Governing Complexity: Design Principles for the Governance of Complex Global Catastrophic Risks

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Abstract

Why are existing global governance structures "not fit for purpose" when it comes to addressing complex global catastrophic risks (CGCR) such as climate breakdown, ecosystem collapse, or parasitic artificial general intelligence? This article argues that a deeper appreciation of these risks as complex – as opposed to complicated – is vital to an effective global governance response. It joins other IR scholarship seeking to invigorate a rigorous research agenda on complex system dynamics within world politics, highlighting the value of complexity theory, not simply as a contextual descriptor, but as a conceptual toolkit to inform CGCR governance research and action. Taking seriously the implications of "restricted complexity," it interrogates why the legacy governing toolkit – the assumptions, heuristics, models, and practices conventionally employed to solve international collective action problems – are unlikely to suffice. It further draws laterally upon design science to offer a novel design model for governing complex systems, with broad application across global policy domains. A case study of the COVID-19 pandemic response illustrates the importance of supplementing inherited "complicated" governance system design and practices with design principles explicitly oriented to working with complexity, rather than against it. We contend that IR scholars and practitioners must update old ways of thinking in light of a complexification of the discipline. Such a shift involves both revisiting the design logics underlying how we build global governance structures, as well as pursuing a generative research agenda more capable of responding adequately to instability, surprise, and extraordinary change.

Introduction

From climate change and ecosystem collapse to parasitic artificial general intelligence or deadly pandemics, we confront daunting challenges within an increasingly globalized civilization, where catastrophic failure anywhere could mean failure everywhere. Global catastrophic risks (GCRs) refers to the threat that slow-moving changes or sudden disruptions pose to an interconnected global system through feedback and contagion effects (Goldin and Mariathasan 2014). These risks are catastrophic in the sense that they "have the potential to inflict serious damage to human well-being on a global scale," potentially threatening the continuation of human civilization as we know it (Bostrom and Ćirković 2008, 1). Due to the tightly coupled linkages of global social, economic, technological, and ecological systems, societies confront multiple emergent and systemic risks that threaten "the possibility of a catastrophic regime shift or even breakdown of a global system that involves many interacting elements that are poorly understood" (Lucas et al. 2018, 294). Our future governance system will have to contend with intensifying natural and social boundaries for the preservation of human civilization, from biosphere fragility points to increasing asymmetric power of individuals to affect disruption – all within imminently shorter timescales than most people can intuit (Rockström et al. 2009).

GCRs are often categorized along variables that indicate their level of *severity*, such as scope, intensity, and probability (Bostrom and Ćirković 2008, 3). We suggest that, from a governance perspective, another crucial variable is level of *complexity*, i.e. the degree to which GCRs are systemically produced and amplified. Some long-standing GCRs, while undoubtedly severe, have relatively low levels of complexity, either because they are largely external to human systems (e.g. asteroid impact) or because they involve a bounded number of key decision-makers (e.g. nuclear war). The focus of this article is a growing number of complex global catastrophic risks (CGCRs) that endogenously arise out of the interactions between human and non-human (natural and technological) systems (Avin et al. 2018). High levels of connectivity, openness, nonlinear dynamics, and emergent properties which produce frequent surprises make it impossible to isolate and "manage" these inherently systemic CGCRs (Young 2017).

Environmental breakdown due to climate change or mass loss of biodiversity constitutes such "a new, highly complex and destabilized 'domain of risk' – which includes the risk of the collapse of key social and economic systems, at local and potentially even global levels" (Laybourn-Langton et al. 2019, 5). Growing global connectivity and increasing human encroachment on ecological systems also facilitates the emergence and spread of deadly infectious diseases, such as coronavirus (COVID-19), with consequences that cascade far beyond public health systems. These and other global threats increasingly play out in the context of rapid developments in artificial intelligence (AI) and information technology which render risk environments even "more diffuse, dispersed, multi-dimensional, nonlinear, and ambiguous" (Arquilla and Ronfeldt 2001, 2), and may themselves constitute CGCRs.

Of course, CGCRs are nothing new to scholars and practitioners working in the well-established areas of climatology, risk management, resilience, and cognate fields (Walker and Salt 2006). These disciplines are especially attentive to the risks of "tipping points," "cascading failures," and systemic breakdown (Avin et al. 2018). An interest in complex or "wicked" problems is also long-standing in public policy scholarship, although, as Alford and Head (2017, 398) observe, the term is often applied without a clear understanding of what makes a problem more or less "wicked." While rarely addressed explicitly (for exceptions, Harrington 2016; Levin et al. 2012), a focus on CGCRs in global political scholarship is readily apparent, especially in the sub-domains of environmental and resilience governance (Galaz 2014; Castro Pereira and Viola; Bernstein and Hoffman 2019). Complexity theory (often referred to as the study of Complex Adaptive Systems) has also long-informed International Relations (IR) and global governance research (Jervis 1997).

This article joins IR scholarship seeking to invigorate a rigorous research agenda on complex system dynamics within a globalized world politics (Orsini et al. 2019). Why is a deeper appreciation of complexity vital to an effective multi-level governance response to global risks? We argue that the complexity of CGCRs is overwhelming the organizational logic of the postwar multilateral order. Operating within a Newtonian-Cartesian paradigm, its architects relied on institutional design principles geared towards addressing *complicated* problems, (seemingly) amenable to linear causal analysis, command-and-control hierarchy, and pareto-optimal solutions. Where problems could be reasonably isolated from underlying sub-systems, this top-down problem-solving approach delivered some notable successes, such as control of ozone-depleting substances under the Montreal Protocol. However, today these legacy design principles are increasingly rendered obsolete in the face of novel problems playing out in complex technological, economic, ecological, and social assemblages operating across different socio-spatial scales (DeLanda 2006).

In making this argument, we highlight the value of complexity theory, not simply as a contextual descriptor of change, but as a conceptual toolkit to inform CGCR governance research and action. We draw upon recent conceptual innovation in the form of "restricted complexity," developed by Morin (2007) and, most recently, Brosig (2019), to specify the task environment posed by real-world global systems. By conceptualizing openness, nonlinearity, and self-organization as relative, not absolute, features of complex systems, restricted complexity avoids too simplistic dichotomies, opening up inquiry into *levels of* complexity displayed by global policy problems and the degree to which they simultaneously contain complicated and complex elements. Rather than implying ungovernable change and inherent unpredictability, restricted complexity emphasizes contingent but systemic effects which produce regularities, recognizable patterns, and recurring mechanisms (Geyer 2003). This approach echoes ongoing scholarly efforts to position complexity theory as a "middle ground," capable of accommodating different epistemological and methodological pathways towards better explanations of global political transformation (Gunitsky 2013, 57).

We propose to supplement inherited global governance system design with design principles explicitly oriented to working with complexity, not against it. In doing so, we also contend that IR scholars must update old ways of thinking in light of the complexification of the discipline. Such a shift involves both revisiting the design logics underlying how we build global governance structures, as well as advancing a generative "complex IR" research agenda more capable of responding adequately to extraordinary change (Kavalski 2015). Our contribution to this endeavor draws laterally upon complexity system theory and design science to offer a policy-relevant design model for governing CGCRs, with broad application across substantive domains. A case study of the COVID-19 pandemic response illustrates the value of this novel design model. It also exposes vexing structural constraints, above all the fact that, as Weiss and Wilkinson (2014, 213) lament, "[e]verything is globalized – that is, everything except politics."

The article begins by applying a complex systems perspective to CGCRs, highlighting the value of integrating complexity theory into IR scholarship and the analytical utility of recent conceptual innovation, with a focus on restricted complexity. Next, it turns to the challenge of governing CGCRs in light of the COVID-19 pandemic response. Drawing on IR scholarship, design science, and complexity theory, the article illustrates the importance of supplementing inherited "complicated" system design and practices with design principles explicitly oriented to dealing with CGCRs.

