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Complexity in Global Politics: Toward a Novel Framework of Analysis

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A Thesis in the Field of International Relations

for the Degree of Master of Liberal Arts in Extension Studies

Harvard University

May 2022

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Abstract

The purpose of this research is to establish the beginnings of a theoretical framework with which to apply the insights of complexity science to an analysis of global institutions. The framework consists of both positive and normative principles for political analysis rooted in complexity theory.

Following the development of key principles, the framework is contrasted with major traditions such as realism, liberalism, and constructivism. The document concludes with a series of brief policy notes aimed at demonstrating application of the framework.

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Chapter I

Research Problem

The purpose of this research is to establish the beginnings of a practical and actionable framework with which to apply the insights of complexity science to the analysis of global institutions. This work will develop a basic framework which may serve as an alternative to major traditions such as realism, liberalism, or constructivism.

To support this framework, I will conduct a literature review highlighting important properties of complex adaptive systems that warrant consideration in the analysis of policy and social institutions. In particular, I will discuss the tendency of such systems to exhibit hierarchical network structure, nonlinear behavior, fat-tailed distributions, inter-temporal optimization, environmental adaptation via adaptive selection among subsystems, variety of subsystems, and capabilities which scale with informational complexity.

In addition to these positive characteristics, I will seek to develop a non-exhaustive set of normative principles which should be considered in the context of complexity-aware policy design. The specific prescriptions to be considered are the avoidance of rigid top-down designs of non-trivial systems, a focus on mechanisms of selection and incentive, and diligent support of pluralism. As with the properties considered in the positivist analysis, these normative principles should be understood as significant but not comprehensive.

I will also seek to differentiate this framework from existing competitors. This will be accomplished with a survey of common modes of analysis and a discussion of

what commonalities and distinctions might exist. Analytical frameworks to be explored in this process will include realism, liberalism, and constructivism.

Having established an initial framework of analysis rooted in complex systems theory and distinguishing it from major alternatives, I will seek to demonstrate the usefulness of this framework by way of application. Specifically, I will provide brief policy notes on several key issues in the domains of economic, security, and climate policy. This will serve both to establish some important political viewpoints which derive from the framework and to demonstrate how the framework might be applied to issues not specifically addressed. Of course, the coverage provided by such a survey is inherently insufficient; the topics in question each demand their own deep and ongoing research. However, such policy notes are useful in connecting an otherwise entirely theoretical framework to concrete policy positions.

This topic is of substantial interest because the range of institutions that can be modeled as complex adaptive systems is quite large. Complexity science therefore offers an abstraction that can be applied quite broadly given a strong framework of analysis. Within the domain of the social sciences, complex systems have been proposed to describe companies, economies, cities, nations, governments, and international organizations (West, 2017).

The potential applications are numerous. A novel framework can serve to sharpen existing bodies of theory by way of criticism and comparative analysis. This work also has implications for historiographical analysis in that it provides new tools for identifying the driving dynamics of systems. Because the subjects of policy analysis can so frequently be modeled as complex systems, the developed framework is likely to have

broad application in policy design. This will be demonstrated in the case analysis which will follow the explication of the framework.

There is a large body of work related to the analysis of complex systems generally. There is also some work related to the application of complex systems to the study of international relations and global governance.

With respect to complex systems generally, the properties I will highlight in the framework are fairly well studied. That complex systems adapt to their ecology, exhibit nonlinearity, and form hierarchical network structures from adaptively selected subsystems has been understood since at least 1987, when John Holland released his primer on the topic (Krakauer, 2019). Similarly, the significance of variety in system optimization has been well understood since W. Ross Ashby's 1956 seminal cybernetics text (1956). Variety has also been recognized as essential for stability in biological systems (Gunderson & Pritchard, 2002) and generalized to non-biological complex systems such as financial markets (Lo, 2017).

The emerging study of ergodicity economics notes that systems optimize through time by maximizing the long-run growth rate, producing behavior that may seem locally sub-optimal (Peters, 2019). The emergence of fat tails as a result of interdependency, and their significance for decision makers ,is extensively examined in the work of Nassim Taleb (2020). The predictable relationship between informational complexity and system capability has been studied for systems including biological organisms, cities, and companies in the work of Geoffrey West (2017).

There is also some literature on the introduction of complexity to questions of international governance. Central to this effort has been a recognition that international

life is massively uncertain and therefore ill-suited to the application of linear causality as commonly practiced within international relations. Perhaps the most notable example is the sudden collapse of the Soviet Union, which ended the Cold War and shocked contemporary analysts. Such predictive failures of classical linear thinking motivated a consideration of complexity as a worthy topic of study (Kavalski, 2007). Additionally, some scholarship has recognized that international politics is not simply complex in the colloquial sense but that participants are appropriately characterized as complex adaptive systems. Complexity has therefore been successful in explaining some transitions in international politics (Lehmann, 2012).

However, it must be noted that previous attempts to introduce complexity science to the analysis of global politics have seen only modest success. Several reasons account for the stall. First, while complexity has demonstrated descriptive value, there has been comparatively little success in driving policy decisions (Lehmann, 2012). Additionally, the community of scholars working on applying complexity theory within international relations has been small. To the extent that complexity does receive attention within the literature, it is largely discussed as a metaphor with minimal attempt to rigorously apply the underlying concepts. The result of all of this is that complexity is largely rejected as a valid paradigm within the theory of international relations (Orsini, et al., 2020).

The goal of this research is to establish a basic framework with which to apply complexity science to the consideration of global politics. In developing such a framework, I will produce an inventory of relevant theoretical concepts from the complexity literature. Thus, I directly address the issue of complexity historically being applied as a useful metaphor rather than a mode of concrete analysis.

Following the establishment of relevant properties, I will demonstrate how a complexity-oriented approach might relate to alternatives by way of comparative analysis. I will then attempt to demonstrate the value of such a framework by applying it in practice through case studies. I suggest that these case studies may also produce novel and useful analyses of the topics addressed. In sum, the contribution of this thesis work will be to dispel the notion of complexity as an unprofitable curiosity by presenting a provably useful initial framework of analysis.

Chapter II

Key Properties of Complexity

Complex adaptive systems are nonlinear systems that make continued adaptation to their environment. In general, such systems emerge from the interaction of comparatively simple components, but their behavior is not easily predicted from them. There are many popular examples of such systems including the brain, insect colonies, and economies (Mitchell, 2009). In the brain, neurons are the primitive building blocks of a more complex super structure which is capable of highly sophisticated cognition through the transmission of electrical impulses. In ant colonies, individual ants respond to simple biological imperatives and chemical signals but aggregately form intricate structures and distribute tasks as needed for group survival. In the modern economy, individual agents pursue their particular interests through transactions which form complex markets of interconnected institutions, industries, and financial products. All of these are specialized and globally distributed to efficiently connect tasks with the goods and services demanded by individuals.

Hierarchical Networks

Within the cross-disciplinary field of complexity science, researchers point to common organizing principles that unite these apparently distinct systems. Specifically, the systems in question are characterized by a hierarchical graph structure in which simple components form super-structures which are in turn composed to form ever more

complex super-structures. This process can be applied recursively to generate graphs of arbitrary depth. Each level of the hierarchy is constructed according to a building block principle; it is a composition of simpler subsystems from the next level down. Thus, exploration of the enormous space of possible system configurations is path-dependent and constrained by the available subsystems.

