorganization, and the replacement of some capacities. Modelling studies have shown that repairing a few nodes in a network might halt a cascading failure and help the system recover. Support to the most affected areas and population are essential as not all people may be affected in the same way by a systemic crisis, potentially amplifying pre-existing socio-economic inequalities (Sachs et al., 2022). Compared to natural disasters which usually impact a limited geographical region, the shift of resources from non-affected regions is more challenging, as the entire world can be affected by a global systemic crisis. Urgent efforts to restore system performance may compete with broader efforts at transformation which usually require ambitious policies and social tipping (Otto et al., 2020).

5.4 | Application to the COVID-19 pandemic and the 2008 global financial crisis

The lack of preventive capacities increased the risks of the emergence of both systemic crises. Against the background of the deregulation of financial markets, international institutions were not prepared to respond to the 2008 global financial crisis (Claessens & Kodres, 2014). The economic framework was not able to anticipate the financial crisis and rating agencies failed to provide an accurate assessment of the situation. There were insufficient monitoring mechanisms as well as micro- and macroprudential regulations before the 2008 global financial crisis. Regarding the COVID-19 pandemic, emerging infectious diseases were identified as one of the main threats to global health security in the 1990s and led to the reform of the International Health Regulations in 2005 (Davies et al., 2015; Fidler & Gostin, 2006). However, the evaluation of pandemic preparedness capacities has not reflected how countries have been affected by the COVID-19 pandemic (Abbey et al., 2020). Investments in national health systems were identified as a key component of preventive resilience but not given enough attention (Sands et al., 2016). High societal costs and long-term impacts of both the COVID-19 pandemic and 2008 the global financial crisis have re-emphasized the need for better prevention of systemic crises. Preventive strategies to avoid global cascading effects therefore require national preparedness efforts, as well as the strengthening of the capacities of international institutions and instruments.

Because of insufficient preventive capacities, massive and unconventional governmental actions were adopted reactively. Regarding the 2008 global financial crisis and, by contrast to the 1920–30s, countries were quick to prevent the collapse of the financial system. In the United States, the Emergency Economic Stabilization Act of 2008 set up a $700 billion Trouble Asset Relief Program to purchase toxic assets from banks. Different mechanisms such as economic packages, guarantees of bank deposits, and the buying of toxic debt were used to inject several trillion US$ in the economy. The large governmental support increased the debt-to-GDP ratio in many advanced economies. Regarding the COVID-19 pandemic, reactions first led to border closure and the widespread adoption of public health countermeasures (e.g., social distancing, testing etc.). However, the societal costs associated with some 'circuit breakers' such as lockdown measures have shown their limitations as they can hardly be used repeatedly (Lewis, 2022). Additional economic measures were adopted in many countries to support the most affected economic sectors. The World Health Organization initially played a prominent international coordination role but was later caught in geopolitical tensions between the United States of America and China (Jones & Hameiri, 2022). Overall, negative multisystemic impacts still arose during both systemic crises and required governmental interventions to provide a safety net for citizens and businesses. These responses were largely effective in preventing further escalation of both systemic crises but came at high economic and societal costs. Furthermore, efforts to tackle the 2008 global financial crisis and the COVID-19 pandemic may be diverting resources from tackling global environmental change and ultimately favouring the emergence of a new systemic crisis (Hendriks et al., 2022).

Recovery capacities proved to be unequal across regions, pointing to the pre-existing vulnerabilities of some regions (e.g., Europe regarding the Eurozone governance) to the shock but also suboptimal capacities for recovery in both situations. Regarding the 2008 global financial crisis, some countries recovered quickly while some EU countries had a slow recovery in the context of the subsequent Euro crisis. Unconventional monetary policies such as negative interest rate and quantitative easing were used to stimulate the economy (Haynes, 2015). The use of this expansionary monetary policy for a long time may make harder for central banks to quickly tighten monetary policy in the current situation of rising inflation (Beckmann et al., 2022). Regarding the COVID-19 pandemic, the rapid manufacturing and distribution of vaccines supported by governments led to a rapid immunization of the population and return to normalcy, particularly in high-income countries. Several countries implemented a temporary 'vaccine pass' to incentivize immunization among the population. However, the lack of sharing of vaccines across the world has impacted global recovery (Hunter et al., 2022). Some countries that were considered as successful in the beginning of the pandemic but kept their 'zero COVID' policy experienced unrest, demonstrating the importance of adaptive governance in facing a systemic crisis.

6 | THE IMPORTANCE OF GOVERNANCE DESIGN

Addressing systemic crises requires a governance system that supports the timely design, adoption, implementation, and evaluation of policies discussed in Section 5 (Cosens et al., 2020). But the core features of systemic crises are different from the central assumptions of simplicity, controllability, and predictability on which the techno-rational order is founded (Geyer & Rihani, 2010; Harrison & Geyer, 2021). A growing scholarship has emerged around forms of governance that seeks to manage complex systems (Galaz, 2019; Oberthür & Stokke, 2011; Pegram & Kreienkamp, 2019; Young, 2017a). This literature has demonstrated that a lack of understanding of the properties of complex systems and their implications in a globalized society have been major obstacles to address the most pressing global challenges. Insights from the study of the governance of complex systems suggests emerging principles to strengthen institutional fit, i.e., how the governance system is designed to effectively prevent, react to, and recover from global systemic crises (Clark & Harley, 2020; Young, 2017a).

6.1 | Approach to governance: Top-down versus bottom-up governance

The fact that resilience capacities cannot only come from specific interventions but also from the design of systems and institutions (Hynes et al., 2022) emphasizes the complementarity between top-down and bottom-up approaches to governance. A centralized command-and-control strategy may be critical for rapid reaction at the onset of a systemic crisis (resilience by interventions) to counterbalance positive feedback. When the situation gets out of control, it can be supported by a state of emergency that suspends normal functions of government and some civil liberties. However, the adoption of a state of emergency may also signal a lack of resilience by design and may impact long-term societal resilience which depends on complex interactions of many stakeholders in society (Ungar, 2021; Wernli, Clausin, et al., 2021). This suggests that the construction of more participative, inclusive – and thus legitimate – governance systems is required over the long-term as diversity can improve capacities for problem solving and innovation (i.e., resilience by design) (Biggs et al., 2012; Cox, 2016; Helbing, 2021; Page, 2017). These capacities are particularly important for recovery and prevention of further systemic crises.

Governing systemic crises implies rapid shifts in governance modes from urgent top-down actions to more participative processes when the situation allows (Young, 2017a). The question of shifting between governance modes also relates to the perceived legitimacy and proportionality of the response over time. Put differently, the governance of systemic crises requires inevitably careful processes to address trade-offs between sectors and scales with large distributional impact on the population (Biggs, Clements, et al., 2021). Frequent disagreement on the nature of the problem itself makes things more challenging (Rittel & Webber, 1973). When a systemic crisis affects fundamental rights and freedoms and prevents the mechanisms for deliberation and collective decision-making that underpin the functioning of democratic systems, the resulting democratic deficit may impact the long-term effectiveness of the response (Parry et al., 2021).

6.2 | Collective action: From discernible loci of control to governing across boundaries

Global systemic crises transcend multiple jurisdictions (Ruhl, 2019), but the current world order rests on the principle of equal sovereignty of nation states. This international anarchical system places the primary responsibility for action at the national level. Similarly, the capacities and competencies of addressing societal issues are classically divided into sectors such as health, trade etc. The national and sectoral levels are the primary foci of the techno-rational order to assert control over a rapidly expanding systemic crisis (Guillén, 2015). While compartmentalized action is often successful, it may not only result in unintended consequences in a highly interconnected system but also reduce global effectiveness as actions taken by other countries and sectors affect the whole system in a non-coherent/coordinated manner (Peters et al., 2019). Hence, transboundary crises management capacities "*also require institutions that facilitate prompt collective action during rapid, surprising and cascading shocks*" (Galaz et al., 2017). The literature on regime complexity has shown that interorganizational collaboration and polycentric governance systems can be effective in managing interdependencies between sectors (Alter, 2022; Gómez-Mera, 2021; Oberthür & Stokke, 2011; Ostrom, 2010; Thiel et al., 2019). However, enduring challenges of designing effective mechanisms for global collective action may be exacerbated in time of crisis given countries' reflex of turning inwards, high transaction costs and incentives to freeride on the efforts of others.

The aggregator technology, which describes how contributions of individual countries lead to the overall level of a global public good, can guide the formulation of policy recommendations (Barrett, 2010; Buchholz & Sandler, 2021; Sandler, 2020). For instance, the surveillance of COVID-19 outbreaks and the achievement of herd immunity both fall into the *weakest link* aggregator type where the smallest contribution determines the overall outcome. Finding a vaccine, another global response to the pandemic is best described as a *best shot (*i.e., the greatest contribution determines the overall level of the provision of a global public good) and requires a different form of international cooperation. In this setting, the public policy recommendation arising from the literature is twofold: (1) (multilateral) efforts and resources should be focused on the most capable countries and (2) coordination should be implemented to avoid duplication unless competition may increase success likelihood.