Complex Systems Analysis and Global Catastrophic Risks

Why is an understanding of complex system dynamics so important to governing CGCRs? Complexity brings into focus the reasons underlying the governance gap between actor intentionality and expectations versus actual policy outcomes. Awareness of the properties of complex systems, above all openness, emergent properties, nonlinear and adaptive dynamics, encourages scholars and practitioners to reframe the problem and, in doing so, seek out new understandings of what complex governance entails (Jervis 1997). In this spirit, governing CGCRs first requires identifying them as such (Peters 2005).

A complex problem can be distinguished from a *complicated* problem. Complicated problems follow an ordered and linear logic, amenable to additive models of causality (Brunnée 2019, 212). They can have many components, but the relationships between the components are fixed, clearly defined, and can be individually distinguished. As such, complicated problems can be highly intricate, but they are ultimately "knowable through proper investigation, and relationships between cause and effect, once discovered, repeat" (Snowden 2005, 46). An ideal-typical example of a complicated system is a jet engine. Anyone with sufficient expertise can understand, control, and predict the behavior of the engine, using a reductionist analytical approach. Governance problems that are relatively static, scale-free, and easy to isolate (e.g. development, production, and distribution of a COVID-19 vaccine) are also amenable to "jet engine solutions:" expert-driven strategies, rational planning, clear task division, and a rules-based governing framework.

CGCRs and other complex problems are fundamentally different to complicated problems. They arise endogenously out of open systems, where elements constantly interact with each other and their environment, giving rise to emergent behavior that cannot be understood in terms of the properties of system elements but only in terms of the relationships between them (Cilliers 1998, 3). Because variation in input can be magnified or dampened by feedback, interactions do not follow linear and controllable patterns, hampering our ability to explain and predict change. With system behavior emerging from the bottom up, the Newtonian mechanics of cause and effect are no longer applicable, meaning that problems cannot be understood and solved by breaking them down into component parts (Mobus and Kalton 2015, 11). Complex systems also self-organize through the simultaneous actions of individual elements, involving parallel processes of adaptation and co-evolution (Gunitsky 2013, 41-3).[1] Although openness, emergence, nonlinearity, and self-organization imply a loss of top-down control and predictive capacity, it is important to note that elements in complex systems do not randomly interact, but usually follow certain rules. While we cannot foresee system behavior, we can identify relational patterns, repeat interactions, path dependencies, and broad directions of change. This makes complex systems at once rule-bound, surprising and, perhaps, governable.

[1] Because of this ability to adjust collectively to new realities, complex systems are sometimes referred to as complex adaptive systems (Holland 1992).

Determining whether a system or policy problem is complicated or complex matters, informing the potential for purposeful interventions at different stages or scales of governance. IR scholarship has only just begun to acknowledge the utility of this distinction (Oatley 2019, 5), recognizing that global economic, political, social, and cultural systems are not remarkably complicated closed mechanical systems, but rather complex systems, displaying varying degrees of openness, emergence, nonlinearity, and adaptive capacity. As Poli (2013, 143) observes, the objective attributes used to *classify* a system as complicated (e.g. the properties of its constituent units and structures) are different to the properties used to *understand* a system as complex. So while the properties that make a system complex can mirror a complicated system, a complex system is a combination of those attributes (ontological complexity) and simultaneously "a function of our present understanding of the system" (epistemological complexity) (Preiser and Cilliers 2010, 266). This helps explain why complex problems are often misclassified and treated as complicated, resulting in ineffective, even counter-productive, attempts to impose a mechanical system logic onto problems which defy linear solutions.

It is important to not conflate complicated and complex problems. However, it is also difficult to maintain this distinction consistently, given that modern systems are "both hideously complicated and bewilderingly complex" (Mulgan and Leadbeater 2013, 43). In practice, global policy problems almost always simultaneously contain complicated (and even simple) subsidiary problems, but are not reducible to either due to the challenge of establishing definitive boundary conditions for mechanisms or subsystems across scales. COVID-19 provides such an example in this study. As will become apparent, CGCR governance design must therefore attend to overlapping orderly and complex environments. It must also contend with differing *degrees of* complexity. IR scholarship has sharpened the observation of Duit and Galaz (2008, 318) that there is a "vast difference" between governing disorderly systems characterized by ubiquitous change and uncertainty versus really-existing complex systems populated by strategic and purposeful co-adaptive agents. For Morin and Gomez-Mera (2019, 19), complexity is a continuum, not a dichotomous variable. They argue that the complexity of a system will correspond to variation in system characteristics (number and diversity of units, density of their interconnections, multiplicity of scales, and degrees of interactions with the external environment).

The concept of "restricted complexity" defined by Brosig (2019, 12) to describe semi-open systems, characterized by "multiple causality, but not nonlinearity or linear relations, where authority is rather decentered than centralized or fully self-organized" is emblematic of recent efforts to systemize IR as simultaneously containing complicated and complex systems (*see also* Gunitsky 2013). First coined by Morin (2007), the notion of *restricted* complexity holds out the promise of bridging the basic insights of complex systems with more orthodox IR analytical instruments focused on capturing interactions among mechanisms and generalizable relationships (Sil and Katzenstein 2010). Scholars admit that syncretizing complexity and epistemological parsimony is a vertiginous challenge, but argue that such a bold move is necessary if complex IR is to engage in theory building and useful, if contingent, explanations of the external world (Gunitsky 2019, 707).

For our purposes, restricted complexity allows us to specify and differentiate among global systems populated by "multiple actors, at a variety of spatial scales, that engage in complex interactions according to nonlinear and networked patterns" (Bousquet and Curtis 2011, 51). Empirical research on trade (Morin and Gomez-Mera 2019), transnational business (Eberlein et al. 2014), peacekeeping (Brosig 2019), global governance (Zürn 2018), international law (Brunnée 2019), regime complexes (Alter and Meunier 2009), global health (Moon 2019), and democratic diffusion (Gunitsky 2013) indicate the value of taking seriously the characteristics of restricted complexity – semi-openness, multiple causality, and dispersed authority – for understanding endogenous sources of global political change, with strategic co-adaptive actors competing or cooperating in the absence of centralized hierarchy. Above all, these dynamics direct our attention to the system as the unit of analysis. Although this holistic perspective sits uneasily with the dominant positivist (experimental scientific) orientation of much IR scholarship (Monteiro 2012), calls to move beyond "the rigid separation of systemic and unit-level effects" (Gunitsky 2013, 37) are gaining traction. This serves as a powerful additive to agent-centric IR, inviting the analyst to consider how the system imposes itself upon the choices and capabilities of actors through "recurring, identifiable, and non-obvious mechanisms" (Gunitsky 2013, 44). It also brings into focus the question of scale and the need to study actors, mechanisms, and institutions within their respective spatio-temporal contexts. For CGCR governance design, it reinforces the importance of knowing what type of system – whether orderly, complex, or disorderly – you are intervening in, and adjusting your epistemological and methodological strategy accordingly. The next section departs from this premise, demonstrating why correct problem specification is key to CGCR governance.

Governing Complexity: Why Existing Structures Are Not Fit for Purpose

Really-existing global governance structures, understood principally as the domain of legalized interstate multilateralism, are widely viewed as unfit for purpose, incapable of responding to pressing global problems (Coen and Pegram 2018, 107). The UN Secretary-General, Antonio Guterres, warns of "a great fracture" imperiling the entire multilateral system (qtd. in UN News 2019). While few disagree that legacy multilateral structures require reform if they are to respond to CGCRs, the scale of reform required provokes vigorous debate (Plesch and Weiss 2015). An avalanche of expert advice on what must be done belies the relative lack of consensus over causal explanations for global regulatory failure, or its solution.