It is typically the case that the search for components from which to compose higher-order structures is carried out through competition among a pool of candidates. The top-level system evolves by way of adaptive selection applied over lower levels of the system hierarchy (Krakauer, 2019). The economy exemplifies this basic pattern quite clearly. An economy is composed of individual industries, which are themselves composed by adaptive selection among companies, which are in turn composed by adaptive selection among employees.

Adaptive Selection

The notion of adaptive selection is, of course, closely associated with the process of evolution. Indeed, many complex systems, such as social institutions, are discussed as having some sort of evolutionary character. This should not be viewed simply as an interesting analogy. Rather, the evolutionary process is foundational to the formation to all complex systems, including social institutions.

The notion that evolution is not unique to biological organisms is not novel. Evolutionary biologist Richard Dawkins, in *The Selfish Gene,* introduced memes (ideas that spread from person to person) as a particular example to demonstrate the existence of an unbounded category of non-biological replicators governed by evolutionary dynamics (Dawkins, 1989). In *Adaptive Markets,* Andrew Lo argues that investment strategies that

shape resource allocation adhere to an evolutionary process in which maladapted strategies are removed from the population by shuttering the firms that employ them (Lo, 2017). This constitutes a narrower case of the previously discussed evolutionary process exhibited by economies in which adaptive selection is applied to the population of firms.

All systems shaped by evolutionary dynamics follow a process of incremental adaptation that is determined by the differential survival of agents whose individual characteristics are governed by some reproducible underlier. Biological organisms survive based on phenotype, which is governed by genes. In Lo's conception of adaptive markets, hedge funds survive based on investment strategy (i.e., ideas or memes). In his writing, this idea is referred to as "evolution at the speed of thought" (Lo, 2017). This logic applies to a broad range of social institutions, which survive based on their systems of management, which are determined, again, by ideas.

In governments, adaptations are born of the differential survival of political ideas among the bureaucrats who staff them. In a democratic context, ideas of governance are selectively removed by way of elections—either by inducing politicians to abandon unpopular ideas or removing the politicians themselves. Democratic institutions are therefore constructed to adapt to the views of their constituency, while more autocratic institutions persist through the selection of ideas that promote stability. In either case, the institutions adapt based on the differential survival of ideas among the actors who manage them. Viewed in this model, we can interpret the various forms of government as evolutionary adaptations to distinct contexts with unique selective pressures.

It is important to observe that the evolutionary processes governing social institutions do not occur in a vacuum. The adaptive value of ideas is a function of the

other participants within the system. This means that social institutions, like biological organisms in a shared environment, form an ecology. This generally means that fully understanding the behavior of an individual institution likely requires understanding its broader ecology and the co-evolution of that ecology's constituents.

Inter-temporal Optimization

It should be noted that the evolutionary process constitutes an inter-temporal optimization problem. Agents withstand selective pressure to the extent they are well-suited to their environment (optimization), and they endure this selective pressure on an ongoing basis (inter-temporal). Thus, the system changes over time to maximize the value of whatever objective function shapes the selection of components. Put alternatively, the behavior of a system changes to facilitate the ongoing accumulation of sustaining resources. Because optimization occurs through time, the dimensionality of the objective is a rate rather than a scalar (i.e., the system is concerned with the rate of ongoing accumulation rather than absolute level of accumulation at a point in time). It is therefore appropriate to think of systems as optimizing with respect to their growth rate as opposed to an absolute value (Peters, 2019). This has important consequences both for interpreting the behavior of complex systems as well as designing policy related to their management.

Ergodicity and Risk Tolerance

One important feature of inter-temporal optimization is that complex systems are generally non-ergodic. An observable is said to be ergodic if its time average is equal to its expectation value (Peters, 2019). Put alternatively, a system is ergodic if it (sooner or

later) visits all its possible states in a uniform and random sense. Yet another framing is that a system is ergodic if any two realizations of the system will have the same distribution of states over the long run. The reason this is generally untrue for adaptive systems is path dependency. Actions and consequences through time are generally not reversible; this is most acutely observable with respect to death or an equivalent end. For example, national governments will generally have reliably different characteristics through time because specific decisions related to the constitution, institutions, policies, etc., create a path that is not easily reversed. Over no amount of time will the government of Yugoslavia become a capitalist democracy; nations that no longer exist cannot modify their political character in any regard.

A key implication of non-ergodicity is that it incentivizes a degree of risk aversion which might be characterized as inefficient in an ergodic context (Peters, 2019). An extreme example of this is the St. Petersburg Paradox. The paradox considers a coin-flipping game in which the player is paid according to the number of consecutive heads; two dollars for one heads, four dollars for two, eight dollars for three, and doubling until the first tails occurs. Critically, the payout is theoretically limitless. How much should one pay to play such a game? Expected value calculations would suggest that one should pay any finite amount to participate, yet intuition and empirical observation firmly reject this course of action (Peters, 2019). A typical player prefers to protect existing wealth (long-term optimal) rather than risk it for a bigger payout (short-term optimal). Similar risk-averse behavior can be observed in trials where participants engaged in iterated bets; participants tend to behave in a way that optimizes the growth rate over time rather than pursuing high expected value of individual bets (Peters, 2019). These results are

consistent with the well-known Kelly criterion which indicates that the growth rate of wealth is maximized by betting on outcomes proportional to their risk-adjusted expected value rather than allocation exclusively to the highest expected value (Kelly, 1956).

One expression of this risk aversion is the emergence of welfare programs in a wide variety of complex systems. Welfare systems promote the long-term growth of participants' resources by minimizing fluctuations in their availability (Peters & Adamou, 2018). One generally thinks of welfare as being uniquely associated with conscious political analysis, downstream of considerations of social responsibility and justice. But the evolutionary advantage of resource redistribution explains its presence in a wide range of contexts subject to the pressures of adaptive selection (Peters & Adamou, 2018). Viewed in these terms, it is not surprising to see resource sharing in both "consciously designed" policy programs such as Social Security, and more organically formed complex systems such as forests of beech trees in which individual trees synchronize their performance to achieve equally successful photosynthesis across all members of the group (Wohlleben, 2016).

The adaptive benefit of welfare systems can be viewed as a specific instance of the broader class of cooperative behavior emerging organically from selective pressure, perhaps most famously explored in Robert Axelrod's *The Evolution of Cooperation*. In that work, Axelrod observed that cooperative behavior was as an evolutionarily stable strategy in the context of an iterated Prisoner's Dilemma, and could likely explain social cooperation more generally (Axelrod, 2006).

Variety and Concentration Risk

Variety is a related consideration for inter-temporally optimizing systems. It is essential that systems maintain a large variety among subsystems in order to avoid concentration risks and support diversification of function which might tend to be useful in shifting environments. The most straightforward explanation of this requirement comes from cybernetics. The law of requisite variety says that the number of states a system has (itself a function of the variety of subsystems) must be greater than the number of states in the system it is to control (Ashby, 1956). Put alternatively, the capabilities of a system to achieve its objectives are a function of the variety of its possible states.