6.3 | Learning for managing co-evolution: From information to experimentation

The process of acquiring new knowledge and insights is critical to the management of complex systems but the disconnect between science and policy is an enduring challenge to the integration of scientific knowledge into effective public policy (Cosens et al., 2021; Ruhl, 2019). Grounding policy in the best available scientific knowledge can be even more challenging in times of systemic crises than in normal times. While science is often ambiguous at the onset of a systemic crisis, a first issue is to identify relevant and high-quality evidence and information for decision-making. Hence the need to leverage multiple sources of evidence (Shea et al., 2020). Transdisciplinary science-policy-society-interfaces, where both evidence and uncertainty can be effectively communicated, can help identify the most effective interventions. A second issue is the dynamic and unpredictable nature of systemic crises which require one to frequently adapt the course of action depending on the effectiveness of earlier decisions. Addressing systemic crises often requires unconventional actions but policy experimentation is challenging in situations that are getting out of control because of the time delay between decision, their implementation, and their measurable effects (Sterman, 2006). Such situations may lead to under- or overreaction in the face of non-linear phenomena. A third issue is thus how to deal with failure. Considering failure as an opportunity for learning is central to a complexity approach (Chandler, 2014; Chapman, 2004). Failure not only originates from incomplete information but also from the adaptation of agents to new rules and policies. A policy that constrains the behaviour of individuals might be initially effective but lose its effectiveness with time as people find ways to circumvent the rules. Adaptation to rules and policies ultimately stresses the importance of co-evolution in addressing systemic crises, i.e., the mutual influence of the governance system and the system to be regulated on each other (Ruhl, 2016; Søgaard Jørgensen et al., 2020).

6.4 | Instruments and mechanisms: Formal versus informal governance to tip positive change

Responses to systemic crises tend to elicit command and control strategies based on governmental interventions (see Section 6.1 above), but informal mechanisms such as social norms and expectations can be instrumental in changing the behaviour of a social system. A first challenge to the use of formal instruments arises at the international level. While the dynamic nature of systemic crises requires rapid action, international law is slow to change (Gostin & Katz, 2016). The risk of mismatch between responses and issues explains the increasing development of soft law in global governance to adapt to constantly evolving global challenges (Young, 2017b). Limitations regarding the effectiveness of command-and-control strategies also exist at the national level. The capacity to enforce adopted rules by threat of penalties is often what makes citizens abide to rules that hinder fundamental rights and freedoms. While sometimes necessary at early phases of responses, governance 'by fear' can be costly and counterproductive especially when rules seem to be arbitrary and inconsistent (Kooiman, 2003). Governance is more likely to be effective when the population understands the decision, finds it proportionate to the situation, and trusts the government (Lenton et al., 2022). All three factors underline the significance of the provision of reliable information to the public. However, a general lack of understanding regarding complex systems may lead to a simplistic narrative (Peters et al., 2019). Developing literacy on complex systems and their behaviour may improve communication of complex issues to the public (Ruhl, 2019). Furthermore, low trust in government associated with polarization in several countries (OECD, 2022; Turchin, 2016a; Vallier, 2021) may both complicate the communication in times of systemic crisis and be exacerbated by them. Overall, the limitations of regulatory approaches suggest that responses to systemic crises should also rely on social norms to tip positive change (Lenton, 2020; Nyborg et al., 2016). Norms can shift quickly when a shock occurs providing a powerful self-regulating societal mechanism.

6.5 | Application to the COVID-19 pandemic and the 2008 global financial crisis

The weaknesses of international institutions, such as the limited effectiveness of the International Health Regulations (2005) regarding the COVID-19 pandemic or "*the absence of a global rule-making authority to oversee global private financial institutions and processes*" (Goldin & Vogel, 2010) regarding the 2008 global financial crisis favoured the emergence of both systemic crises. Given these governance gaps, both systemic crises showed the need for top-down governance at the national level when the situation got out of control. Top-down governance was critical not only to address issues in the respective sector of origin of each systemic crisis but also to massively support the economy. The response to the COVID-19 pandemic relied on an escalation of the top-down approach with the adoption of 'state of emergency' in many countries. The state of emergency supported a pre-existing trend of strengthening the executive power and tested democratic resilience in many countries (Guasti, 2020; Youngs, 2022). Yet, as discussed in previous sections, both crises also showed the limitations of top-down governance as a solution to a crisis lasting several years. For example, contestation of mask mandate and mandatory immunization arose in several countries during the COVID-19 pandemic.

Since the response was primarily orchestrated from a national/sectoral perspective, collective action became a dominant problem across countries and sectors with difficulties to agree on common solutions even when they existed (e.g., vaccines in the case of the COVID-19 pandemic). Nonetheless, several adaptations took place at the global level with a shift from the G7/G8 to the G20, as the main global forum for financial issues, after the 2008 global financial crisis. The most relevant reform in the banking sector was the adoption of the 'Basel III Regulation' set of measures and minimal requirements which aim to strengthen the regulation, supervision, and risk management of banks (Allen et al., 2012). Regarding the COVID-19 pandemic, the World Health Organization member states have been negotiating a global treaty on pandemic prevention, preparedness, and response (Phelan & Carlson, 2022). While multilateral negotiations are ongoing, a key issue is to depart from a focus on reactive capacities in human health to adopt a One Health approach which include primary prevention of pandemic of animal origin (Bernstein et al., 2022; Ruckert et al., 2021).

Third, though learning has been at center stage of both systemic crises, the mechanisms adopted in the wake of each crisis show a lack of a complex systems perspective to understand the implications of different decisions over both the short-term and long-term. The COVID-19 pandemic showed the importance of science as the most reliable source of evidence. Foremost, the rapid evolution of the pandemic has necessitated the rapid development of learning mechanisms that synthesize evidence to policymakers. In many countries the governance of the COVID-19 pandemic relied on an epidemiological task force (Yin et al., 2021) but failed to integrate broader source of knowledge and disciplines (Rajan et al., 2020). A simplistic narrative was conveyed at the onset of the COVID-19 pandemic when the first wave was presented as a single event (and not as the first of recurring waves that have characterized previous pandemics). Regarding the 2008 global financial crisis, the recognized failure to predict it resulted in an effort to improve evaluation of systemic risks including the development of stress test (Bisias et al., 2012; Hartwig et al., 2021). Several institutions have integrated the evaluation of systemic risks (e.g., the global systemically important banks), but a recent review showed that most methods developed to assess systemic risks focus *"on individual financial institutions rather than on system stability"* (Ellis et al., 2022).

Fourth, formal and informal instruments were mobilized during both systemic crises. Regarding the 2008 global financial crisis (Claessens & Kodres, 2014), micro-prudential regulations were adopted to strengthen the capacity of individual financial institutions (Ellis et al., 2022) and to ensure a safe and orderly resolution in case of bankruptcy. Regional measures were taken to integrate systemic assessment of risks in the banking sector. Finally, budgetary rules concerning public debts and deficits were enacted or reinforced. At the onset of the COVID-19 pandemic, many governments enacted stringent regulations implying limitations on freedom of movement, freedom of trade, freedom of association, and the right to education, often at the expense of the legislative branch. In addition to regulations, many governments and international organizations step up their capacity to provide information in the context of large misinformation (Osborne & Pimentel, 2022). Some countries further used (dis)-incentives to increase the rate of vaccination (Campos-Mercade et al., 2021). Finally, social norms also played a key role in slowing down transmission during the COVID-19 pandemic, especially in countries where countermeasures were not mandatory.

7 | CONCLUSION

The complexity-based framework presented in this article contributes to a better understanding of the mechanisms underlying systemic crises and their implications for governance and policymaking. The application of the framework to the 2008 global financial crisis and the COVID-19 pandemic reveals that they both share fundamental properties of complex systems. First, the interplay between excess versus insufficient connectivity is associated with the emergence and dynamics of global systemic crises. Second, different types of non-linear contagion dynamics can turn perturbations of a seemingly functional system into cascades that cause global disruptions. Controlling such failure cascades is difficult and costly because of their non-linear nature. Third, both systemic crises underline the importance of building capacity to face shocks either by design or interventions. Fourth, these capacities can in turn support preventive, reactive, and recovery processes. While all three processes matter, both systemic crises demonstrated the prohibitive costs associated with relying on recovery resilience by governmental intervention after a crisis erupted. While these rapid actions were effective, the resulting extraordinary burden inevitably led to other issues being sidelined. Fifth, the occurrence of both global systemic crises exposed the mismatch between the design of our governance systems and complex contemporary global challenges. Both crises led to institutional and governance changes which would have been unlikely, or slower, to happen without a shock of such magnitude to the system.

A complexity lens is useful for understanding and responding to global disruptions, but it does not always provide totally new insights compared to other relevant scientific approaches. One of the main strengths of a complexity lens resides in combining insights from different disciplines into a meaningful whole. While not providing a unique set of prescriptions, a complexity lens further emphasizes the importance of governance design to address systemic crises. Contrary to the thinking that the 'complex' is not amenable to human action, a complexity lens shows that actions taken after the onset of the global financial crisis of 2008 and the COVID-19 pandemic were able to mitigate their potentially devastating effects on human societies. These actions were ultimately effective but incurred disproportionate societal costs. The broad and lasting societal effects resulting from both crises suggest that relying on reactive and recovery capacities to face systemic crises is not a sustainable approach. This should come as a warning at a time of rapid global environmental change that may trigger further systemic crises.