What can complexity theory bring to this debate? First, complexity brings to the fore foundational questions underpinning a "policy-relevant science of institutional design" (Wendt 2001, 1047): How and why have design choices been made in the past? What works? And what goals should we pursue? This section identifies the true design problem which CGCRs pose to global governance structures, why the "complicated" legacy toolkit – the assumptions, heuristics, models, and practices conventionally employed to solve policy problems – is unlikely to suffice, and why engaging the implications of complex systems behavior is now vital.

The Design Problem Confronting Global Governance Structures

What is the design problem confronting global governance structures? There is no shortage of candidates. Background system conditions provide important clues. As Homer-Dixon (2007, 14) argues, globalization is "not just a process of growing economic interdependence" but rather "an almost vertical rise in the scope, connectedness, and speed of *all* humankind's activities and impacts." Decision-makers must contend with increasingly open, rapidly-changing global systems, intimately linked with large-scale natural and technological systems. From climate change to health pandemics to financial crises, it is now impossible to ignore "the power of the global" within local political processes and outcomes (Hurrell 2017, 39). And yet, while such global problems demand global solutions, that demand has not translated into structures capable of governing at this highest level of political assembly. International regimes, and in particular their core multilateral structures, remain significantly constrained by unit-level interactions: the competing preferences of nation states.

For liberal functionalist scholars, post-war legacy structures have served to facilitate interstate coordination and political cooperation, deepening interdependence, and globalization as a result (Abbott and Snidal 1998). This has set in motion processes of "self-reinforcing interdependence," helping "create conditions that, ironically, now impede [multilateral] effectiveness" (Hale et al. 2013, 66). Hale and Held (2018, 130) argue that self-reinforcing interdependence has produced four "second order" cooperation problems: growing multipolarity, harder problems, institutional inertia, and fragmentation. However, as Barnett and Finnemore (2004) demonstrate, international organizations are not just functional throughputs for collective action problems. Reflecting this more critical line of inquiry, Zürn (2018) argues that the arbitrary authority accrued to supranational structures is endogenously fomenting contestation and resistance from below, fueling legitimation problems. Other scholars have consistently questioned the strong cooperation narrative in liberal accounts of multilateralism, inquiring how and by whom governance problems have been defined (Acharya 2014). It is salutary to remember that multilateral structures have not been predominantly designed to attend solely to "well-understood collective action problems," but have always been in the business of "managing power, especially unequal power" (Hurrell 2017, 25).

The governance of CGCRs must contend with these multiple power-political and organizational challenges. It is a formidable task, made harder by the fact that the architects of the post-war multilateral order did not have the technical and conceptual apparatus to design solutions for the types of global problems which these institutions are now called upon to solve. Hale et al. (2013, 81) argue that "problems have got harder" both in their "extensity" ("scope of problems has increased") and their "intensity" ("problems penetrate more deeply into societies"). This is an important point. However, while descriptively instructive, "extensity" and "intensity" provide only partial insight into the true design problem posed by global policy dilemmas. Specifically, the terms fail to engage fully with the implications of key characteristics of complex systems; above all, differing degrees of openness and nonlinearity which tests the limits of existing governance systems to cope with change and uncertainty.

Legacy structures, from the UN Security Council to the General Agreement on Tariffs and Trade (subsequently the World Trade Organization), were originally geared towards managing primarily complicated problems such as maintaining interstate peace and tariff harmonization among industrialized nations. Many of these issues involved difficult negotiations but few required deeply global and systemic interventions. Today, multilateral venues must not only wrestle with a growing list of competing state demands but are regularly called upon to "manage" complex system behavior – a daunting task even if all states showed extraordinary levels of support. Climate change, for example, poses a unique challenge, requiring deep and radical structural interventions across complex socio-economic and technical systems (Bernstein and Hoffmann 2019). Other long-standing problems have become more complex as global connectivity has grown, as illustrated by a move from traditional to "networked" security (Avant and Westerwinter 2016) or the increasing frequency of hard-to-contain infectious disease outbreaks (Jones et al. 2008).

We contend that contemporary global governance problems must be understood in terms of a relative shift from "complicated" to "complex," rather than "hard" to "harder." More complexity is not necessarily a bad thing. Indeed, with appropriate governance frameworks in place, complexity could be "the most productive" realm for human interaction (Geyer and Pickering 2011, 14). However, as global problems have become more complex, global governance structures have become ever-more complicated and, as a result, less resilient and increasingly maladaptive. The continual addition of complicated functions often increases complexity even further (Arthur 1994, 70). As such, accelerating efforts to enhance global system coordination have helped produce the very conditions whereby the mechanisms for dealing with a more volatile world are now more susceptible to failure. Importantly, maladaptive outcomes are not always accidental. Unlike complicated problems which operate under conditions close to, or in, equilibrium, complex social problems have a history; generating path dependencies and power asymmetries which are difficult to anticipate or override. As such, powerful actors often advocate new layers of complicated bureaucracy to "block or divert policies that genuinely address the problems' underlying causes" (Homer-Dixon 2007, 267).

The problem also lies at a more axiomatic level. As Geyer (2003, 241) notes, the present multilateral system was established when the linear reductionist paradigm reached its zenith in the social sciences, as well as in the Western policy community. Operating within a Weberian mechanization-bureaucratization paradigm, strongly informed by an ascendant neoclassical economics, the architects of the multilateral system engineered its structures according to certain design principles, including role definition, bureaucratic chains of command, expert specialization, legal hierarchies, and the building up of capacities to tackle very specific problems. Although reform and the addition of new components is a feature of past decades, updates generally reinforce old design logics with increasingly dysfunctional results. The failure of the complicated paradigm for resolving complex problems is particularly evident in the climate domain, where efforts to reduce emissions through top-down target-setting under the 1997 Kyoto Protocol have contributed little to halt global warming (Rosen 2015). While the 2015 Paris Agreement provides a promising enabling framework for "pragmatic complex multilevel governance" (Harrison and Geyer 2019, 24), this potential will not be fully realized absent due recognition of the deeply systemic nature of the climate change challenge.

However, it is important to emphasize that the legacy toolkit remains important to determining "what works" in relation to policy-applied interventions in appropriate contexts: constrained environments, conducive to probabilistic assessment, and amenable to complicated outcomes. At a more macro-systems scale, decision-makers often confront policy challenges displaying both complex and complicated problems playing out on different scales. The notion of restricted complexity is helpful here. By encouraging explicit specification of enabling and constraining system features at different scales – semi-openness, multiple causality, dispersed authority – restricted complexity provides a heuristic framework for contingent causal description to be updated in light of new information. This reflects a governance reality which requires policymakers to navigate a continual cycle between the political interdependencies and multi-scalar boundaries of global problems.

As we explore below, COVID-19 provides an illustration of the governance challenges posed by overlapping task environments and differing degrees of complexity. Given the importance of expert inquiry and top-down infection control measures, the pandemic could be mistaken for a purely complicated problem. However, upon closer inspection, complexity arises in unexpected failures, unintended consequences, and the difficulty of pinning down clear causal relationships. While containment measures, such as border closures and social distancing policies, have demonstrated that social systems can be closed and isolated to a degree, the costs and consequences associated with these interventions have exposed deep linkages and high degrees of interconnection between semi-open global systems (Reynolds 2020). Multiple causality opens up inquiry not just into the initial transmission of COVID-19 to humans but also the complex interactions of human and natural systems which have made transmission more likely in the first place (Brulliard 2020). Finally, as will be discussed, dispersed authority and overlapping hierarchies are conspicuous in the global health space, where the question of "who runs the world and why" is as pertinent as ever (Clinton and Sridhar 2017).