In addition to system capability, variety is also important with regard to self-preservation through time. As a complex system becomes well adapted to a particular environment, it may filter out subsystems that are likely to be useful in alternative contexts (but not in its present context). Therefore, highly optimized systems that do not preserve variety may fail to survive a change in their environment (Lo, 2017). We can therefore think of variety and mutation as a sort of insurance policy: as variety increases so do the system's chances of surviving arbitrary changes in environment (Lo, 2017).

Accumulating and Encoding Information

Complex systems are, in general, not cognizant of the adaptive process or aware of their entire developmental history. Rather, evolved entities will efficiently encode the accumulated knowledge of the adaptive process. This is well understood in a biological context where information accumulated through the evolutionary process is encoded in DNA. In an investment firm, the accumulated knowledge of market dynamics is encoded

as an investment strategy. In computer programs, the accumulated knowledge of desirable algorithmic behavior is represented as files in the physical memory of a computer. For social institutions, accumulated information is encoded as laws, norms, customs, and so on.

The essential point is that the accumulated knowledge of social institutions is not generally represented as a moment-by-moment account of the history or an exhaustive enumeration of facts and conclusions. Rather, knowledge that has been acquired in the adaptive process is more efficiently encoded in some memetic artifacts such as records, governing documents, and shared ideas among members.

More sophisticated entities require greater informational complexity. Simple organisms contain less genetic information than complex ones. Bacteria have less than protozoa, protozoa less than reptiles, reptiles less than humans. Greater informational complexity is, typically, required to specify more complex functionality (Sagan, 1977). This is important because the logic applies beyond the consideration of genetic information in the context of living organisms. Human capabilities are supported by large quantities of extragenic information which is stored in brains, books, websites, and a wide range of other repositories. This relationship between degree of function and informational complexity exists for a broad range of complex systems including social institutions. To cite one example, a study of 28,853 publicly traded companies in the United States from 1950 to 2009 identified predictable scaling relationships between the number of employees a company had and its net income, gross profit, total assets, and sales. Another study of cities showed predictable scaling relationships between city

population and incomes, patents (per capita), employment in research and development, and employment in creative work (West, 2017).

Nonlinearity, Fat Tails

Previous reference was made to the characteristic unpredictability of complex systems. Steven Wolfram has noted that many complex systems exhibit a property known as computational irreducibility; many non-trivial systems cannot in fact be reliably anticipated, even in principle. The system would need to be run in order to anticipate the behavior at any point in the future (Pines, 2019). This coheres with general intuition that fine-grained prediction of social systems is not generally possible. The typical approach to deal with this problem is to replace deterministic prediction with statistical models. But even this approach can be problematic due to the phenomenon known as fat-tailed distributions.

Fat-tailed probability distributions are those with a relatively high likelihood of extreme outcomes, particularly with respect to the normal distribution. Such distributions commonly emerge in the context of complex systems because of the interdependence of the components. Because system components are tightly interconnected, they do not behave independently. Rather, constituent agents will be aligned in typical behavior most of the time and coordinated in deviation from that normal behavior when it occurs. In contrast, independent components tend to produce normal distributions by the logic of the central limit theorem. For an instructive example, consider the distribution of returns in the stock market. Such returns are not normally distributed but instead follow a fat-tailed distribution (Taleb, 2020). This is because the buy and sell orders of stock market participants are not independent. Rather, many individuals will buy to chase the benefits

of an upswing (raising prices further) or engage a panic selling in the face of a downswing (depressing prices further).

The existence of fat tails has several important consequences. First, as was alluded to previously, the existence of fat tails has negative implications for the usefulness of statistical analysis. To name a few concerns, under fat-tailed distributions, the law of large numbers will converge more slowly, if at all; typical metrics, such as mean and variance, may cease to be meaningful; and common models, such as linear regression, may fail to apply (Taleb, 2020). Such analyses may even be counter-productive by instilling in the practitioner an unwarranted confidence in his or her understanding of the underlying system.

The other important consequence relates to expectations regarding the behavior of complex systems following fat-tailed distributions. Extreme events should be expected. Relative to the normal distribution, outcomes are more likely to be very close to or very far from average. Comparatively few moderate outcomes should be anticipated.

Relation to Political Analysis

The literature in international relations has thus far recognized some limited scope for the consideration of complexity. In particular, the field has acknowledged that international politics are highly uncertain and ill-described by straightforward linear causal analysis. This toehold in the literature owes largely to the fact that the abrupt collapse of the Soviet Union and the end of the Cold War were largely unanticipated by contemporary analysts (Kavalski, 2007). Complexity would not have predicted the particular outcome (certainly not the timing), but it clearly embraces the possibility of abrupt and unpredictable shifts. While the abstraction of complex adaptive systems has

been useful in explaining historical transitions, critics argue that complexity has been broadly unsuccessful in providing useful conclusions about policy making (Lehmann, 2012). Instead, reference to complexity has tended to be metaphorical and without detailed reference to underlying concepts. This has ultimately resulted in complexity being treated as an unserious framework for the study of international relations (Orsini, et al., 2020).

The above literature review identifies particular characteristics that may be broadly useful in the analysis of complex systems. Specifically, the tendency of such systems to exhibit hierarchical network structure, nonlinear behavior, fat-tailed distributions, inter-temporal optimization, environmental adaptation via adaptive selection among subsystems, variety of subsystems, and capabilities that scale with informational complexity, have been noted. By aggregating a specific list of important traits to be considered, it may be possible to develop complexity from a convenient explanation of uncertainty to a usable framework in policy analysis.

Chapter III

Normative Framework

We have thus far discussed qualitative elements of complex adaptive systems and related them to social institutions. This may be sufficient to begin understanding and describing the behavior of such institutions, supporting a positivist analysis. If we hope to be able to make policy prescriptions, our framework must also be able to draw normative conclusions from an understanding of the key properties of complex systems. What follows is a limited set of prescriptive principles for policy design, along with justification rooted in the characteristics of complexity heretofore discussed.

To the extent this normative framework can be neatly summarized, the following is a reasonable attempt. Avoid heavily designed solutions to complex social problems; instead seek to create an environment that might foster incrementally adapted solutions. One might break this prescription into the following points. Avoid top-down designs, except those of very simple systems, recognizing that complexity must be evolved. Focus on the mechanism of selection; carefully design the incentives which govern the differential success of individual actors. Diligently support pluralism and redistribution; adaptive systems may tend to concentrate resources to deleterious outcomes if not carefully managed. Intervene with caution; the characteristic unpredictability of complex systems may lead to outcomes which substantially differ from policy makers' intent.

Avoid Top-Down Designs

The first important principle for policy design is that attempts at top-down solutions are likely to be unsuccessful. While high-level regulators are well-positioned to specify objectives, they are ill-suited to manage the details of their implementation. Such considerations are better left to the discretion of local actors. There are several reasons that this is likely to be true. Because policy makers are so often concerned with complex social phenomena, the systems that address their concerns are necessarily complex as well. Such systems are, almost by definition, prohibitively difficult to design from scratch. This essential limitation is the basis of a principle known as Gall's Law which is discussed in more detail below. Additionally, the high informational complexity required for a regulator to effectively exercise control necessitates a fine-grained perception of its subjects. Agents at the bottom of a system hierarchy have the most direct information about the conditions they seek to manage. The comparatively coarse perception of agents atop a hierarchy makes them ill-suited to identify efficacious adaptations to local context.