Several key issues require scholarly and policy attention. The first is to expand our understanding of analytics regarding systemic crises both before (i.e., in terms of an early-warning system) and during a crisis (Galaitsi et al., 2022; Scheffer et al., 2009) to build data-driven dynamical systems to resilience (Yabe et al., 2022). A second issue is to better link capacities to face systemic crises and the provision of global public goods from a multilateral perspective. Understanding which properties of complex systems relate to the nature of global public goods may enhance the capacity for effective governance design. A relevant policy foundation is the Sendai framework for disaster reduction which seeks to better understand the nature of risk, to strengthen governance in times of crisis, to prevent crisis, and to be prepared to react and recover quickly (United Nations Office for Disaster Risk Reduction, 2015). Third, the allocation of resources to build resilience to systemic crises should involve a careful reflection about trade-offs between efficiency, sustainability, well-being, and resilience (Chaigneau et al., 2022). Actions to address global systemic crises are likely to align best with sustainability goals when these actions address the root causes of the issue at stake. By contrast, one can expect diminishing return as well as increasing trade-offs with efficiency and sustainability when actions to build resilience exclusively focus on reactive and recovery capacities.

A third issue is the rather rapid succession of systemic crises in this early 21st century. These systemic crises are apparently not linked but each new crisis unfolds in societies in which the effects of the previous crises are not yet dissipated. In other words, the drivers of systemic events seem to be embedded in the way our current social order is constructed (Centeno et al., 2015) giving rise to a situation of 'permacrisis' (The Collins, 2022). Two opposite hypotheses may be made regarding the importance of systemic crises as an evolutionary driver of social complexity (Turchin et al., 2022). First, the current multilateral international institutional order, mainly designed after World War II to prevent major military conflicts between powerful states, may become outdated and ineffective. The resulting architecture of fragility may lead to systemic crises of increasing frequency and magnitude. After a period of elevated instability, new, or repurposed organizations may emerge signalling a transformation to a new global order. The opposite hypothesis is that the past systemic crises may have already altered the trajectory of societies towards a more resilient path through gradual adaptation (Josepha Debre & Dijkstra, 2021). While governance reforms have been undertaken since the global financial crisis of 2008 and others are underway regarding the COVID-19 pandemic, this paper suggests that the governance-issue mismatch has not fundamentally changed. The re-emergence of major geopolitical tensions is likely to make any reform of international institutions even more challenging.

In conclusion, global systemic crises are one of the most important threats faced by humanity. While they challenge our capacity to cooperate (Turchin, 2016b), they are not a fatality. Preventing, reacting to, and recovering from systemic crises requires developing capacities which are, in turn, translated into sound actions and governance. A key question to foster these capacities is whether and how social actors can tip a system towards a more societally desirable trajectory (Folke et al., 2021; Lenton, 2020; Young, 2021). Among several ongoing efforts, a transformation of knowledge systems is essential to support a broader societal transformation towards sustainable and resilient societies (Arthur, 2021; Folke et al., 2021; Wernli, 2021; Young, 2021). Better preparing people to understand complex systems will not only foster innovative solutions for the governance of systemic risks in strongly interconnected systems but also the thinking needed regarding the future of global governance (Weiss & Wilkinson, 2021). A critical endeavour is to develop science diplomacy as a strong interface to translate the knowledge gained in the study of complex systems into the design of multilateral institutions that not only help prevent, react to, and recover from systemic crises but also support a broader transformation towards more sustainable societies.

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REFERENCES

Abbey, E.J., Khalifa, B.a.A., Oduwole, M.O., Ayeh, S.K., Nudotor, R.D., Salia, E.L. et al. (2020) The Global Health security index is not predictive of coronavirus pandemic responses among Organization for Economic Cooperation and Development countries. *PLoS One*, 15, e0239398. Available from: https://doi.org/10.1371/journal.pone.0239398

Abel, N., Cumming, D.H. & Anderies, J. (2006) Collapse and reorganization in social-ecological systems: questions, some ideas, and policy implications. *Ecology and Society*, 11, 1–25.

Acemoglu, D. & Robinson, J.A. (2012) *Why nations fail: the origins of power, prosperity, and poverty*. New York: Crown Publishing Group.

Albert, R., Jeong, H. & Barabási, A.-L. (2000) Error and attack tolerance of complex networks. *Nature*, 406, 378–382. Available from: https://doi.org/10.1038/35019019

Alderson, D.L. & Doyle, J.C. (2010) Contrasting views of complexity and their implications for network-centric infrastructures. *IEEE Transactions on Systems, Man, and Cybernetics-Part A: Systems and Humans*, 40, 839–852.

Allen, B., Chan, K.K., Milne, A. & Thomas, S. (2012) Basel III: is the cure worse than the disease? *International Review of Financial Analysis*, 25, 159–166. Available from: https://doi.org/10.1016/j.irfa.2012.08.004

Alter, K.J. (2022) The promise and perils of theorizing international regime complexity in an evolving world. *The Review of International Organizations*, 17, 375–396. Available from: https://doi.org/10.1007/s11558-021-09448-8

Aral, S. & Eckles, D. (2019) Protecting elections from social media manipulation. *Science*, 365, 858–861. Available from: https://doi.org/10.1126/science.aaw8243

Armstrong Mckay, D.I., Staal, A., Abrams, J.F., Winkelmann, R., Sakschewski, B., Loriani, S. et al. (2022) Exceeding 1.5 degrees C global warming could trigger multiple climate tipping points. *Science*, 377, eabn7950. Available from: https://doi.org/10.1126/science.abn7950

Arsenault, C., Gage, A., Kim, M.K., Kapoor, N.R., Akweongo, P., Amponsah, F. et al. (2022) COVID-19 and resilience of healthcare systems in ten countries. *Nature Medicine*, 28, 1314–1324. Available from: https://doi.org/10.1038/s41591-022-01750-1

Arthur, W.B. (2021) Foundations of complexity economics. *Nature Reviews Physics*, 3, 136–145. Available from: https://doi.org/10.1038/s42254-020-00273-3

Artime, O., Benigni, B., Bertagnolli, G., D'andrea, V., Gallotti, R., Ghavasieh, A. et al. (2022) *Multilayer network science: from cells to societies*. Cambridge: Cambridge University Press.

Artime, O. & De Domenico, M. (2022) From the origin of life to pandemics: emergent phenomena in complex systems. *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences*, 380, 20200410. Available from: https://doi.org/10.1098/rsta.2020.0410

Bak, P., Tang, C. & Wiesenfeld, K. (1987) Self-organized criticality: an explanation of the 1/f noise. *Physical Review Letters*, 59, 381–384. Available from: https://doi.org/10.1103/PhysRevLett.59.381

Bali, A.S., He, A.J. & Ramesh, M. (2022) Health policy and COVID-19: path dependency and trajectory. *Policy and Society*, 41, 83–95. Available from: https://doi.org/10.1093/polsoc/puab014

Bardosh, K., De Figueiredo, A., Gur-Arie, R., Jamrozik, E., Doidge, J., Lemmens, T. et al. (2022) The unintended consequences of COVID-19 vaccine policy: why mandates, passports and restrictions may cause more harm than good. *BMJ Global Health*, 7, e008684. Available from: https://doi.org/10.1136/bmjgh-2022-008684

Barrat, A., Barthélemy, M. & Vespignani, A. (2008) *Dynamical processes on complex networks*. Cambridge: Cambridge University Press.

Barrett, C., Channakeshava, K., Huang, F., Kim, J., Marathe, A., Marathe, M.V. et al. (2012) Human initiated cascading failures in societal infrastructures. *PLoS One*, 7, e45406. Available from: https://doi.org/10.1371/journal.pone.0045406