Understanding complexity as a governance design problem demands that IR scholars critically rethink whether "present building codes," "blueprints," and "modest renovations" are adequate to the task (Weiss and Wilkinson 2014, 214). As the next section argues, pioneering research in the field of system design science can inform the hunt for new building codes for governing systemic risks within large-scale social systems. The proven utility of *planned design* for addressing complicated problems persists. However, a new *adaptive design* approach is finding favor among system architects operating in settings of high social complexity. Focused less on predetermined solutions or reacting to emergent characteristics, adaptive design requires above all "stepping into the complex system" (Klijn and Snellen 2009, 34); designing and enabling mechanisms and strategies capable of setting in motion and stabilizing desirable complex outcomes, ever cognizant of the uncertainty posed by complex task environments.

Systems Thinking and Design Science: Planned Versus Adaptive Design

Governing CGCRs is a design problem. But what is design? How might combining complexity thinking and design science improve responses to CGCRs? At root, given that governance structures are rarely designed *ex nihilo*, design is about devising "courses of action aimed at changing existing institutions into preferred ones" (Simon 1996, 111). Outcomes may include the material artefacts that we typically associate with design, such as a building or computer information system, as well as non-material artefacts, such as public policies, management practices or global governance institutions.

The traditional *planned design* model follows a linear step-by-step process: problems are analyzed by breaking them down into component parts (*problem definition*) and these observations are then synthesized, yielding a plan for implementation (*problem solution*) (Buchanan 1992, 15). The underlying assumption is that we can arrive at optimal design solutions and define them a priori. This model of design remains pervasive in policy planning, where continuity and efficiency have long served as important measures of accomplishment (Rittel and Webber 1973). However, in complex environments, "there are no 'solutions' in the sense of definitive and objective answers," and pathways forward may only emerge through observation, experimentation, and experience (ibid, 155). In this context, design is more about "sketching" than about "engineering," "planning" or "constructing" (Chou and Ravinet 2019, 450).

While the traditional model of planned design remains useful for addressing complicated problems, complex problems call for a fundamentally different approach to design that selects flexibility over continuity and effectiveness over efficiency. These and other related attributes are reflected in *adaptive design* approaches that allow for continuous incremental adaptations. The idea of adaptive design emerged first in programming and software design, but it has increasingly found application in policy design for complex social systems, from health and education systems to urban planning (Gerrits and Teisman 2012).

Adaptive design does not produce what software developers call a "Big Design Up Front." Instead of attempting to define a near-perfect solution *a priori*, it starts with a "good enough" model and allows for modifications to evolve and be added in an incremental fashion as patterns of change become visible. This accepts the reality that at "the initial stage of the design process opportunities are rife for mistakes: about what the key issue is, who the relevant parties are, cause-effect relationships, even institutional designers' true interests" (Wendt 2001, 1044). A "good enough" approach does not mean, however, that design evolution is left to chance. While there are no pre-defined, context-independent rules for design development, system architects can use directional goals and enabling constraints – boundary conditions that allow for a range of possible outcomes – to steer complex systems in a desirable direction.

An adaptive approach privileges effectiveness in the long run over short-term efficiency. As Simon (1996, 124) argues, in a complex world, it is advisable "not to follow out one line until it succeeds completely or fails definitely, but to begin to explore several tentative paths, continuing to pursue a few that look most promising at a given moment." Contrary to conventional wisdom, such redundancy, diversity, and overlap of functions is actually desirable in complex environments, promoting experimentation and innovation. Importantly, they also enhance system resilience by ensuring that sudden failure of any individual part can be compensated by others (Kotschy et al. 2015, 53). This is vital with regard to the governance of CGCRs. Small-scale, contained failures may encourage learning, adaptation, and innovation, but system-wide cascading failures would be catastrophic. This mode of thinking is making inroads among decision-makers as the limitations of "one-shot 'big bang' policies" on highly complex problems become increasingly apparent (Levin et al. 2012, 125).

"[D]esign is always to re-design" (Latour 2008, 5), and that is particularly true for adaptive design approaches that do not work towards pre-defined end targets. This new understanding of design also challenges the sequential relationship between problem definition and problem solution. In other words, not only are responses subject to continuous refinement, but also the problem itself changes, so that problem-framing and designed solutions co-adapt (Van der Bijl-Brouwer 2019, 36-7). Diagnostics are crucial but not conclusive, and problem definition is an ongoing process rather than a distinct first step. Importantly, adaptive design approaches also acknowledge that information and knowledge in complex systems are dispersed, localized, and often contested. Therefore, collaborative and deliberative processes are an inherent part of defining the problem and arriving at adaptive design principles capable of enabling a sustainable governance response to CGCRs.

It is also worth flagging parallel debates in public policy and public administration, where a long-standing concern with policy design fell out of fashion in the mid-1990s when rapid globalization and a shift from "government" to market- and network-based "governance" seemed to erode state capacity to engage in policy tool choice and implementation (Howlett and Lejano 2012). However, an emergent strand of public policy scholarship has embraced "governance" as a new dynamic design problem, broadening policy design thinking "beyond policy tool choices, examining combinations of substantive and procedural instruments and their interactions in complex policy mixes" (Howlett et al. 2015, 300). This new wave of scholars has also started to explore the value of cross-fertilizing insights from domestic policy design with the study of global public policy and transnational administration. Importantly as Chou and Ravinet (2019) emphasize, this must happen in a manner that is attentive to questions of power, accountability, and legitimacy, moving away from traditional conceptions of policy design processes as "neutral" and "rational." Such considerations highlight the enduring need for "design" in a globalized and increasingly complex world and inform our design principle approach for CGCRs outlined below.

The Practical Relevance of a Design Principles Approach

Design thinking which integrates insights from complexity theory and design science has much to offer global governance research and practice. For our purposes, it invites critical reflection on how to devise design principles which can guide emergent efforts towards constituting a new toolkit for governing large-scale social systems. Jones (2014, 104) offers a useful definition of design principles:

> Design principles offer guidelines and a foundation for practitioners to enhance engagement and evolve better practices. Principles are elicited from systems theoretic concepts, yet do not propose any new theory. They provide elements for practitioners to form new frameworks enabling integration of other concepts for specific design contexts.

A design principle approach is not intended to be prescriptive, but rather to meet the demands of designers working in social environments characterized by restricted complexity, namely, to combine a stable evolving framework which can allow for as wide a variety of local interactions as possible. Design is that which agents do deliberately. Using principles, they try to anticipate the needs of governance recipients and future ideal states, with a view to enabling "appropriate, organized high-leverage action in the increasingly complex and systemic problems as *design situations*" (Jones 2014, 105). In another sense, this is an exercise in clarifying complexity. As the following case study demonstrates, tailoring interventions to system contexts defined by restricted complexity requires specifying the right mix of complicated and complex policy tools – bringing both orderly and disorderly perspectives into conversation with one another.

COVID-19 Pandemic Response: Utility and Limitations of the Legacy Toolkit

Current global governance structures remain deeply embedded in "complicated" design principles. In the absence of a central hierarchy, international public administration has been endowed with legitimacy derived from formal law, techno-rational management, specialization, and expertise (Kingsbury et al. 2005). Global policy design is expected to follow a step-by-step rational design process, during which decision-makers consult with experts to define and dissect a problem (*problem definition and decomposition*), develop efficient solutions to achieve pre-defined targets (*optimizing problem solutions*), and enable implementation through top-down or delegated enforcement (*implementation planning and execution*) (Hawkins and Jacoby 2006). The advent of CGCRs has exposed the limits of this legacy toolkit which grossly overestimates human capacity to predict, understand, and control global and local change.