Gall's Law states that any complex system that works is invariably found to have evolved from a simple system that worked (Gall, 1986). This means that a functional complex system of a given scale must be iteratively constructed from comparatively simple systems of smaller scale. Meanwhile, attempts to construct large complex systems from scratch will tend to be unsuccessful. This result follows naturally from the evolutionary dynamics from which such systems are generally constituted. For any non-trivial objective, the ideal (or even adequate) construction of a solution-providing system is not clear *ex-ante*. The prohibitively large search space of candidate systems is iteratively reduced by adaptive selection of subsystems.

Most would regard as implausible the idea of "building" or "engineering" a tree, bird, or other living organism. These are forbiddingly complicated entities whose structure is specified by large quantities of information accumulated over long periods of evolutionary history. The same logic applies to non-biological systems with structural complexity which defies direct specification. Governments, cities, economies—none of these can reliably operate at a large scale except by incremental adjustment and expansion from smaller-scale versions. The validity of this conclusion is well supported by the historical record.

The modern governments of today are generally outgrowths of smaller versions which developed and expanded through time. In America, the framers of the Constitution did not enumerate anything like the full panoply of departments and agencies that presently constitute the United States government. Rather, they provided a comparatively simple document upon which iterative evolutionary process could generate vast bureaucratic complexity. The iteratively constructed American government might reasonably be viewed as quite successful, while its own foreign policy failures undercut the case for the alternative. The United States has been party to several misfires in the category of top-down governmental construction, most notably in Vietnam and, more recently, in Iraq and Afghanistan.

At the level of transnational institutions, one can point to the North Atlantic Treaty Organization (NATO) as a relatively successful instance of sustained supra-national coordination. Notably, it was formed as an organic expression of shared security concerns among the constituent states. By contrast, its doomed sibling, the Southeast Asia Treaty Organization (SEATO), lacked a galvanizing threat which was common to

its members. In NATO, member states created a superstructure to manage their own security. In SEATO, member states created a superstructure to manage the security of nations largely absent from its membership (Powaski, 1998).

The same is true of the largest cities and economies. The roughly 8.4 million people who comprise the metropolis that is New York City originated as a 17th-century trading outpost, home to fewer than 300 Dutch colonists. Within that city, the New York Stock Exchange began as an 18th-century gathering of two dozen stockbrokers, and incrementally evolved to its present form as a financial hub connecting global institutions to each other and trillions of dollars' worth of securities. In obvious contrast, the "administrative utopianism" induced early leaders of the Soviet Union to imagine that they could build modern cities and economies nearly from scratch. The society was to transition directly from war, revolution, and famine into five-year construction plans and an economy smoothly managed by a centralized statistical bureau. The disconnect between ground conditions and bureaucrats' perceptions was famously deleterious (Scott, 2008). It would be inappropriate to infer from this that markets are strictly preferable to governments; clearly all mature economies involve some combination of the two. But government interventions will tend to fail to the extent that they privilege highly centralized control over delegation to appropriately incentivized local actors

Much to the chagrin of development economists and foreign-aid practitioners, attempts at top-down design of institutions have a broadly uninspiring track record. Economist William Easterly has discussed extensively how aid organizations operating in Third World countries have failed to achieve development objectives. Experts engage in the self-defeating application of top-down growth models which supplant organic

expression of the information and preferences of those individuals at whom such policy is aimed (Easterly, 2001, 2006, 2013).

This is not to say that high-level organization is unachievable; rather, it requires appropriate structure and delegation of responsibilities among subsystems. The United States' war effort following the attack on Pearl Harbor is instructive. The government succeeded in this massively complex and rapid mobilization through the coordination of existing industrial and military apparati; composing subsystems that in turn delegated the necessary tasks to their constituents. The impulse toward military mobilization may have been top-down but its implementation was not. The constituent subsystems of the war effort were incrementally adapted to handle the specific tasks over which they had discretion of implementation.

Top-down impositions of political solutions are structurally unlikely to be successful. Effective social systems are complex and must, therefore, come from evolutionary process rather than design. Comparatively simple systems, which successfully perceive and manage fine-grained local details, must be composed and expanded to form the more complex institutions required to address higher order concerns.

Process Before Outcomes

Another related principle for policy designers is to be concerned with process over specific outcomes. Complex systems behave nonlinearly with respect to inputs. This means that the response to any given policy intervention, particularly a complicated one, is unpredictable. In the domain of complexity, the space of possible outcomes is sufficiently large that highly specific predictions are effectively equivalent to statements

about outcomes that are not going to occur. This has contributed substantially to complexity's lack of currency in policy design—what good is a theory that effectively says we cannot make predictions about anything? But this characteristic unpredictability does not mean that policy makers are unable to take action. The adaptive process is extremely powerful and can be harnessed to achieve pro-social objectives so long as attribution, payoffs, and penalties are appropriately configured.

Entropy and Selection

Rather than specifying the details of a desired solution (as in the case of "administrative utopianism"), regulators can profitably focus their attentions on constructing the conditions that foster efficacious adaptation. In an evolutionary process, desirable outcomes are achieved through the combination of entropy and selection. *Entropy* refers to high variability or diversity among the population of candidates upon which selective pressure is applied. *Selection* refers to the mechanism by which undesirable adaptations are identified and removed from the population. It is crucial to stress that as long as an appropriate selection mechanism exists, higher entropy is an unalloyed good. More volatility implies a higher prevalence of good and bad candidates; functional selection means that only the good candidates are preserved. Thus, given a selection mechanism, higher entropy implies greater fitness among the final population. In technical terms, this asymmetrically positive payoff constitutes a convex response function with respect to volatility. Such a system, which benefits from disorder, is referred to as anti-fragile (Taleb, 2014).

The most obvious example of this in practice is a market economy. Firms, in their desire to obtain a profit, supply a population of candidate goods and services. Effective

demand—the capacity and desire of the population to pay for these goods and services—functions as the selection mechanism. Those products for which there is sufficient effective demand to generate profit for the producer, are the ones that survive. Based on the surviving "ecology" of products, new niches open and the cycle repeats. When structured appropriately, this is a mechanism by which markets produce a rich collection of available goods and services.

Viewed through this lens, it becomes possible to evaluate policy in terms of managing an adaptive ecology. The means by which an external regulator can shape outcomes is through the management of entropy and selection.

The first component to be considered is entropy. Because the presence of selection ensures an asymmetric benefit with respect to entropy, it follows that it is desirable to foster greater variability in the population of candidates. In the context of a market economy, this might mean programs making it easier for new firms to emerge by providing support for entrepreneurship or a social safety net for those who take risks. This is precisely the issue with the statistical bureau imagined by Lenin for the provision of goods and services within the Soviet economy. There is nothing inherently problematic about statistics; efficient coordination of economic mobilization through the rigorous identification of supply and demand is laudable. But the presupposition of the goods and services to be measured crushes adaptive dynamism by removing entropy (Scott, 2008). Under such a regime there is no variability in the population, removing the possibility of efficacious adaptive selection.