Barrett, S. (2010) *Why cooperate? The incentive to supply global public goods*. Oxford and New York: Oxford University Press.
Battiston, S., Caldarelli, G., May, R.M., Roukny, T. & Stiglitz, J.E. (2016) The price of complexity in financial networks. *Proceedings of the National Academy of Sciences of the United States of America*, 113, 10031–10036. Available from: https://doi.org/10.1073/pnas.1521573113
Battiston, S., Delli Gatti, D., Gallegati, M., Greenwald, B. & Stiglitz, J.E. (2012) Liaisons dangereuses: increasing connectivity, risk sharing, and systemic risk. *Journal of Economic Dynamics and Control*, 36, 1121–1141. Available from: https://doi.org/10.1016/j.jedc.2012.04.001
Battiston, S., Farmer, J.D., Flache, A., Garlaschelli, D., Haldane, A.G., Heesterbeek, H. et al. (2016b) Complex systems. Complexity theory and financial regulation. *Science*, 351, 818–819. Available from: https://doi.org/10.1126/science.aad0299
Battiston, S., Farmer, J.D., Flache, A., Garlaschelli, D., Haldane, A.G., Heesterbeek, H. et al. (2016c) Complexity theory and financial regulation. *Science*, 351, 818–819. Available from: https://doi.org/10.1126/science.aad0299
Battiston, S., Puliga, M., Kaushik, R., Tasca, P. & Caldarelli, G. (2012) DebtRank: too central to fail? Financial networks, the FED and systemic risk. *Scientific Reports*, 2, 541. Available from: https://doi.org/10.1038/srep00541
Beckmann, J., Gern, K.-J. & Jannsen, N. (2022) Should they stay or should they go? Negative interest rate policies under review. *International Economics and Economic Policy*, 19, 885–912. Available from: https://doi.org/10.1007/s10368-022-00547-4
Béné, C., Newsham, A., Davies, M., Ulrichs, M. & Godfrey-Wood, R. (2014) Review article: resilience, poverty and development. *Journal of International Development*, 26, 598–623. Available from: https://doi.org/10.1002/jid.2992
Bernstein, A.S., Ando, A.W., Loch-Temzelides, T., Vale, M.M., Li, B.V., Li, H. et al. (2022) The costs and benefits of primary prevention of zoonotic pandemics. *Science. Advances*, 8, eabl4183. Available from: https://doi.org/10.1126/sciadv.abl4183
Biggs, R., Clements, H., De Vos, A., Folke, C., Manyani, A., Maciejewski, K. et al. (2021) What are social-ecological systems and social-ecological systems research?
Biggs, R., De Vos, A., Preiser, R., Clements, H., Maciejewski, K. & Schlüter, M. (2021) *The Routledge handbook of research methods for social-ecological systems*. Abingdon and New York: Taylor & Francis.
Biggs, R., Schlüter, M., Biggs, D., Bohensky, E.L., Burnsilver, S., Cundill, G. et al. (2012) Toward principles for enhancing the resilience of ecosystem services. *Annual Review of Environment and Resources*, 37, 421–448. Available from: https://doi.org/10.1146/annurev-environ-051211-123836
Biggs, R., Schlüter, M. & Schoon, M.L. (2015) *Principles for building resilience: sustaining ecosystem services in social-ecological systems*. Cambridge: Cambridge University Press.
Bisias, D., Flood, M., Lo, A.W. & Valavanis, S. (2012) A survey of systemic risk analytics. *Annual Review of Financial Economics*, 4, 255–296.
Bodin, Ö., Alexander, S.M., Baggio, J., Barnes, M.L., Berardo, R., Cumming, G.S. et al. (2019) Improving network approaches to the study of complex social–ecological interdependencies. *Nature Sustainability*, 2, 551–559. Available from: https://doi.org/10.1038/s41893-019-0308-0
Booth, A., Reed, A.B., Ponzo, S., Yassaee, A., Aral, M., Plans, D. et al. (2021) Population risk factors for severe disease and mortality in COVID-19: a global systematic review and meta-analysis. *PLoS One*, 16, e0247461. Available from: https://doi.org/10.1371/journal.pone.0247461
Böttcher, L., Luković, M., Nagler, J., Havlin, S. & Herrmann, H.J. (2017) Failure and recovery in dynamical networks. *Scientific Reports*, 7, 41729. Available from: https://doi.org/10.1038/srep41729
Böttcher, L., Nagler, J. & Herrmann, H.J. (2017) Critical behaviors in contagion dynamics. *Physical Review Letters*, 118, 088301. Available from: https://doi.org/10.1103/PhysRevLett.118.088301
Buchholz, W. & Sandler, T. (2021) Global public goods: a survey. *Journal of Economic Literature*, 59, 488–545. Available from: https://doi.org/10.1257/jel.20191546
Buldyrev, S.V., Parshani, R., Paul, G., Stanley, H.E. & Havlin, S. (2010) Catastrophic cascade of failures in interdependent networks. *Nature*, 464, 1025–1028.
Campos-Mercade, P., Meier, A.N., Schneider, F.H., Meier, S., Pope, D. & Wengström, E. (2021) Monetary incentives increase COVID-19 vaccinations. *Science*, 374, 879–882. Available from: https://doi.org/10.1126/science.abm0475
Carpenter, S., Walker, B., Anderies, J.M. & Abel, N. (2001) From metaphor to measurement: resilience of what to what? *Ecosystems*, 4, 765–781. Available from: https://doi.org/10.1007/s10021-001-0045-9
Centeno, M.A., Nag, M., Patterson, T.S., Shaver, A. & Windawi, A.J. (2015) The emergence of global systemic risk. *Annual Review of Sociology*, 41, 65–85. Available from: https://doi.org/10.1146/annurev-soc-073014-112317
Centola, D. (2010) The spread of behavior in an online social network experiment. *Science*, 329, 1194–1197. Available from: https://doi.org/10.1126/science.1185231
Centola, D. (2018) *How behavior spreads: the science of complex contagions*. Princeton and Woodstock: Princeton University Press.
Centola, D., Becker, J., Brackbill, D. & Baronchelli, A. (2018) Experimental evidence for tipping points in social convention. *Science*, 360, 1116–1119. Available from: https://doi.org/10.1126/science.aas8827
Chaigneau, T., Coulthard, S., Daw, T.M., Szaboova, L., Camfield, L., Chapin, F.S. et al. (2022) Reconciling well-being and resilience for sustainable development. *Nature Sustainability*, 5, 287–293. Available from: https://doi.org/10.1038/s41893-021-00790-8
Chandler, D. (2014) *Resilience: the governance of complexity*. Abingdon, Oxon: New York, NY: Routledge.
Chapman, J. (2004) *System failure: why governments must learn to think differently*. London: Demos.
Cinelli, M., Quattrociocchi, W., Galeazzi, A., Valensise, C.M., Brugnoli, E., Schmidt, A.L. et al. (2020) The COVID-19 social media infodemic. *Scientific Reports*, 10, 16598. Available from: https://doi.org/10.1038/s41598-020-73510-5
Claessens, M.S. & Kodres, M.L.E. (2014) *The regulatory responses to the global financial crisis: some uncomfortable questions*. Washington, DC: International Monetary Fund.
Clark, W.C. & Harley, A.G. (2020) Sustainability science: toward a synthesis. *Annual Review of Environment and Resources*, 45, 331–386. Available from: https://doi.org/10.1146/annurev-environ-012420-043621
Clemens, W.C. (2013) *Complexity science and world affairs*. Albany: State University of New York Press.
Cohen, R., Erez, K., Ben-Avraham, D. & Havlin, S. (2001) Breakdown of the internet under intentional attack. *Physical Review Letters*, 86, 3682–3685. Available from: https://doi.org/10.1103/PhysRevLett.86.3682
Comfort, L.K., Boin, A. & Demchak, C.C. (2010) *Designing resilience: preparing for extreme events*. Pittsburgh, PA: University of Pittsburgh Press.
Cosens, B., Ruhl, J.B., Soininen, N., Gunderson, L., Belinskij, A., Blenckner, T. et al. (2021) Governing complexity: integrating science, governance, and law to manage accelerating change in the globalized commons. *Proceedings of the National Academy of Sciences of the United States of America*, 118, e2102798118. Available from: https://doi.org/10.1073/pnas.2102798118

Cosens, B.A., Ruhl, J., Soininen, N. & Gunderson, L. (2020) Designing law to enable adaptive governance of modern wicked problems. *Vanderbilt Law Review*, 73, 1687.

Cox, M. (2016) The pathology of command and control: a formal synthesis. *Ecology and Society*, 21, 1–8. Available from: https://doi.org/10.5751/ES-08698-210333

Cumming, G.S. & Peterson, G.D. (2017) Unifying research on social-ecological resilience and collapse. *Trends in Ecology & Evolution*, 32, 695–713. Available from: https://doi.org/10.1016/j.tree.2017.06.014

Dakos, V., Carpenter, S.R., Nes, E.H.V. & Scheffer, M. (2015) Resilience indicators: prospects and limitations for early warnings of regime shifts. *Philosophical Transactions of the Royal Society, B: Biological Sciences*, 370, 20130263. Available from: https://doi.org/10.1098/rstb.2013.0263

Davies, S.E., Kamradt-Scott, A. & Rushton, S. (2015) *Disease diplomacy: international norms and global health security*. Baltimore: Johns Hopkins University Press.

Dessie, Z.G. & Zewotir, T. (2021) Mortality-related risk factors of COVID-19: a systematic review and meta-analysis of 42 studies and 423,117 patients. *BMC Infectious Diseases*, 21, 855. Available from: https://doi.org/10.1186/s12879-021-06536-3

Di Muro, M.A., La Rocca, C.E., Stanley, H.E., Havlin, S. & Braunstein, L.A. (2016) Recovery of Interdependent Networks. *Scientific Reports*, 6, 22834. Available from: https://doi.org/10.1038/srep22834

Dryzek, J.S., Bachtiger, A., Chambers, S., Cohen, J., Druckman, J.N., Felicetti, A. et al. (2019) The crisis of democracy and the science of deliberation. *Science*, 363, 1144–1146. Available from: https://doi.org/10.1126/science.aaw2694

Duan, C., Nishikawa, T., Eroglu, D. & Motter, A.E. (2022) Network structural origin of instabilities in large complex systems. *Science Advances*, 8, eabm8310. Available from: https://doi.org/10.1126/sciadv.abm8310

Elliott, M., Golub, B. & Jackson, M.O. (2014) Financial networks and contagion. *American Economic Review*, 104, 3115–3153.

Ellis, S., Sharma, S. & Brzeszczyński, J. (2022) Systemic risk measures and regulatory challenges. *Journal of Financial Stability*, 61, 100960. Available from: https://doi.org/10.1016/j.jfs.2021.100960

Farzanegan, M.R., Feizi, M. & Gholipour, H.F. (2021) Globalization and the outbreak of COVID-19: an empirical analysis. *Journal of Risk and Financial Management*, 14, 105.

Fatás, A. & Summers, L.H. (2016) *Hysteresis and fiscal policy during the global crisis [online]. Vox EU CEPR*. Available from: https://voxeu.org/article/hysteresis-and-fiscal-policy-during-global-crisis [Accessed 14 September 2021].

Fidler, D.P. & Gostin, L.O. (2006) The new international health regulations: an historic development for international law and public health. *The Journal of Law, Medicine & Ethics*, 34, 85–94, 4. Available from: https://doi.org/10.1111/j.1748-720X.2006.00011.x

Folke, C., Hahn, T., Olsson, P. & Norberg, J. (2005) Adaptive governance of social-ecological systems. *Annual Review of Environment and Resources*, 30, 441–473.