However, the orderly, stable, and state-driven legacy structures still have an important role to play. As elaborated above, most CGCRs play out in a context of restricted complexity. As such, effective governance responses to global risks are likely to simultaneously contain complicated and complex problem elements. This case study of the COVID-19 pandemic serves to empirically examine when, where, and how complicated design principles retain utility and why they should be supplemented – not replaced – with a set of more adaptive complex design principles.

Problem Definition and Decomposition

In complicated task environments, where relationships are orderly, knowable, and linear, "techno-rational elites and decision-making are the ideal actors for obtaining the best possible outcomes" (Geyer and Pickering 2011, 6). Relying on substantial expert input and building on past experience, decision-makers can break down problems, establish causal relationships, and make predictions about system behavior. However, high levels of order and predictability rarely apply to real-world global challenges, where restricted complexity reveals recurrent causal patterns and a degree of order, but does not allow us to draw law-like, universally applicable conclusions (Brosig 2019).

Expertise remains undeniably crucial in the context of COVID-19 and other public health emergencies, where generating epidemiological evidence is a first-order priority and science-based policy is of critical importance. Past experience has also proven vital, with countries such as Hong Kong or South Korea able to successfully draw on lessons learned during the recent SARS and MERS outbreaks in their response to COVID-19 (Lancet Editorial 2020). However, there is no one-size-fits-all playbook for preventing or containing a pandemic. This is not only because viruses vary in pathogenic potential, but also because context-specific, emergent system properties have the potential to surprise even well-informed observers. This is particularly true in today's highly interconnected world, where viruses are able to spread fast and far, and the disruptions they cause cascade through global economic, social, and ecological systems (Reynolds 2020).

This task environment calls for a particular kind of self-critical, adaptable, cautious, empirical, and multidisciplinary expertise (Tetlock 2017). Because problems are relationally constituted, they are often difficult to demarcate clearly and observers need to be explicit about the system boundaries of their models and predictions. For example, COVID-19 problem elements and their constituent complexity – configurations of actors, resources, and political opportunity structures – will vary significantly according to scale; whether local, sub-national, national, or global. It is also important to recognize that expertise operates in an environment of strategic interactions. As Benvenisti (2020, 1) notes, the World Health Organization (WHO) is built on the "mistaken assumption" that global health governance poses a classic coordination problem; with major players sincerely committed to achieving a well-understood, shared collective goal. As COVID-19 makes clear, global health governance poses not only *coordination problems*, but also a series of *cooperation problems* riven with competing political, economic, and social demands. Indicative of this problem type, the WHO's technical decision to declare COVID-19 as a Public Health Emergency of International Concern (PHEIC) – the highest level of alert requiring an immediate international response – was mired in interstate discord and political symbolism (Borger 2020).

Ultimately, restricted complexity compels decision-makers to exercise humility with regard to expert predictive capabilities and to accept that problem construction and solution description will be subject to inaccurate, incomplete, and uncertain information ("bounded rationality"). Rather than becoming fixated with individual puzzle pieces, public health decision-makers would be well-advised to step back to appreciate the whole – if incomplete – picture. Bounded rationality also has important political implications. According to Drezner (2009), complexity may serve to advantage well-resourced actors able to impose their preferences on problem framing and solution description through informal channels, with deleterious effects on institutional authority and public accountability.

Optimizing Problem Solutions

Optimization is widely viewed as an axiomatic strategy for rational action in the world (Slote 1989). Functionalist theories of formal international organizations emphasize their ability to "increase the efficiency of collective activities" by providing stable, centralized, relatively autonomous, and "neutral" coordination structures (Abbott and Snidal 1998, 4-5). Although the ideal image of a top-down sequence of authoritative control has long been problematized

(Simon 1974), it persists in IR scholarship on supranational bodies with particularly strong formal powers (Cooper et al. 2008). In complicated task environments, where goals are well-defined, possible solutions can be identified up-front, costs are known, and coordination capacities are high, optimization is a viable goal. Yet, in a world characterized by dense inter-systemic connectivity and "dispersed authority" (Brosig 2019, 11), hierarchical coordination is unable to create and maintain a stable and predictable order. This is particularly true on the global level where inter-systemic coordination efforts confront cooperation problems, without recourse to effective structures of command, delegation, or formal binding obligations (Krisch 2017, 244).

This does not negate the need for global governance. Formal structures providing clear definitions of tasks and relationships remain important, especially in global emergency situations, when fast and decisive action is required. However, COVID-19 has demonstrated the fragility of global response structures and their limited effectiveness in addressing complex problem components. As the pandemic unfolded, the WHO sought to serve as a central hub for information, expertise, and technical assistance, as well as a key facilitator in the development of a vaccine. Yet, it quickly came under fire for its delayed, at times contradictory response and, above all, for its deferential posture towards China. Intense criticism of the WHO culminated in the United States' decision to withdraw from the body – a development which will further undermine the coordination capacity of the already chronically underfunded organization. WHO critics often neglect to note that its design renders it entirely dependent upon state cooperation to achieve its ambitious mandate. The formal authority of the WHO to act without prior approval by member states means little in the absence of powers to compel information-sharing, protective measures, or enforcement.[2] WHO authority is undermined even further in light of the ongoing fragmentation of the global health landscape, which has seen the emergence of a host of new players, both public and private, many of which enjoy more financial resources than the WHO (Clinton and Sridhar 2017).

The politicization of the COVID-19 crisis even extends into ostensibly "scientific" issues, such as the efficacy of face masks in limiting viral transmissions. The hope that a vaccine will provide a "complicated" solution to the pandemic might have to be qualified in light of the

[2] The WHO Constitution grants the Executive Board the authority "to take emergency measures within the functions and financial resources of the Organization to deal with events requiring immediate action" (WHO 2020, Art. 28i).

"complex" challenge of convincing people to be vaccinated (Harrison and Wu2020), as well as the need to counter attempts by powerful countries to corner the market on COVID-19 vaccines (Lexchin 2020). Moreover, as WHO Director-General Tedros Adhanom Ghebreyesus has emphasized, COVID-19 "is much more than a health crisis" (WHO Director-General 2020a). It has exposed the frailty of a global economy that prioritizes efficiency over resilience (Evans 2020), and given rise to a series of unintended secondary and tertiary inter-systemic shocks that cannot be dealt with by the WHO or any single specialized agency. Optimizing policy at the individual country level has also created new problems at the system level, with UN officials sounding the alarm of a "crisis within a crisis" as evidence mounts that COVID-19 response measures are disrupting key supply chains, risking a global food crisis (UN DGC 2020).

COVID-19 presents a situation of genuine uncertainty where numerous known, unknown, and unknowable variables interact and "tickbox" solutions are only viable in limited contexts. Even vaccine development under laboratory conditions requires high tolerance of failsafe trial and error, nonlinear processes, and unexpected immunological responses (Baylor College of Medicine 2020). Extending this biological analogy to governing large-scale social systems, governance becomes more a matter of building resilience, than preventing surprise (Holling 1994). Under conditions of genuine uncertainty, the willingness of decision-makers to depart from the optimizing standard – to minimize control – may be the origin of stable system behavior (Wendt 2001, 1031).

Implementation Planning and Execution

In a complicated environment, "good practice" can be worked out up-front, requiring only minimal adjustments during the implementation process (Snowden and Boone 2007). Rational action can be directed through the use of material incentives and legal enforcement. Much IR research has focused on how to achieve the latter on the international level, either through apex structures with direct binding authority (UN Security Council and supranational judicial bodies) or indirect authority relationships based on legal, procedural, and substantive grounds (Avant et al. 2010). Theories of legalization suggest that rational end-goals can be achieved through rules-based supranational governing frameworks and the toggling of strategic mechanisms (e.g. legal obligation, precision of language, delegation to adjudicator) to enhance and stabilize system function (Abbott et al. 2000).