The next component to be considered is the means of selection. If the adaptive process is thought of as a sort of heuristic optimization, then the selection mechanism is

the basis of the objective function, the target that the system seeks to optimize. It is therefore of paramount importance to regulators that the means of selection be appropriately configured. In contexts with a well-determined mechanism of selection, there is opportunity for highly desirable adaptation. Consider, for example, the enormous and high-quality population of books, art, and music available through public channels. Demand from at least some subset of the population is the selection mechanism which determines the content to be preserved for easy access. Whatever criticisms of Western capitalism may exist, it is difficult to dispute that the same mechanism of selection by effective demand has driven a panoply of available goods and services in the economies of its adherents. In the political domain, functional democracy is the result of voting, a selection mechanism whereby which politicians are preserved or removed based on their coherence with public preferences.

Managing System Pathology

But just as well-structured selection can yield efficacious results, a misguided selection mechanism can drive deleterious outcomes concomitant with the optimization of its associated objective. Critically, policy designers must be careful about what is not incentivized or explicitly constrained; any sufficiently sophisticated optimization system will sacrifice all else for incremental improvements in the objective. Perhaps the starkest demonstration of this principle is provided by Nick Bostrom's thought experiment of the Paperclip Maximizer, an artificial intelligence with the apparently innocuous task of creating as many paperclips as possible. A sufficiently mature version of such a system could lead to dystopic outcomes by trading even humanity's essential resources for the trivial benefit of incrementally more paperclips (Bostrom, 2003).

While this may be the stuff of science fiction, one can identify inchoate analogs of such a system in practice. Indeed, complex institutions are observably capable of frightening innovations in pursuit of codified objectives. The 2008 financial crisis saw the global banking system externalize mortgage risk, wreaking massive damage in the form of unemployment, foreclosures, and economic instability in pursuit of incrementally greater profits. The economic interest of individual nations is generally in conflict with curtailing carbon emissions, which leads to a tragedy of the commons wherein most countries pursue their domestic interests and emit beyond globally optimal levels.

At the corporate scale, in January of 2021, the National Football League made history by airing games on Nickelodeon, a children's network co-branded with popular intellectual properties such as SpongeBob SquarePants. From the broadcast, clearly aimed at introducing football to a new generation, one can infer that both the NFL and (perhaps more surprisingly) ViacomCBS view their institutional objectives as priming children to eventually participate in injurious physical activities.

Mature complex systems adopt this apparently pathological behavior when the mechanisms of subsystem selection do not preclude it. Mainstream economic theory identifies such pathological behaviors as externalities to be regulated by the state. Complexity agrees, but goes further to note that, because the systems under consideration are continuously optimizing rather than static, mature economic actors will continuously seek out new externalities to exploit. So long as bankers and executives are hired for their capacity to generate profits and not economic stability, so long as politicians are elected for their effectiveness in remediating domestic but not global concerns, then the

institutions in question will tend to subjugate these competing but not explicitly pro-adaptive social goods.

The resolution is to ensure that any selection mechanism will, or can be updated to, remove pathological actors. This is what author Nassim Taleb refers to as having "skin in the game," the notion that an actor will be held individually accountable for any harms it might inflict upon others (Taleb, 2018). To ensure this condition is to ensure that pathological behavior is adaptively selected out of the population. Importantly, even if the full set of pathological behaviors is impossible to predict or specifically regulate ex-ante, it will tend to diminish in prevalence to the extent it is unfavored in the process of selection. By contrast, institutions that are pro-social and avoid the externalization of harms will tend to flourish where such properties are favored by selection.

In addition to the regulation of externalities prescribed by mainstream economic theory, this analysis might tend to support apparently capricious political positions such as "breaking up" the banks or single-issue voting for climate conscious candidates. While these choices might seem arbitrary and extreme, a mechanism of occasional but massive retaliation to institutional pathology might serve to make it generally maladaptive.

Pluralism and Redistribution

The next normative principle to consider is the essentiality of pluralism and redistribution. It is critical that policy makers regard active diversification as being of paramount importance. The motivation for this principle is partially explained through our previous discussion of entropy and selection: higher entropy among a population subject to selection leads to greater fitness net of selection. But the significance of pluralism stretches further. Beyond the value of experimentation, diversity is also

necessary as a means of managing collective risks created by undue correlation. As populations converge on behavior that is most efficient at a point in time, monotonicity creates widely shared exposure to shifting underlying conditions, and the multiplicative character of evolutionary processes only serve to make this dynamic more pernicious. Because success in one generation implies greater representation in the next, the natural tendency will be for concentrations to build over time. Such concentration can be diffused by conscientious regulatory intervention or by (more violent) natural dislocation.

Risks of Concentration

To the extent that a population is uniform in its behaviors, it is vulnerable to shared risks when common behavior runs afoul of selective pressure. Therefore, diversification serves as an important means of group preservation. This issue is clearly exemplified by single-industry economies, such as tourism in the Caribbean islands or oil in Iraq or Venezuela. The decision to specialize in the geography's comparative advantage is generally quite profitable but can lead to sharp reversals when travel is restricted by a pandemic, or climate change leads to a pivot away from oil. Obviously, this prescription can be taken to unproductive extremes: the greatest degree of diversification would be provided by totally random behavior untethered from information provided by the environment.

How might this trade-off be appropriately addressed? The previously discussed Kelly criterion provides some clues. Rather than uniformly pursuing the highest expected value behavior, long-run growth is promoted by an allocation proportional to expected value. As uncertainty surrounding the future increases, so does the value of greater diversification (Kelly, 1956).

The risk of concentration is particularly acute with regard to a shifting environment. As populations adopt behavior that is advantageous within a particular context, they become increasingly ill-positioned for a change in that context. The most conspicuous recent example is the disruption of global supply chains in the wake of the COVID-19 pandemic. Over many decades, cheap and reliable connectivity of production processes across sprawling geography has created an environment of efficient globalized production. Optimizing for this environment, many corporations eschewed local production and redundancy in favor of cheaper dependencies. However, as the pandemic disrupted these critical connections, supply chains buckled and the availability of goods faltered (Harapko, 2021). Just as firms become accustomed to an apparently stable context, they also become vulnerable to changing conditions. To put it succinctly, just-in-time becomes not-in-time if anything changes.

Similar examples abound in the history of financial crises—a reality that is well captured by the existence of the phrase "too big to fail." In the years prior to 1998, many financial institutions (most notoriously a hedge fund inauspiciously named Long Term Capital Management) became heavily exposed to Russian debt, confident that the government's ability to print its own currency precluded any real possibility of default. When the context changed and the debt default occurred in August 1998, it triggered more than just domestic turmoil in Russia. The ensuing American market panic required the Federal Reserve to intervene and supervise a recapitalization of LTCM (Lowenstein, 2011).

Tendency Toward Concentration

These concentration risks are reinforced by the multiplicative nature of the adaptive process. The most successful memes of one moment have the most broadcasters in the next. The most successful investments of one cycle have the most capital to deploy in the next. This dynamic suggests inherently unstable distributions, a tendency toward concentration. Of particular concern is the unstable distribution of wealth in which inequality tends to expand unless explicitly checked—a process that can be observed empirically (Adamou, et al., 2020). It is therefore desirable for external regulators to engage in some measure of redistribution regardless of any philosophical or moral concern about inequality. The natural concentration of resources works at a cross purpose even to the goal of aggregate accumulation. Natural concentration undercuts the growth affirming risk aversion previously discussed in the contexts of both the Kelly criterion and systems of wealth pooling (Peters & Adamou, 2018).