Folke, C., Polasky, S., Rockström, J., Galaz, V., Westley, F., Lamont, M. et al. (2021) Our future in the Anthropocene biosphere. *Ambio*, 50, 834–869. Available from: https://doi.org/10.1007/s13280-021-01544-8

Fraccascia, L., Giannoccaro, I. & Albino, V. (2018) Resilience of complex systems: state of the art and directions for future research. *Complexity*, 2018, 44. Available from: https://doi.org/10.1155/2018/3421529

Frank, A.B., Collins, M.G., Levin, S.A., Lo, A.W., Ramo, J., Dieckmann, U. et al. (2014) Dealing with femtorisks in international relations. *Proceedings of the National Academy of Sciences of the United States of America*, 111, 17356–17362. Available from: https://doi.org/10.1073/pnas.1400229111

Fu, F., Christakis, N.A. & Fowler, J.H. (2017) Dueling biological and social contagions. *Scientific Reports*, 7, 43634. Available from: https://doi.org/10.1038/srep43634

Furlanetto, F., Lepetit, A., Robstad, Ø., Rubio-Ramírez, J. & Ulvedal, P. (2021) Estimating hysteresis effects.

Gai, P. & Kapadia, S. (2010) Contagion in financial networks. *Proceedings of the Royal Society A: Mathematical, Physical and Engineering Sciences*, 466, 2401–2423.

Galaitsi, S., Kurth, M., Fries, S. & Linkov, I. (2022) Mainstreaming resilience analytics: 10 years after the Fukushima disaster. *Integrated Environmental Assessment and Management*, 18, 1551–1554. Available from: https://doi.org/10.1002/ieam.4623

Galaitsi, S.E., Keisler, J.M., Trump, B.D. & Linkov, I. (2021) The need to reconcile concepts that characterize systems facing threats. *Risk Analysis*, 41, 3–15. Available from: https://doi.org/10.1111/risa.13577

Galaz, V. (2019) *Global challenges, governance, and complexity: applications and Frontiers*. Cheltenham and Horthampton: Edward Elgar Publishing, Incorporated.

Galaz, V., Tallberg, J., Boin, A., Ituarte-Lima, C., Hey, E., Olsson, P. et al. (2017) Global governance dimensions of globally networked risks: the state of the art in social science research. *Risk, Hazards & Crisis in Public Policy*, 8, 4–27. Available from: https://doi.org/10.1002/rhc3.12108

Gao, J., Barzel, B. & Barabasi, A.L. (2016) Universal resilience patterns in complex networks. *Nature*, 530, 307–312. Available from: https://doi.org/10.1038/nature16948

Gelfand, M.J., Jackson, J.C., Pan, X., Nau, D., Pieper, D., Denison, E. et al. (2021) The relationship between cultural tightness–looseness and COVID-19 cases and deaths: a global analysis. *The Lancet Planetary Health*, 5, e135–e144. Available from: https://doi.org/10.1016/s2542-5196(20)30301-6

Geyer, R. & Rihani, S. (2010) *Complexity and public policy: a new approach to twenty-first century politics, policy and society*. London; New York: Routledge.

Gill, S. (2015) *Critical perspectives on the crisis of global governance: reimagining the future*. Basingstoke and New York: Springer.

Goldin, I. & Mariathasan, M. (2014) *The butterfly defect: how globalization creates systemic risks, and what to do about it*. Princeton: Princeton University Press.

Goldin, I. & Vogel, T. (2010) Global governance and systemic risk in the 21st century: lessons from the financial crisis. *Global Policy*, 1, 4–15. Available from: https://doi.org/10.1111/j.1758-5899.2009.00011.x

Gómez-Mera, L. (2021) *International regime complexity*. Oxford: Oxford University Press.

Gostin, L.O., Debartolo, M.C. & Katz, R. (2017) The global health law trilogy: towards a safer, healthier, and fairer world. *The Lancet*, 390, 1918–1926. Available from: https://doi.org/10.1016/s0140-6736(17)31261-8

Gostin, L.O. & Katz, R. (2016) The international health regulations: the governing framework for Global Health security. *The Milbank Quarterly*, 94, 264–313. Available from: https://doi.org/10.1111/1468-0009.12186

Grafton, R.Q., Doyen, L., Béné, C., Borgomeo, E., Brooks, K., Chu, L. et al. (2019) Realizing resilience for decision-making. *Nature Sustainability*, 2, 907–913. Available from: https://doi.org/10.1038/s41893-019-0376-1

Granovetter, M.S. (1973) The strength of weak ties. *American Journal of Sociology*, 78, 1360–1380.

Guasti, P. (2020) The impact of the COVID-19 pandemic in central and Eastern Europe. *Democratic Theory*, 7, 47–60. Available from: https://doi.org/10.3167/dt.2020.070207

Guillén, M.F. (2015) *The architecture of collapse: the global system in the 21st century*. Oxford and New York: Oxford University Press.

Gunderson, L.H. & Holling, C.S. (2001) *Panarchy: understanding transformations in human and natural systems*. Washington, DC: Island press.

Haldane, A.G. & May, R.M. (2011) Systemic risk in banking ecosystems. *Nature*, 469, 351–355. Available from: https://doi.org/10.1038/nature09659

Haldane, V., De Foo, C., Abdalla, S.M., Jung, A.-S., Tan, M., Wu, S. et al. (2021) Health systems resilience in managing the COVID-19 pandemic: lessons from 28 countries. *Nature Medicine*, 27, 964–980. Available from: https://doi.org/10.1038/s41591-021-01381-y

Hale, H.E. (2013) Regime change cascades: what we have learned from the 1848 revolutions to the 2011 Arab uprisings. *Annual Review of Political Science*, 16, 331–353. Available from: https://doi.org/10.1146/annurev-polisci-032211-212204

Hale, T. & Held, D. (2017) *Beyond gridlock*. Cambridge and Melford: John Wiley & Sons.

Hale, T., Held, D. & Young, K. (2013) Gridlock: from self-reinforcing interdependence to second-order cooperation problems. *Global Policy*, 4, 223–235. Available from: https://doi.org/10.1111/1758-5899.12068

Hamilton, J.D. (2016) Chapter 3 - macroeconomic regimes and regime shifts. In: Taylor, J.B. & Uhlig, H. (Eds.) *Handbook of macroeconomics*. Oxford: Elsevier.

Harper, K. (2017) *The fate of Rome: climate, disease, and the end of an empire*. Princeton University Press: Princeton.

Harrison, N.E. & Geyer, R. (2021) *Governing complexity in the 21st century*. Abingdon and New York: Routledge.

Hartwig, B., Meinerding, C. & Schüler, Y.S. (2021) Identifying indicators of systemic risk. *Journal of International Economics*, 132, 103512.

Haynes, P. (2015) The international financial crisis: the failure of a complex system. In: Geyer, R. & Cairney, P. (Eds.) *Handbooks of research on public policy*. Cheltenham: Edward Elgar Pub.

Helbing, D. (2012) Systemic risks in society and economics. In: Helbing, D. (Ed.) *Social self-organization*, Kindle edition. Berlin Heidelberg: Springer, pp. 7295–7891.

Helbing, D. (2013) Globally networked risks and how to respond. *Nature*, 497, 51–59. Available from: https://doi.org/10.1038/nature12047

Helbing, D. (2021) *The next civilization*. Berlin, Heidelberg: Springer.

Held, D. & Young, K. (2013) Global governance in crisis? Fragmentation, risk and world order. *International Politics*, 50, 309–332. Available from: https://doi.org/10.1057/ip.2013.9

Hendriks, S.L., Montgomery, H., Benton, T., Badiane, O., Castro De La Mata, G., Fanzo, J. et al. (2022) Global environmental climate change, covid-19, and conflict threaten food security and nutrition. *BMJ*, 378, e071534. Available from: https://doi.org/10.1136/bmj-2022-071534

Herrfahrdt-Pähle, E., Schlüter, M., Olsson, P., Folke, C., Gelcich, S. & Pahl-Wostl, C. (2020) Sustainability transformations: socio-political shocks as opportunities for governance transitions. *Global Environmental Change*, 63, 102097. Available from: https://doi.org/10.1016/j.gloenvcha.2020.102097

Holling, C.S. (1973) Resilience and stability of ecological systems. *Annual Review of Ecology and Systematics*, 4, 1–23. Available from: https://doi.org/10.1146/annurev.es.04.110173.000245

Homer-Dixon, T., Walker, B., Biggs, R., Crépin, A.-S., Folke, C., Lambin, E.F. et al. (2015) Synchronous failure: the emerging causal architecture of global crisis. *Ecology and Society*, 20, 1–16. Available from: https://doi.org/10.5751/ES-07681-200306

Hubrich, K. & Tetlow, R.J. (2015) Financial stress and economic dynamics: the transmission of crises. *Journal of Monetary Economics*, 70, 100–115.