However, such rule frameworks are often either unavailable or too weak to encourage (powerful) actors to comply, especially when it comes to supplying global public goods (Kaul et al. 1999). Health has a powerful claim to being a core global public good, serving as a precondition, outcome, and indicator of a sustainable society. It is also plagued with disagreements over which goods to produce, at what quantities, for which beneficiaries, and paid for by whom. COVID-19 has placed such concerns in sharp relief, with observers pointing to rampant non-compliance with the formally binding, but non-enforceable, International Health Regulations (IHR) (Wilson et al. 2020). Many states have proven reluctant to follow WHO recommendations on active surveillance, early detection, and response management, with the WHO Director-General (2020b) lamenting "alarming levels of inaction." A request by the WHO for $31.3 billion in funds to assist low- and middle-income states was running a funding gap of $27.9 billion at the close of July 2020 (Kelland and Nebehay 2020). While some have suggested equipping the WHO, or another body, with "powers equivalent to those of a weapons inspector to avoid another catastrophic pandemic" (Probyn 2020), such reform proposals will confront opposition from states who consistently privilege sovereignty over granting the WHO the requisite authority to fulfil its mandate (Stewart 2020).

Even in the absence of intense political conflict, implementation challenges may arise over time as system dynamics change. Nonlinear relationships pose a formidable challenge, as witnessed in the exponential growth curves of COVID-19 infections. However, nonlinear does not mean ungovernable. As the dramatic viral suppression in countries like Hong Kong and New Zealand demonstrate, nonlinear processes can be controlled through adjustable containment measures. Nevertheless, recurrent infection outbreaks in these countries also highlight the social cost of closing open systems (border controls) for a highly interdependent and mobile global populace. Recovery from COVID-19 will require constant learning, taking into account a broad set of values, perspectives, and knowledge. In an increasingly complex world, where the social and economic cost of catastrophe is falling disproportionately on the most vulnerable, the "efficiency rationale" that underpins much discussion of multilateral legitimacy looks increasingly tenuous (Zürn 2018).

The pandemic could have the salutary effect of reminding policymakers that restricted complexity is the norm, not the exception – and we will have to find ways of "living with it, and even taking advantage of it, rather than trying to ignore or eliminate it" (Axelrod and Cohen

2000, 9). Such observations cut against established ways of "doing governance." The exclusionary nationalist pandemic policies of some major states fail to acknowledge that "integrated and complex systems are only as strong their weakest links" (Goldin 2020). COVID-19 is a global catastrophe, but recovery is not in question. The same cannot be said for other global risks, including the possibility of deadlier pandemics. As states continue to withhold data, block WHO access to monitor outbreaks, and refuse to coordinate support to the world's poorest countries, the population and social structures of the global ecumene become less resilient to future CGCRs.

COVID-19 Pandemic Response: Systemic Design Principles and Prototypes for Governing Complex Global Catastrophic Risk

This section illustrates the importance of supplementing the inherited "complicated" system design and practices described above with design principles explicitly oriented to dealing with restricted complexity. Table 1 presents a general complex design model for governing CGCRs, with principles categorized according to major phases in the process of addressing policy problems. In practice, these phases are not mutually exclusive and there is likely to be significant overlap and need for repeat iterations. Complex governance is already being deployed, often uneasily, within existing legacy structures. This may hold out the hope for "refactoring" (undertaking a sequence of small system-preserving changes) to cumulatively produce significant transformation (Fowler 2018). However, others are more skeptical. The cognitive limits of humans will often thwart efforts to intend successful refactoring. In turn, "the exercise of foresight," as Holling (2001, 401) wryly observes, "is often brilliantly directed to protect the positions of individuals rather than to further larger societal goals."

Table 1. Systemic Design Principles for Governing Complex Global Catastrophic Risk

Problem type	Restricted Complexity, where semi-openness, multiple causality, and dispersed authority produce frequent surprises

Goal	Resilient and sustainable design that survives by constantly evolving and adapting to changing circumstances
Governance Phases	**Systemic Design Principles**
Exploration and discovery	1. Assessing scope of complexity 2. Enhancing sensitivity to complexity 3. Transparency 4. Deliberation and participation
Designing and enabling	1. Ordering complexity 2. Boundary-setting and enabling constraints 3. Experimentation and learning 4. Self-preservation (fail-safe)
Stabilization and evaluation	1. Leverage points 2. Feedback coordination and course correction 3. Evaluation and ratcheting 4. Conflict resolution and collective discipline

Problem Identification: Exploration and Discovery

In an increasingly complex world, decision-makers cannot ever fully define, understand, and predict the problems they face. Nevertheless, the risk of catastrophic systemic failure demands that we continuously seek to "make sense" of problems in their changing spatio-temporal contexts (Kurtz and Snowden 2003).

Assessing scope of complexity. Sense-making enables comprehension of ongoing complexity which can serve as a springboard into action (Weick 1995). A situational whole-systems understanding of the problem is required. Sense-making has an explicitly forward-looking orientation, but its goal is not to offer predictions but to identify and connect "chains of contingencies that could shape the future" (Bernstein et al. 2000, 53). For example, the World Economic Forum has produced a dynamic "Transformation Map" to help decision-makers understand the complex interdependencies which inform COVID-19 (WEF 2020). It is crucial that planners grasp such interdependencies, otherwise it is not possible to prioritize. For some observers, a loss of systemic sense-making is itself a serious existential risk (Mecklin 2020, 6-7). Tools such as the Cynefin framework (Snowden and Boone 2007) or the Stacey matrix (Stacey 2002) can help decision-makers assess the situations they operate in, supported by new modelling and data analysis methods. Such tools can be vital to separate complex from complicated task environments and evaluate the degree of openness, nonlinearity, and adaptive capacity displayed by a given system. Policymakers can also make use of new visualization tools, such as "fitness landscapes," which may reveal informative patterns of complex system behavior over time (Geyer and Pickering 2011).

Enhancing sensitivity to complexity. Complex problems cannot be modelled without comprehensive data. The COVID-19 crisis has highlighted a problematic lack of reliable data on the spread of the virus, especially in the Global South (Milan and Trere 2020). As Holling (2004, 9) notes, beyond fast, dynamic variables that trigger readily-observable change (e.g. rise in infections), it is crucial that CGCR analysts also "recognize the sustaining properties of slow variables" where change is harder to detect and/or easier to dismiss (e.g. diminishing resilience of public health systems). Big and open data initiatives hold much promise for identifying indicative patterns in large-scale complex social systems (Gurin and Manley 2015). This potential is already being harnessed to strengthen early warning systems for public health emergencies. Examples include HealthMap and the Global Public Health Intelligence Network (GPHIN) which use multilingual algorithms to monitor web-based data sources for signs of infectious disease outbreaks (Al-Tawfiq et al. 2014). However, to be useful, big data tools require an "openness of analysts and policy makers to discontinuities, a curiosity about anomalous data, and a willingness to engage in speculative thinking" (Feder 2002, 114).

Transparency. CGCR governance should be transparent by design (not just by intention). This is necessary to neutralize game theoretic dysfunctions which create incentives for powerful actors to hoard information. COVID-19 has put the spotlight on transparency failures, from allegations that China delayed the release of vital data (Kuo 2020), to a lack of information on the role and makeup of national pandemic task forces around the world (Rajan et al. 2020). Scholarship suggests at least two key mechanisms for enhancing transparency: first, appropriately designed information environments (Kelley 2017); second, respondents (or "targets") who trust regulators are more likely to generate accurate information (Edelenbos and

Eshuis 2009, 208). Such trust, in turn, must be built through continuous, open, and transparent communication of risks. Clear and consistent public messaging has proven important to encourage compliance and symptom reporting in public health emergencies (Yamanis 2020). On the international level, procedural transparency improvements could enhance compliance with the IHR and specific WHO recommendations (Eccleston-Turner and Kamradt-Scott 2019). Big and open data initiatives may also increase accountability and transparency of governance interventions, encourage collaboration, and promote public participation in decision-making (Gurin and Manley 2015). For example, "citizen science" projects have the potential to advance public agency and trust in emergency situations such as COVID-19 (Provenzi and Barello 2020). However, the move towards big data also raises additional transparency issues regarding its management, along with privacy concerns and the fear that it "may widen existing inequalities and social divides" (Leonelli 2018).