Pluralism: A Thought Experiment

One can examine these dynamics by way of a thought experiment carried out with computer simulation. Suppose there is a population of agents whose survival is determined by how well their actions are suited to their environment. The agents who survive in any given generation reproduce, and the process repeats in the next generation. This dynamic is interesting, as it corresponds to a surprisingly broad range of social phenomena. Agents can be understood as modeling ideas that survive and reproduce according to how well they appeal to (and sustain) a population; or firms that survive according to how well their products match public demand; or even governmental entities that persist and expand according to their coherence with the political environment.

Reproduction can thus be interpreted as greater mindshare in the case of ideas, greater market size in the case of a firm, or greater power and scale in the case of a political institution.

The purpose of this thought experiment is to observe the dynamics of growth under various regimes of exogenous rebalancing (i.e., redistribution). We can apply different decision rules, determining how agents reproduce across generations, which correspond to different degrees of rebalancing (offspring that are more like parents imply less rebalancing, and vice versa). The appropriate interpretation of rebalancing is dependent on the social context; promoting contrarian perspectives in the face of intellectual homogeneity, taxation or anti-trust in the face of growing firms, or break ups of large governmental bodies. For each decision rule, we can apply the following procedure (the below is a high-level algorithm; for more detailed implementation consult the source code discussed at the end of this section):

1) Choose an environment parameter between 0 and 1.

2) Create an initial population of agents which each have an action parameter between 0 and 1.

3) For a given number of generations repeat the following subprocess:

3a) Select those agents that have an action parameter close in value to the environment parameter. Such agents are deemed to be well adapted to the environment and will survive to the next generation.

3b) Remove all other agents from the population.

3c) For all surviving agents, create a child in accordance with the pre-specified decision rule.

4) Display the growth trajectory of the population; higher growth is associated with greater environmental fitness over time.

In applying this procedure, we will consider three different decision rules; the degree of rebalancing is expressed by the degree of variation from parent to child agent (in each case, the action parameter of the child is the action parameter of the parent blended with a degree of random noise):

1. the "copy" rule, in which the child parameter is only marginally different from the parent, is associated with no rebalancing (i.e., the surviving agents replicate themselves in the population, largely uninterrupted).
2. the "rebalance" rule, which involves a more substantive random weight, is associated with moderate rebalancing (i.e., surviving agents have a tendency to replicate themselves within the population but with moderate interference).
3. the "large_rebalance" rule, in which an agent's action parameter is predominantly random noise and is associated with substantial rebalancing (i.e., the characteristics of the surviving agents are largely unimportant in shaping the next generation).

We begin by examining the success of the three decision rules in an environment that does not change. In all cases, the prevailing action parameter among the population converges to match the environment, and the population grows accordingly. However, without rebalancing the population is most attuned to the fixed environment and therefore grows most rapidly. Indeed, the population growth rates are inversely proportional to the degrees of rebalancing applied (greater rebalancing results in a lesser degree of convergence to the fixed environmental parameter). The significance of this result is to

say that, *in a reliably fixed environment*, aggregate growth is associated with allowing success to flourish unencumbered. In an unchanging world, a population may be well advised to read only the "best" books, produce only the "best" products, and give ever more power to the "best" governing institutions.

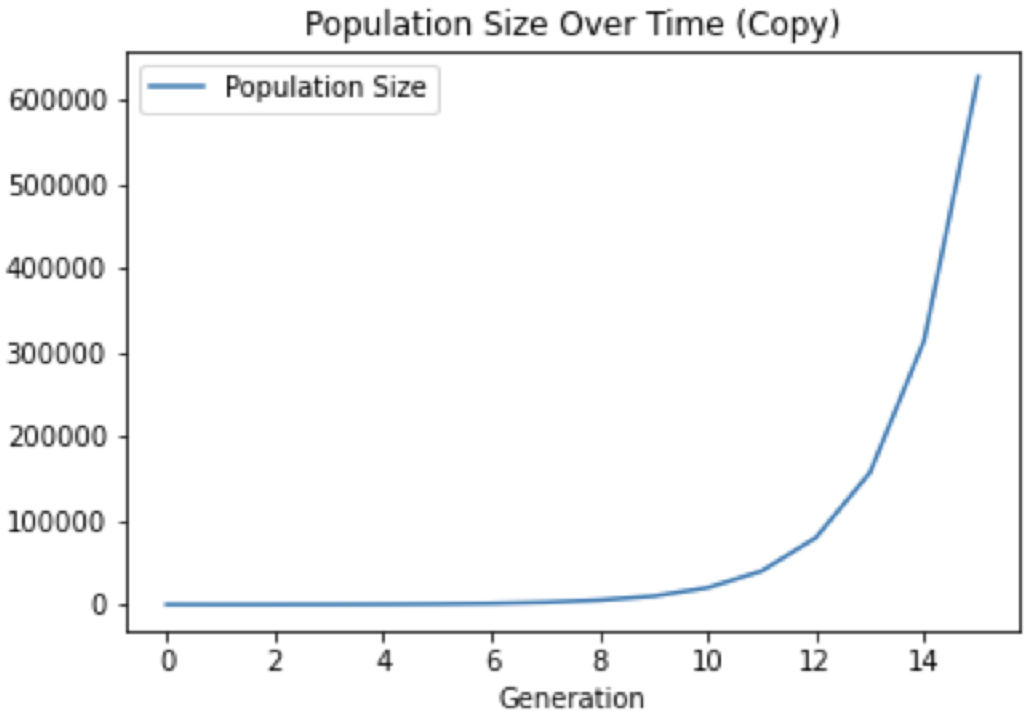


Figure 1. Population Growth in Fixed Environment: Copy Rule.

In an unchanging environment, the population without rebalancing grows quickly and smoothly.

Source: thesis author.

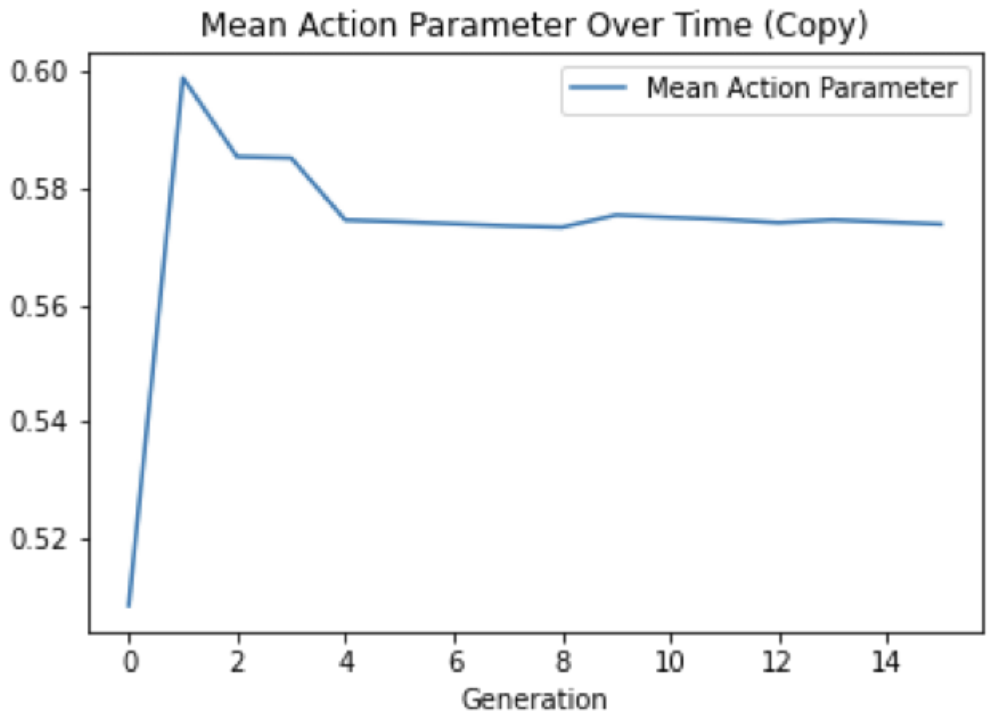


Figure 2. Mean Action Parameter in Fixed Environment: Copy Rule.