Hunter, D.J., Abdool Karim, S.S., Baden, L.R., Farrar, J.J., Hamel, M.B., Longo, D.L. et al. (2022) Addressing vaccine inequity — Covid-19 vaccines as a global public good. *New England Journal of Medicine*, 386, 1176–1179. Available from: https://doi.org/10.1056/NEJMe2202547

Hynes, W., Trump, B.D., Kirman, A., Haldane, A. & Linkov, I. (2022) Systemic resilience in economics. *Nature Physics*, 18, 381–384. Available from: https://doi.org/10.1038/s41567-022-01581-4

Jackson, M.O. & Pernoud, A. (2021) Systemic risk in financial networks: a survey. *Annual Review of Economics*, 13, 171–202. Available from: https://doi.org/10.1146/annurev-economics-083120-111540

Johnson, M.A. & Mamun, A. (2012) The failure of Lehman brothers and its impact on other financial institutions. *Applied Financial Economics*, 22, 375–385. Available from: https://doi.org/10.1080/09603107.2011.613762

Jones, B.A., Grace, D., Kock, R., Alonso, S., Rushton, J., Said, M.Y. et al. (2013) Zoonosis emergence linked to agricultural intensification and environmental change. *Proceedings of the National Academy of Sciences of the United States of America*, 110, 8399–8404. Available from: https://doi.org/10.1073/pnas.1208059110

Jones, L. & Hameiri, S. (2022) Explaining the failure of global health governance during COVID-19. *International Affairs*, 98, 2057–2076. Available from: https://doi.org/10.1093/ia/iiac231

Joseph, J. (2013) Resilience as embedded neoliberalism: a governmentality approach. *Resilience*, 1, 38–52. Available from: https://doi.org/10.1080/21693293.2013.765741

Josepha Debre, M. & Dijkstra, H. (2021) COVID-19 and policy responses by international organizations: crisis of Liberal international order or window of opportunity? *Global Policy*, 12, 443–454. Available from: https://doi.org/10.1111/1758-5899.12975

Kaufman, G.G. & Scott, K.E. (2003) What is systemic risk, and do Bank regulators retard or contribute to it? *The Independent Review*, 7, 371–391.

Kaul, I., Grunberg, I. & Stern, M. (1999) *Global public goods: international cooperation in the 21st century*. Oxford and New York: Oxford University Press.

Kemp, L., Xu, C., Depledge, J., Ebi, K.L., Gibbins, G., Kohler, T.A. et al. (2022) Climate endgame: exploring catastrophic climate change scenarios. *Proceedings of the National Academy of Sciences of the United States of America*, 119, e2108146119. Available from: https://doi.org/10.1073/pnas.2108146119

Kinzig, A., Ryan, P., Etienne, M., Allison, H., Elmqvist, T. & Walker, B. (2006) Resilience and regime shifts: assessing cascading effects. *Ecology and Society*, 11, 20–23.

Kivelä, M., Arenas, A., Barthelemy, M., Gleeson, J.P., Moreno, Y. & Porter, M.A. (2014) Multilayer networks. *Journal of Complex Networks*, 2, 203–271. Available from: https://doi.org/10.1093/comnet/cnu016

Kooiman, J. (2003) *Governing as governance*. London, Thousand Oaks, New Dehli: Sage Publications.

Korkali, M., Veneman, J.G., Tivnan, B.F., Bagrow, J.P. & Hines, P.D. (2017) Reducing cascading failure risk by increasing infrastructure network interdependence. *Scientific Reports*, 7, 44499. Available from: https://doi.org/10.1038/srep44499

Ladyman, J. & Wiesner, K. (2020) *What is a complex system?* New Haven and London: Yale University Press.

Lee, K., Grépin, K.A., Worsnop, C., Marion, S., Piper, J. & Song, M. (2021) Managing borders during public health emergencies of international concern: a proposed typology of cross-border health measures. *Globalization and Health*, 17, 62. Available from: https://doi.org/10.1186/s12992-021-00709-0

Lenton, T.M. (2020) Tipping positive change. *Philosophical Transactions of the Royal Society, B: Biological Sciences*, 375, 20190123. Available from: https://doi.org/10.1098/rstb.2019.0123

Lenton, T.M., Boulton, C.A. & Scheffer, M. (2022) Resilience of countries to COVID-19 correlated with trust. *Scientific Reports*,

12, 75. Available from: https://doi.org/10.1038/s41598-021-03358-w
Levin, S. (1999) *Fragile dominion: complexity and the commons*. Reading, MA: Perseus.
Levin, S., Xepapadeas, T., Crépin, A.-S., Norberg, J., De Zeeuw, A., Folke, C. et al. (2013) Social-ecological systems as complex adaptive systems: modeling and policy implications. *Environment and Development Economics*, 18, 111–132.
Lewis, D. (2022) What scientists have learnt from COVID lockdowns. *Nature*, 609, 236–239. Available from: https://doi.org/10.1038/d41586-022-02823-4
Linkov, I., Fox-Lent, C., Read, L., Allen, C.R., Arnott, J.C., Bellini, E. et al. (2018) Tiered approach to resilience assessment. *Risk Analysis*, 38, 1772–1780. Available from: https://doi.org/10.1111/risa.12991
Linkov, I. & Trump, B.D. (2019) *The science and practice of resilience*. Berlin and Heidelberg: Springer.
Loomba, S., De Figueiredo, A., Piatek, S.J., De Graaf, K. & Larson, H.J. (2021) Measuring the impact of COVID-19 vaccine misinformation on vaccination intent in the UK and USA. *Nature Human Behaviour*, 5, 337–348. Available from: https://doi.org/10.1038/s41562-021-01056-1
Lorenz, J., Battiston, S. & Schweitzer, F. (2009) Systemic risk in a unifying framework for cascading processes on networks. *The European Physical Journal B*, 71, 441–460.
Martin, R. & Sunley, P. (2014) On the notion of regional economic resilience: conceptualization and explanation. *Journal of Economic Geography*, 15, 1–42. Available from: https://doi.org/10.1093/jeg/lbu015
May, R.M., Levin, S.A. & Sugihara, G. (2008) Ecology for bankers. *Nature*, 451, 893–894. Available from: https://doi.org/10.1038/451893a
Mckee, M. & Stuckler, D. (2016) Health effects of the financial crisis: lessons from Greece. *The Lancet Public Health*, 1, e40–e41. Available from: https://doi.org/10.1016/S2468-2667(16)30016-0
Meadows, D.H., Meadows, D.L., Randers, J. & Behrens, W.W. (1972) The limits to growth a report for the Club of Rome's project on the predicament of mankind. 1972. *New York*.
Merton, R.K. (1936) The unanticipated consequences of purposive social action. *American Sociological Review*, 1, 894–904.
Michelen, M., Manoharan, L., Elkheir, N., Cheng, V., Dagens, A., Hastie, C. et al. (2021) Characterising long COVID: a living systematic review. *BMJ Global Health*, 6, e005427. Available from: https://doi.org/10.1136/bmjgh-2021-005427
Mikulewicz, M. (2019) Thwarting adaptation's potential? A critique of resilience and climate-resilient development. *Geoforum*, 104, 267–282. Available from: https://doi.org/10.1016/j.geoforum.2019.05.010
Mitchell, M. (2009) *Complexity: a guided tour*. Oxford and New York: Oxford University Press.
Morgan, S. (2018) Fake news, disinformation, manipulation and online tactics to undermine democracy. *Journal of Cyber Policy*, 3, 39–43. Available from: https://doi.org/10.1080/23738871.2018.1462395
Mosam, A., Fisher, D.A., Hunter, M.B., Kunjumen, T., Mustafa, S., Nair, T.S. et al. (2022) Public health and emergency workforce: a roadmap for WHO and partner contributions. *BMJ Global Health*, 7, e009592. Available from: https://doi.org/10.1136/bmjgh-2022-009592
Motter, A.E. & Lai, Y.-C. (2002) Cascade-based attacks on complex networks. *Physical Review E*, 66, 065102.
Naqvi, A. & Monasterolo, I. (2021) Assessing the cascading impacts of natural disasters in a multi-layer behavioral network framework. *Scientific Reports*, 11, 20146. Available from: https://doi.org/10.1038/s41598-021-99343-4
Nielsen, B.F., Simonsen, L. & Sneppen, K. (2021) COVID-19 superspreading suggests mitigation by social network modulation. *Physical Review Letters*, 126, 118301. Available from: https://doi.org/10.1103/PhysRevLett.126.118301
Nyborg, K., Anderies, J.M., Dannenberg, A., Lindahl, T., Schill, C., Schlüter, M. et al. (2016) Social norms as solutions. *Science*, 354, 42–43.
Oberthür, S. & Stokke, O.S. (2011) *Managing institutional complexity: regime interplay and global environmental change*. Cambridge and London: MIT Press.
OECD. (2022) *Building trust to reinforce democracy*. Paris: OECD.
Ord, T. (2020) *The precipice: existential risk and the future of humanity*. New York: Hachette Books.
Osborne, J. & Pimentel, D. (2022) Science, misinformation, and the role of education. *Science*, 378, 246–248. Available from: https://doi.org/10.1126/science.abq8093
Ostrom, E. (2010) Polycentric systems for coping with collective action and global environmental change. *Global Environmental Change*, 20, 550–557. Available from: https://doi.org/10.1016/j.gloenvcha.2010.07.004
Otto, I.M., Donges, J.F., Cremades, R., Bhowmik, A., Hewitt, R.J., Lucht, W. et al. (2020) Social tipping dynamics for stabilizing Earth's climate by 2050. *Proceedings of the National Academy of Sciences of the United States of America*, 117, 2354–2365. Available from: https://doi.org/10.1073/pnas.1900577117
Page, S.E. (2017) *The diversity bonus: how great teams pay off in the knowledge economy*. Princeton and Oxford: Princeton University Press.
Pai, M., Kasaeva, T. & Swaminathan, S. (2022) Covid-19's devastating effect on tuberculosis care — a path to recovery. *New England Journal of Medicine*, 386, 1490–1493. Available from: https://doi.org/10.1056/NEJMp2118145
Parisi, G. (1999) Complex systems: a physicist's viewpoint. *Physica A: Statistical Mechanics and its Applications*, 263, 557–564. Available from: https://doi.org/10.1016/S0378-4371(98)00524-X
Parry, L.J., Asenbaum, H. & Ercan, S.A. (2021) Democracy in flux: a systemic view on the impact of COVID-19. *Transforming Government: People, Process and Policy*, 15, 197–205. Available from: https://doi.org/10.1108/TG-09-2020-0269
Pegram, T. & Kreienkamp, J. (2019) *Governing complexity: design principles for improving the governance of complex global catastrophic risks*. London: UCL Global Governance Institute.
Peleg, K., Bodas, M., Hertelendy, A.J. & Kirsch, T.D. (2021) The COVID-19 pandemic challenge to the all-hazards approach for disaster planning. *International Journal of Disaster Risk Reduction*, 55, 102103. Available from: https://doi.org/10.1016/j.ijdrr.2021.102103
Peters, B.G., Pierre, J. & Galaz, V. (2019) Simple solutions for complexity? In: *Global challenges, governance, and complexity*. Cheltenham and Horthampton: Edward Elgar Publishing.
Phelan, A.L. & Carlson, C.J. (2022) A treaty to break the pandemic cycle. *Science*, 377, 475–477. Available from: https://doi.org/10.1126/science.abq5917
Pierre, J. & Peters, B.G. (2019) *Governance, politics and the state*. London: Red Globe Press.
Quinlan, A.E., Berbés-Blázquez, M., Haider, L.J. & Peterson, G.D. (2015) Measuring and assessing resilience: broadening understanding through multiple disciplinary perspectives. *Journal of Applied Ecology*, 53, 677–687.
Rajan, D., Koch, K., Rohrer, K., Bajnoczki, C., Socha, A., Voss, M. et al. (2020) Governance of the Covid-19 response: a call for more inclusive and transparent decision-making. *BMJ Global Health*, 5, e002655. Available from: https://doi.org/10.1136/bmjgh-2020-002655
Ren, X.-L., Gleinig, N., Helbing, D. & Antulov-Fantulin, N. (2019) Generalized network dismantling. *Proceedings of the National Academy of Sciences of the United States of America*, 116,