Deliberation and participation. Deliberative mechanisms should complement expert assessments by ensuring a "flow of experiential knowledge through the system" (Wagenaar 2007, 18). Although the critical importance of community involvement and knowledge co-production is well-established in global health, it is frequently ignored in the face of acute health emergencies. Yet, it is precisely "[i]n unstable times when societies are undergoing rapid and far-reaching changes [that] the broadest possible range of knowledge and insights is needed" (Marston et al. 2020, 1677). COVID-19 has brought into sharp relief how pre-existing inequalities can be exacerbated by infectious diseases outbreaks and subsequent governance responses, highlighting the need to give voice to vulnerable and marginalized groups in pandemic policy development. Deliberative and participatory mechanisms can also raise public awareness and understanding of complex task environments, build public support for policy change, and mobilize communities to take action themselves (Hovmand 2014). This is especially important in a post-lockdown context, with containment strategies relying heavily on community cooperation and individual responsibility. There are several ways in which citizens can be directly engaged in problem diagnosis, from the rapid deployment of community engagement taskforces (Marston et al. 2020) to popular assemblies, mini publics or e-democracy solutions (Smith 2009). The latter may provide new opportunities for transnational public deliberation and decision-making, although tools to support this – such as Democracy Earth (2015) – are still in their infancy.

CGCRs are not static and any intervention may change the situation in unforeseeable ways. Broad goal-setting requires supplementing with strategic exploration of possibilities by many agents. Designing and enabling responses to CGCRs requires continuous learning, through coordinated experimentation, simultaneous probing of strategies, feedback loops on success and failure, rapid action to correct failures before they cascade, and incentives for scaling up success.

Ordering complexity. Polycentric governance theory pioneered by Elinor Ostrom (2010) has demonstrated that effective responses to "wicked problems" often emerge from bottom-up dynamics, absent central command-and-control. Modes of collaboration that underpin these responses are diverse, transcending the traditional dichotomy between state and market. Complex governance is not an exercise of superimposition by a "trans-historical designer" (Wendt 2001, 1037), but rather the enabling of progressive, if imperfect, adaptation towards orderly complexity (Jessop 1998, 33). This process has been termed "meta-governance" (Sørensen and Torfing 2009) or "experimentalist governance," understood as "an institutionalized process of participatory and multilevel collective problem solving, in which the problems (and the means of addressing them) are framed in an open-ended way, and subjected to periodic revision by various forms of peer review in the light of locally generated knowledge" (De Búrca et al. 2014, 477). The Sustainable Development Goals (SDGs) represent an ambitious attempt to steer complex global policy problems towards orderly complexity. Indeed, the SDGs could provide a holistic meta-governance framework for COVID-19 response and recovery. Meta-governance on the global level is also increasingly provided by polycentric governance networks that facilitate public-private collaboration to tackle complex challenges across scales. An example is the Global Outbreak Alert and Response Network (GOARN), a network "orchestrated by the WHO" and consisting of public health bodies, technical organizations and laboratories, NGOs, and international organizations, that aims to share information and connect resources to enable rapid responses to serious infectious disease outbreaks (Abbott and Hale 2014, 201).

Boundary-setting and enabling constraints. To nudge complex systems towards sustainability, designers often set broad boundaries that should not be crossed (e.g. Rockström et al. 2009). Within these boundaries, however, decision-makers should allow for a wide variety of bottom-up innovation and learning, recognizing that "[c]omplexity is all about making changes in the present with a sense of direction but not with a specific goal, other than in very limited circumstances" (Snowden 2016). Broad boundaries can act as "enabling constraints", catalyzing purposeful interaction and collaboration without prescribing behavior (Juarrero 2000, 41). For example, calls for a "green recovery" from COVID-19 (Bleischwitz 2020) point to the need for an adaptive boundary-setting framework for post-pandemic economic growth that provides general orientation but does not prescribe specific policies. Such enabling constraints can take the form of norms, heuristics, or more formalized "do no harm" principles, as illustrated by the European Union's COVID-19 recovery plan which makes funds conditional on environmentally sustainable investments (Rankin 2020).

Experimentalism and learning. Small-scale experiments are key to "probing" the behavior of a complex system (Snowden and Boone 2007, 74). Experimentation may emerge spontaneously, but it can also be orchestrated using enabling constraints. Importantly, these experiments should not be viewed as a recipe for finding the "right" solution but as a way to explore how the system behaves and a basis for directing resources towards productive strategies. Policymakers should also be aware of the challenges associated with scaling up successful local pilot experiments to a higher level or across contexts (Gilson and Schneider 2010). COVID-19 has seen adaptive policy experimentation on multiple levels, from the deployment of AI-assisted chatbots to disseminate curated information (Miner et al. 2020) to the repurposing of streets for pedestrians and bicycles (Connolly 2020). While many of these experiments emerged as ad-hoc emergency responses, desirable new practices, rules, and norms have the potential to become "locked-in". However, the long-term success of such initiatives will hinge largely on the ability and willingness of non-state actors to participate within local political processes. The pandemic could also inspire change on the international level, for example, through experimentation with "digital summits" that could complement traditional formats for international negotiations (Calliari et al. 2020).

Self-preservation (fail-safe). Given that the introduction of new elements can significantly alter outcomes in complex systems, governance requires adopting multiple safe-to-fail experiments. As Tuckett et al. (2020, 2) note, "optimization" in the context of radical uncertainty "causes fragility rather than resilience." As such, policymakers are advised to cultivate a self-reflexive "irony" where they "must recognize the likelihood of failure but proceed as if success were possible" (Jessop 2003, 110). Because learning inevitably involves failure, they must also learn how to "fail safely." Indeed, if contained, failure can increase a complex system's long-term sustainability (Homer-Dixon 2007, 23). However, CGCR planners must ensure that policies have a low cost of failure and do not pose a systemic risk through processes of contagion. With COVID-19 lockdowns easing, and in the absence of a reliable evidence base, governments around the world must engage in careful "trial and error" strategies to probe how the system responds and where they can safely intervene (Kupferschmidt 2020). Going forward, COVID-19 is also likely to stimulate vigorous debate on "gain-of-function" (GOF) experiments involving pathogens with pandemic potential. Such experiments may enhance understanding of disease-causing agents, but also often increase transmissibility and/or virulence of pathogens, posing a biosecurity hazard (Selgelid 2016).

Stabilization and Evaluation of Policy Interventions

In an evolutionary design context, the designer is never finished. A number of complex design principles focus upon stabilizing system dynamics through strategic intervention, responding to unintended consequences, stabilizing reciprocal expectations among participants, and rebalancing power differentials in the interests of system integrity and social cohesion.