In an unchanging environment without rebalancing, the average action parameter of the population quickly stabilizes at a level which coheres with the fixed environment parameter.

Source: thesis author

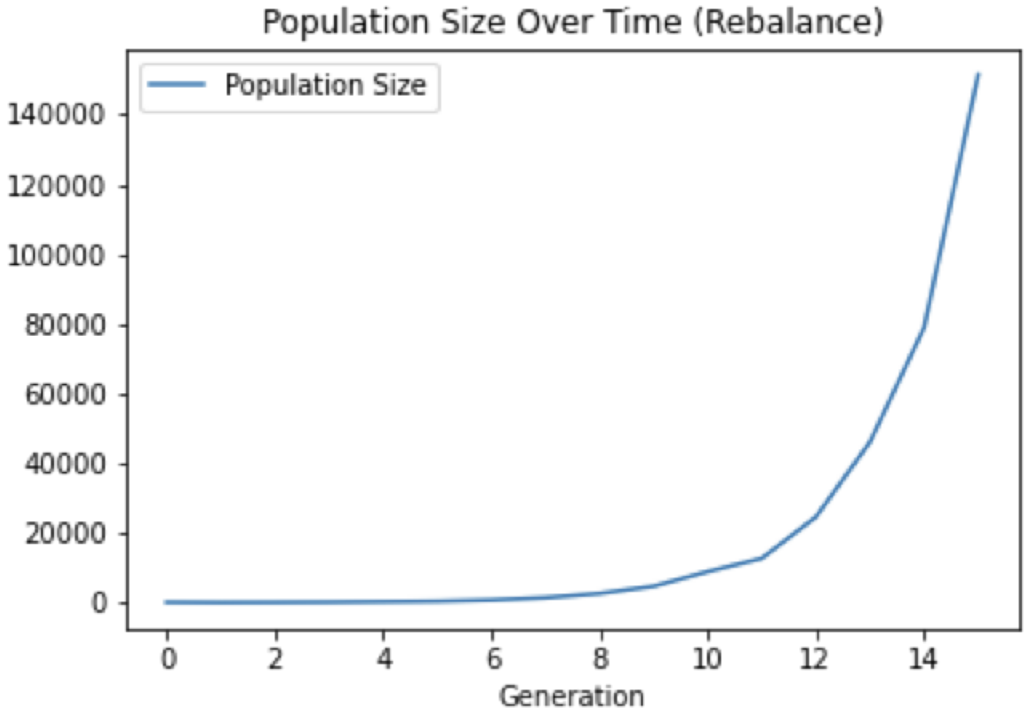


Figure 3. Population Growth in Fixed Environment: Rebalance Rule.

In an unchanging environment, the population with rebalancing grows smoothly but slower than the population without rebalancing.

Source: thesis author

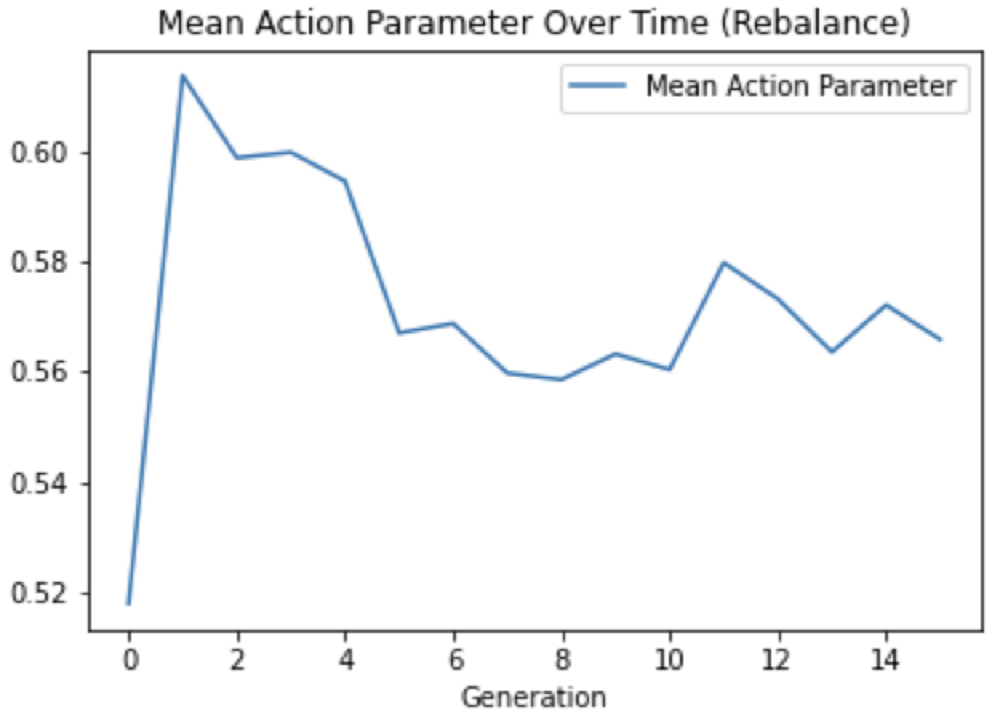


Figure 4. Mean Action Parameter in Fixed Environment: Rebalance Rule.

In an unchanging environment with rebalancing, the average action parameter of the population is volatile. Rebalancing prevents a strong fit to the fixed environment parameter.