6554–6559. Available from: https://doi.org/10.1073/pnas.1806108116
Rittel, H.W. & Webber, M.M. (1973) Dilemmas in a general theory of planning. *Policy Sciences*, 4, 155–169.
Rocha, J.C., Peterson, G., Bodin, Ö. & Levin, S. (2018) Cascading regime shifts within and across scales. *Science*, 362, 1379–1383. Available from: https://doi.org/10.1126/science.aat7850
Rockström, J., Steffen, W., Noone, K., Persson, Å., Chapin Iii, F.S., Lambin, E. et al. (2009) Planetary boundaries: exploring the safe operating space for humanity. *Ecology and Society*, 14, 1–33.
Romer, C.D. & Romer, D.H. (2017) New evidence on the aftermath of financial crises in advanced countries. *American Economic Review*, 107, 3072–3118. Available from: https://doi.org/10.1257/aer.20150320
Ronellenfitsch, H. & Katifori, E. (2016) Global optimization, local adaptation, and the role of growth in distribution networks. *Physical Review Letters*, 117, 138301. Available from: https://doi.org/10.1103/PhysRevLett.117.138301
Rosenau, J.N. (1995) Governance in the twenty-first century. *Global Governance*, 1, 13–43.
Ruckert, A., Gonçalo Das Neves, C., Amuasi, J., Hindmarch, S., Brux, C., Winkler, A.S. et al. (2021) One health as a pillar for a transformative pandemic treaty. Graduate Institute of International and Development Studies, Global Health.
Ruhl, J. (2019) Governing Cascade failures in complex social-ecological-technological systems: framing context, strategies, and challenges. *Vanderbilt Journal of Entertainment and Technology Law*, 22, 407.
Ruhl, J.B. (1996) Fitness of law: using complexity theory to describe the evolution of law and society and its practical meaning for democracy. *Vanderbilt Law Review*, 49, 1406.
Ruhl, J.B. (2016) Financial complexity: regulating regulation. *Science*, 352, 301. Available from: https://doi.org/10.1126/science.352.6283.301-a
Sachs, J.D., Karim, S.S.A., Aknin, L., Allen, J., Brosbøl, K., Colombo, F. et al. (2022) The lancet commission on lessons for the future from the COVID-19 pandemic. *The Lancet*, 400, 1224–1280. Available from: https://doi.org/10.1016/s0140-6736(22)01585-9
Sandler, T. (2020) COVID-19 and collective action. *Peace Economics, Peace Science and Public Policy*, 26, 1–8.
Sands, P., Mundaca-Shah, C. & Dzau, V.J. (2016) The Neglected Dimension of Global Security--A Framework for Countering Infectious-Disease Crises. *New England Journal of Medicine*, 374, 1281–1287. Available from: https://doi.org/10.1056/NEJMsr1600236
Sato, C.F. & Lindenmayer, D.B. (2018) Meeting the global ecosystem collapse challenge. *Conservation Letters*, 11, e12348. Available from: https://doi.org/10.1111/conl.12348
Scheffer, M. (2010) Complex systems: foreseeing tipping points. *Nature*, 467, 411–412.
Scheffer, M., Bascompte, J., Brock, W.A., Brovkin, V., Carpenter, S.R., Dakos, V. et al. (2009) Early-warning signals for critical transitions. *Nature*, 461, 53–59.
Scheffer, M., Carpenter, S.R., Lenton, T.M., Bascompte, J., Brock, W., Dakos, V. et al. (2012) Anticipating critical transitions. *Science*, 338, 344–348. Available from: https://doi.org/10.1126/science.1225244
Scholl, M.P., Calinescu, A. & Farmer, J.D. (2021) How market ecology explains market malfunction. *Proceedings of the National Academy of Sciences of the United States of America*, 118, e2015574118. Available from: https://doi.org/10.1073/pnas.2015574118
Schwarcz, S.L. (2019) Systematic regulation of systemic risk. *Wisconsin Law Review*, 1, 1–53.
Schweitzer, F., Fagiolo, G., Sornette, D., Vega-Redondo, F., Vespignani, A. & White, D.R. (2009) Economic networks: the new challenges. *Science*, 325, 422–425. Available from: https://doi.org/10.1126/science.1173644
Shea, K., Runge, M.C., Pannell, D., Probert, W.J.M., Li, S.-L., Tildesley, M. et al. (2020) Harnessing multiple models for outbreak management. *Science*, 368, 577–579. Available from: https://doi.org/10.1126/science.abb9934
Shrestha, N., Shad, M.Y., Ulvi, O., Khan, M.H., Karamehic-Muratovic, A., Nguyen, U.-S.D.T. et al. (2020) The impact of COVID-19 on globalization. *One Health*, 11, 100180. Available from: https://doi.org/10.1016/j.onehlt.2020.100180
Sieczka, P., Sornette, D. & Holyst, J.A. (2011) The Lehman brothers effect and bankruptcy cascades. *The European Physical Journal B*, 82, 257–269. Available from: https://doi.org/10.1140/epjb/e2011-10757-2
Silva, S. & Pena, L. (2021) Collapse of the public health system and the emergence of new variants during the second wave of the COVID-19 pandemic in Brazil. *One Health*, 13, 100287. Available from: https://doi.org/10.1016/j.onehlt.2021.100287
Simpson, N.P., Mach, K.J., Constable, A., Hess, J., Hogarth, R., Howden, M. et al. (2021) A framework for complex climate change risk assessment. *One Earth*, 4, 489–501. Available from: https://doi.org/10.1016/j.oneear.2021.03.005
Singh, S., Bartos, M., Abdalla, S., Legido-Quigley, H., Nordström, A., Sirleaf, E.J. et al. (2021) Resetting international systems for pandemic preparedness and response. *BMJ*, 375, e067518. Available from: https://doi.org/10.1136/bmj-2021-067518
Smolyak, A., Levy, O., Vodenska, I., Buldyrev, S. & Havlin, S. (2020) Mitigation of cascading failures in complex networks. *Scientific Reports*, 10, 16124. Available from: https://doi.org/10.1038/s41598-020-72771-4
Søgaard Jørgensen, P., Folke, C., Henriksson, P.J.G., Malmros, K., Troell, M., Zorzet, A. et al. (2020) Coevolutionary governance of antibiotic and pesticide resistance. *Trends in Ecology & Evolution*, 35, 484–494. Available from: https://doi.org/10.1016/j.tree.2020.01.011
Stavroglou, S.K., Pantelous, A.A., Stanley, H.E. & Zuev, K.M. (2020) Unveiling causal interactions in complex systems. *Proceedings of the National Academy of Sciences of the United States of America*, 117, 7599–7605. Available from: https://doi.org/10.1073/pnas.1918269117
Steffen, W., Richardson, K., Rockstrom, J., Cornell, S.E., Fetzer, I., Bennett, E.M. et al. (2015) Sustainability. Planetary boundaries: guiding human development on a changing planet. *Science*, 347, 1259855. Available from: https://doi.org/10.1126/science.1259855
Steffen, W., Rockström, J., Richardson, K., Lenton, T.M., Folke, C., Liverman, D. et al. (2018) Trajectories of the earth system in the Anthropocene. *Proceedings of the National Academy of Sciences of the United States of America*, 115, 8252–8259. Available from: https://doi.org/10.1073/pnas.1810141115
Sterman, J.D. (2006) Learning from evidence in a complex world. *American Journal of Public Health*, 96, 505–514. Available from: https://doi.org/10.2105/AJPH.2005.066043
Stuckler, D., Reeves, A., Loopstra, R., Karanikolos, M. & Mckee, M. (2017) Austerity and health: the impact in the UK and Europe. *European Journal of Public Health*, 27, 18–21. Available from: https://doi.org/10.1093/eurpub/ckx167
Sugihara, G., May, R., Ye, H., Hsieh, C.-H., Deyle, E., Fogarty, M. et al. (2012) Detecting causality in complex ecosystems. *Science*, 338, 496–500. Available from: https://doi.org/10.1126/science.1227079
Suhrcke, M., Stuckler, D., Suk, J.E., Desai, M., Senek, M., Mckee, M. et al. (2011) The impact of economic crises on communicable disease transmission and control: a systematic review of the evidence. *PLoS One*, 6, e20724. Available from: https://doi.org/10.1371/journal.pone.0020724
Tainter, J.A. (1988) *The collapse of complex societies, Cambridge*. Cambridgeshire; New York: Cambridge University Press.
The British Academy. (2021) *The COVID Decade: understanding the long-term societal impacts of COVID-19 [Online]*. Available