Leverage points. Leverage points are "places within a complex system where a small shift in one thing can produce big changes in everything" (Meadows 1999, 1). Leverage points use positive feedback (change reinforcing) to drive the system in a desirable direction and negative feedback (change reducing) to stabilize the system (Gunitsky 2013). Identifying these points is often an exercise in counter-intuition, privileging, for example, analysis of institutional crises or failure as opportunities to effect big structural change (Abson et al. 2017). Meadows identifies twelve places to intervene in a complex system, arguing that the most powerful – but also the most contentious – are those that shift the paradigm of a complex system (i.e. the shared ideas that underpin its goals, structures, rules, and other parameters). In the case of COVID-19, interventions such as lockdowns and social distancing measures can serve as low-level leverage points to stabilize the system. However, to drive long-term resilience and prevent future pandemics, policymakers must identify "deep leverage points;" places where interventions are more difficult but have greater potential for truly transformative change (Fischer and Riechers 2019). Provocatively, Meadows suggests that slowing economic growth may be the key leverage point available to solve many of the world's most wicked problems (Meadows 1999, 1). Along similar lines, human and ecosystem research has explored the "exotic effects of capital accumulation" (Perrings 2010) – including the unleashing of new zoonotic diseases such as COVID-19 through growth-oriented economic practices of agricultural intensification, deforestation, wildlife trade, and biodiversity destruction (Brulliard 2020).

Feedback coordination and course correction. A systems approach to governing complex problems privileges assessment of feedback effects and responsiveness to corrective information and unintended consequences (Richardson 1991). Stable feedback systems which allow participants to monitor system behavior over time facilitate the co-design of adaptive responses (Zivkovic 2015). This may be particularly consequential to pursuing feedback loop closure (internalizing "negative externalities" in cost equations), as well as attributing responsibility to actors externalizing harm to the commons. Feedback also permits system participants to engage in "exaptation" (Parry 2013), noticing unexpected side-effects, then repurposing. COVID-19 has compelled governments to constantly re-evaluate pandemic response measures in light of a dynamic scientific evidence base, as well as unintended negative consequences of lockdowns and social distancing policies. At the same time, positive side-effects, such as a temporary drop in air pollution or the introduction of more flexible work arrangements, open up possibilities for exaptation. On the global level, COVID-19 illustrates the urgent need for feedback coordination between ostensibly separate governance domains, for example by driving forward the "One Health" agenda that links human health to the health of animals and ecosystems (Mushi 2020).

Evaluation and ratcheting. In contrast to a complicated system, actions in complex systems "change the environment in which they operate" and as such "identical but later behavior does not produce identical results" (Jervis 1997, 55). This observation highlights a key point: problem and response co-evolve. As such, systemic responses to complex problems require continuous evaluation (searching, judging, measuring, verifying) to assess policy blockage, drift, and productive strategy adaptation. However, evaluation should not be equated with conventional problem-solving, given that "wicked problems" do not lend themselves to a predefined set of potential solutions or corresponding metrics (Rittel and Webber 1973). Global health scholars have long urged that the focus of health security governance must shift from discussions of reactionary "counter-measures" to "prevention and health system strengthening" (Paul et al. 2020, 2). However, building up health system capacities will take time and, crucially, additional financial support for developing countries. A potential Framework Convention on Global Health could incorporate innovative features from other international treaties, such as the Paris Agreement's "pledge, review, and ratchet" mechanism to ensure continuous evaluation and a gradual rise in ambition levels.

Conflict resolution and collective discipline. Systemic design for CGCR governance must also be resilient to capture, internal corruption, and rogue activity. In the case of COVID-19, calls for "individual and collective discipline, a heightened sense of solidarity and a shared sense of purpose" (Gurria 2019) have been undermined by a resurgence of zero-sum thinking, with powerful actors actively undermining collaborative approaches (Boseley 2020). For many, the pandemic has also raised concerns about emergent CGCRs – such as the deliberate misuse of biotechnology – as exponential technologies accelerate the asymmetric power of individuals with civilization-devastating motives (Bostrom 2019). These are vexing design problem. There is no hierarchy at the global scale capable of delivering meaningful costs to powerful states, organizations, or individuals who are moved to violate the collective interest. Even where local hierarchy is effective, it is corruptible, often predatory, and prone to polarization. Frontier research is probing novel democratic mechanisms to resolve distributive conflict at scale (Bauwens et al. 2019). Other scholars are investigating collective discipline through decentralized reputational architectures (Watt and Wu 2018) or control mechanisms such as graduated sanctions (Wilson et al. 2013). Ultimately, however, complex governance requires responsible agents, guided by an ethical orientation which acknowledges that there is no "outside;" no "view from nowhere" (Cilliers 1998).

Conclusion

This article has explored the implications of complexity thinking for governing complex global catastrophic risks (CGCRs). Such risks are different from other existential risks, not due to their scale or severity, but rather the governance challenge they pose due to unusually high levels of complexity. It has explored why many complexity experts regard it as crucial to distinguish between "complicated" and "complex" problems. The utility of this distinction has been evidenced through an interrogation of why legacy multilateral structures may be necessary – but not sufficient – when it comes to responding to the complex drivers of CGCRs. A comparative assessment of the COVID-19 pandemic response in light of complicated and complex system design principles has evidenced the importance of supplementing inherited governance design and practices in the face of mounting global complexity and risk imperatives.

This study underlines the utility of complexity theory in exposing the deficiencies in global governance structures when confronted with CGCRs. However, we do not simply offer a critique of existing ways of doing governance. Drawing upon recent conceptual innovation in complex IR scholarship, we have also sought to contribute to a burgeoning research agenda demonstrating the empirical applicability of complexity theory for understanding and addressing global policy challenges. Above all, this study demonstrates that there is no simple dichotomy between a complicated problem-solving linear model and complexity-inspired approach when it comes to intervening in system contexts defined by restricted complexity. Our case study suggests that establishing right relationship between overlapping and multiscalar complicated and complex domains is an important and daunting task for scholars, implying that contingent explanatory theories will require careful specification. This echoes Bernstein et al.'s (2000, 52) still pertinent concern that IR scholars often do not specify "carefully the temporal and geographic domains to which their theories are applicable." For the policymaker, COVID-19 makes clear that *ex ante* intervention proposals based on linear causal modelling should factor in expert insight on complex socio-technical, political, and economic system dynamics, which will inevitably inform the outcome of such "complicated" interventions.

To govern at "the edge of order and chaos," Waldrop (1993, 333) suggests, is "to keep as many options open as possible. You go for viability, something that's workable, rather than what's 'optimal'…you're trying to maximize robustness, or survivability, in the face of an ill-defined future." Building upon such observations, this article has also drawn laterally upon systems thinking and design science to offer a novel framing of COVID-19 in light of governance principles designed to respond to the complex drivers of CGCRs, holding out the promise of imprinting a new logic of change onto global governance structures beyond top-down regulation. In so doing, it contributes to widening the applicability of complexity theory and design science to mainstream IR research, as well as enriching a global governance research agenda which is less concerned with *determining* complicated outcomes, as *enabling* complex outcomes at the highest and lowest levels of political assembly. It has also presented a novel design model for enabling responsive multi-level mechanisms, capacities, and strategies that work *with* complexity, with broad application to other global policy domains.

It is vital that IR scholars take seriously the core insight of complex systems theory; that we can only determine outcomes in carefully specified constrained environments. Intervening in complex systems where no simple direction of causality is apparent requires a carefully tailored mix of governance tools, supplementary, but distinct to, command-and-control structures or market-based mechanisms. This is readily apparent when it comes to COVID-19 and even more formidable challenges, above all stabilizing the Earth's exceedingly complex biosphere. Engineering "expert" solutions will not suffice. There is no "mission control" for cooling our rapidly warming planet, increasing biodiversity, preventing future pandemics, or aligning AI technologies with human objectives and values. However, it is important to not mistake complexity for crisis. Complexity is the norm, not the exception in world politics. A complex governance approach to CGCRs holds out the promise of preventing calamitous failure. Contrary to conventional belief, "constrained breakdown" may be desirable; setting in motion processes of restructuring, renewal, and long-term adaptation (Homer-Dixon 2007: 23). Threading the needle of constrained breakdown within our increasingly complex globalized civilization, as opposed to chaotic collapse, may well prove to be the defining story of this century.

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