from: https://www.thebritishacademy.ac.uk/publications/covid-decade-understanding-the-long-term-societal-impacts-of-covid-19/ [Accessed 4 April 2021].
The Collins. (2022) *The Collins word of the year 2022 is … permacrisis [Online]*. Available from: https://www.collinsdictionary.com/woty [Accessed 13 December 2022].
Thiel, A., Blomquist, W.A. & Garrick, D.E. (2019) *Governing complexity: analyzing and applying polycentricity*. Cambridge: Cambridge University Press.
Thurner, S., Klimek, P. & Hanel, R. (2018) *Introduction to the theory of complex systems*. Oxford: Oxford University Press.
Topp, S.M. (2020) Power and politics: the case for linking resilience to health system governance. *BMJ Global Health*, 5, e002891. Available from: https://doi.org/10.1136/bmjgh-2020-002891
Toynbee, A.J. & Somervell, D.C. (1987a) *A study of history: abridgement of volume 1–6*. New York and Oxford: OUP.
Toynbee, A.J. & Somervell, D.C. (1987b) *A study of history: abridgement of volume 7–10*. New York and Oxford: Oxford University Press.
Tu, Y. (2000) How robust is the internet? *Nature*, 406, 353–354. Available from: https://doi.org/10.1038/35019222
Turchin, P. (2003) *Historical dynamics: why states rise and fall*. Princeton University Press: Princeton.
Turchin, P. (2016a) *Ages of discord*. Chaplin, CT: Beresta Books.
Turchin, P. (2016b) *Ultrasociety: how 10,000 years of war made humans the greatest cooperators on earth*. Chaplin, CT: Beresta Books.
Turchin, P., Whitehouse, H., Gavrilets, S., Hoyer, D., François, P., Bennett, J.S. et al. (2022) Disentangling the evolutionary drivers of social complexity: a comprehensive test of hypotheses. *Science Advances*, 8, eabn3517. Available from: https://doi.org/10.1126/sciadv.abn3517
Turner, B.L., 2nd, Kasperson, R.E., Matson, P.A., Mccarthy, J.J., Corell, R.W., Christensen, L. et al. (2003) A framework for vulnerability analysis in sustainability science. *Proceedings of the National Academy of Sciences of the United States of America*, 100, 8074–8079. Available from: https://doi.org/10.1073/pnas.1231335100
Ungar, M. (2021) *Multisystemic resilience: adaptation and transformation in contexts of change*. New York and Oxford: Oxford University Press, USA.
United Nations Office for Disaster Risk Reduction. (2015) *Sendai Framework for Disaster Risk Reduction. 2015-2030*.
Upshaw, T.L., Brown, C., Smith, R., Perri, M., Ziegler, C. & Pinto, A.D. (2021) Social determinants of COVID-19 incidence and outcomes: a rapid review. *PLoS One*, 16, e0248336. Available from: https://doi.org/10.1371/journal.pone.0248336
Valdez, L.D., Shekhtman, L., La Rocca, C.E., Zhang, X., Buldyrev, S.V., Trunfio, P.A. et al. (2020) Cascading failures in complex networks. *Journal of Complex Networks*, 8, 1–23. Available from: https://doi.org/10.1093/comnet/cnaa013
Valensise, C.M., Cinelli, M., Nadini, M., Galeazzi, A., Peruzzi, A., Etta, G. et al. (2021) Lack of evidence for correlation between COVID-19 infodemic and vaccine acceptance. *arXiv preprint arXiv:2107.07946*.
Vallier, K. (2021) *Trust in a polarized age*. New York and Oxford: Oxford University Press.
Vespignani, A. (2010) Complex networks: the fragility of interdependency. *Nature*, 464, 984–985.
Vespignani, A. (2012) Modelling dynamical processes in complex socio-technical systems. *Nature Physics*, 8, 32–39. Available from: https://doi.org/10.1038/nphys2160
Wang, N., Wu, N., Dong, L.-L., Yan, H.-K. & Wu, D. (2016) A study of the temporal robustness of the growing global container-shipping network. *Scientific Reports*, 6, 34217. Available from: https://doi.org/10.1038/srep34217
Wangersky, P.J. (1978) Lotka-Volterra Population Models. *Annual Review of Ecology and Systematics*, 9, 189–218. Available from: https://doi.org/10.1146/annurev.es.09.110178.001201
Watts, D.J. (2002) A simple model of global cascades on random networks. *Proceedings of the National Academy of Sciences of the United States of America*, 99, 5766–5771. Available from: https://doi.org/10.1073/pnas.082090499
Weiss, T.G. & Wilkinson, R. (2021) *Global governance futures*. Abingdon and New York: Routledge.
Welsh, M. (2014) Resilience and responsibility: governing uncertainty in a complex world. *The Geographical Journal*, 180, 15–26.
Wernli, D. (2021) *LERU statement on the role of academic institutions in building resilient and sustainable societies*. Leuven: League of European Research Universities.
Wernli, D., Clausin, M., Antulov-Fantulin, N., Berezowski, J., Biller-Andorno, N., Blanchet, K. et al. (2021) Building a multisystemic understanding of societal resilience to the COVID-19 pandemic. *BMJ Global Health*, 6, e006794. Available from: https://doi.org/10.1136/bmjgh-2021-006794
Wernli, D., Tediosi, F., Blanchet, K., Lee, K., Morel, C., Pittet, D. et al. (2021) A complexity lens on the COVID-19 pandemic. *International Journal of Health Policy and Management*, 11, 2769–2772. Available from: https://doi.org/10.34172/ijhpm.2021.55
Westley, F.R., Tjornbo, O., Schultz, L., Olsson, P., Folke, C., Crona, B. et al. (2013) A theory of transformative agency in linked social-ecological systems. *Ecology and Society*, 18, 1–16. Available from: https://doi.org/10.5751/ES-05072-180327
Wiesner, K., Birdi, A., Eliassi-Rad, T., Farrell, H., Garcia, D., Lewandowsky, S. et al. (2018) Stability of democracies: a complex systems perspective. *European Journal of Physics*, 40, 014002. Available from: https://doi.org/10.1088/1361-6404/aaeb4d
Yabe, T., Rao, P.S.C., Ukkusuri, S.V. & Cutter, S.L. (2022) Toward data-driven, dynamical complex systems approaches to disaster resilience. *Proceedings of the National Academy of Sciences of the United States of America*, 119, e2111997119. Available from: https://doi.org/10.1073/pnas.2111997119
Yang, Y., Nishikawa, T. & Motter, A.E. (2017) Small vulnerable sets determine large network cascades in power grids. *Science*, 358, eaan3184. Available from: https://doi.org/10.1126/science.aan3184
Yin, Y., Gao, J., Jones, B.F. & Wang, D. (2021) Coevolution of policy and science during the pandemic. *Science*, 371, 128–130. Available from: https://doi.org/10.1126/science.abe3084
Young, O.R. (2017a) Beyond regulation: innovative strategies for governing large complex systems. *Sustainability*, 9, 938.
Young, O.R. (2017b) *Governing complex systems: social capital for the anthropocene*. Cambridge, MA: The MIT Press.
Young, O.R. (2021) *Grand challenges of planetary governance*. Cheltenham and Horthampton: Edward Elgar Publishing.
Youngs, R. (2022) COVID-19 and democratic resilience. *Global Policy*, 1–8. Available from: https://doi.org/10.1111/1758-5899.13137
Yuan, X., Hu, Y., Stanley, H.E. & Havlin, S. (2017) Eradicating catastrophic collapse in interdependent networks via reinforced nodes. *Proceedings of the National Academy of Sciences of the United States of America*, 114, 3311–3315. Available from: https://doi.org/10.1073/pnas.1621369114
Zeeman, E.C. (1979) *Catastrophe theory. Structural stability in physics*. Berlin and Heidelberg: Springer.
Zhong, J., Zhang, F., Yang, S. & Li, D. (2019) Restoration of interdependent network against cascading overload failure. *Physica A: Statistical Mechanics and its Applications*, 514, 884–891. Available from: https://doi.org/10.1016/j.physa.2018.09.130

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