Source: thesis author

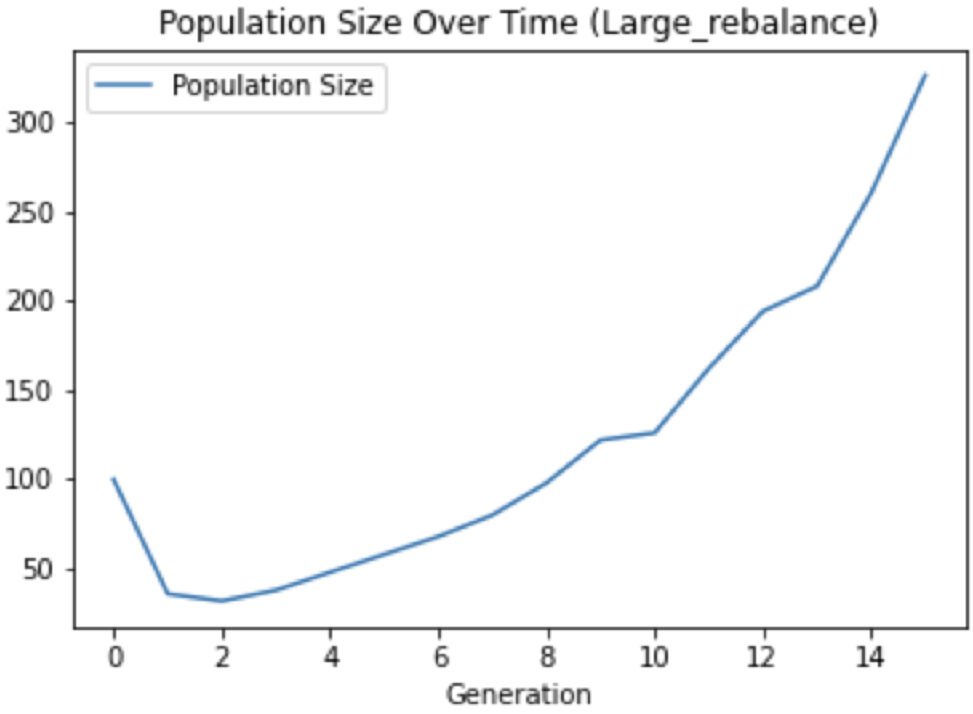


Figure 5. Population Growth in Fixed Environment: Large Rebalance Rule.

In an unchanging environment, the population with large rebalancing grows less smoothly and less quickly than either no or moderate rebalancing.

Source: thesis author

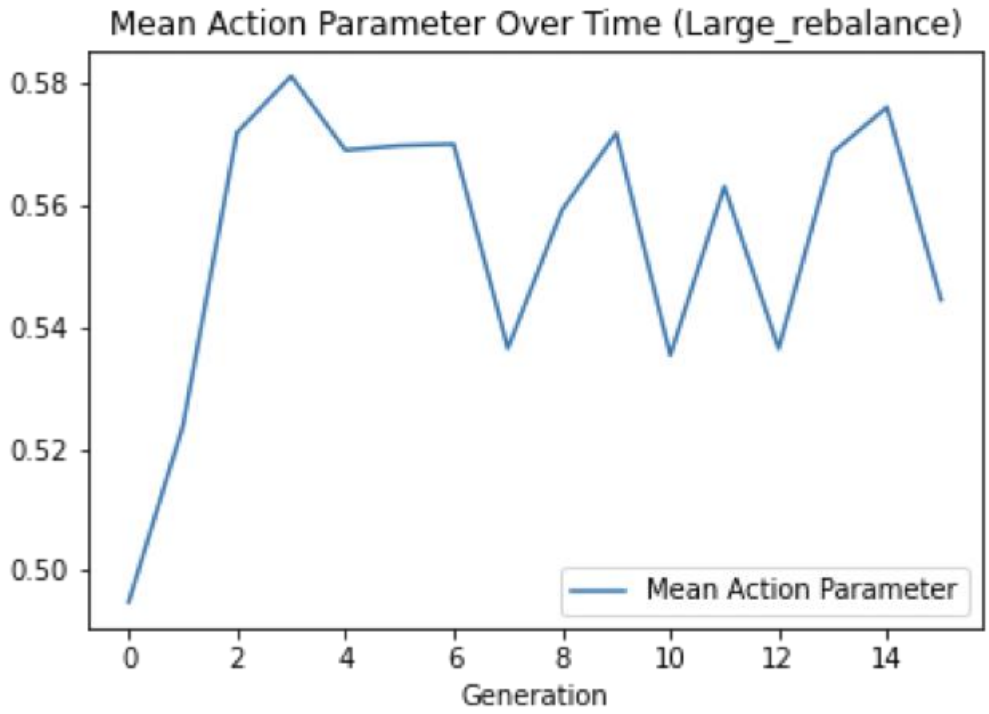


Figure 6. Mean Action Parameter in Fixed Environment: Large Rebalance Rule.

In an unchanging environment with large rebalancing, the average action parameter of the population is very volatile. Large rebalancing prevents a fit to the fixed environment parameter.

Source: thesis author

However, the results are quite different in the case of an environment that changes. In the second experiment, the environmental parameter is updated in each time step with a degree of random noise (i.e., what is environmentally fit changes over time). In this case, the population without rebalancing initially grows quickly by matching the environment but collapses entirely when the environment changes and becomes hostile to

the homogeneous population. The moderate rebalancing population grows smoothly; it fits the environment to an extent but preserves the variation necessary to survive sharp changes. Interestingly, growth in the heavily rebalanced population is comparatively shaky and slow. While some rebalancing is necessary to avoid concentration, an excessive application can result in suppressing the information provided by the environment. These results are highly significant because instability of environment is to be expected in any social context. As such, the results suggest that rebalancing, redistribution, and the maintenance of pluralism are of critical importance.

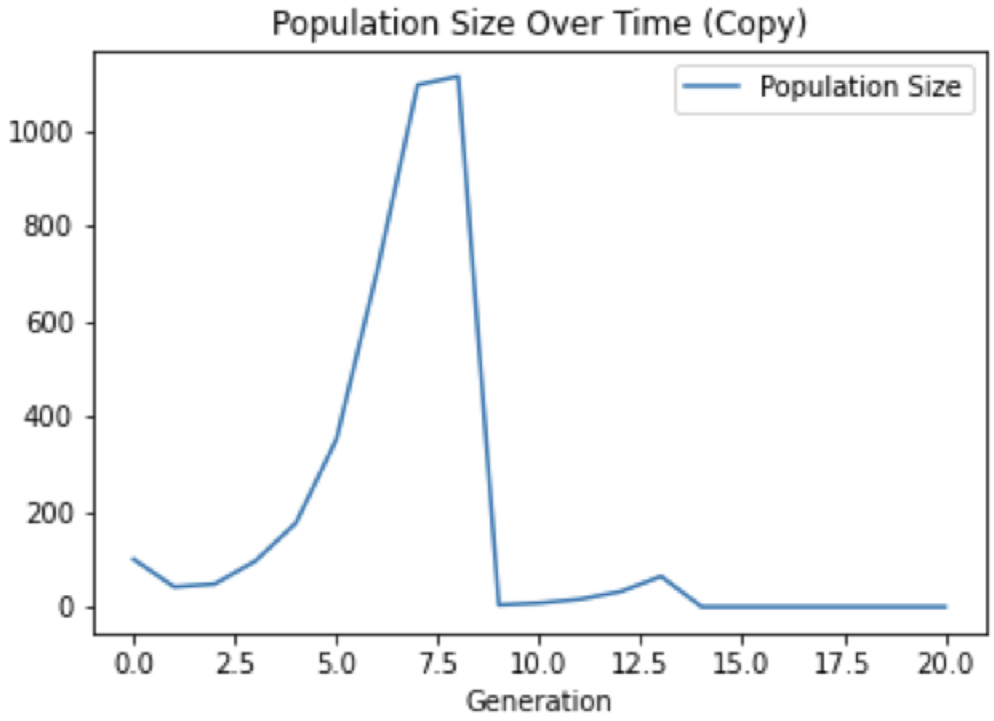


Figure 7. Population Growth in Shifting Environment: Copy Rule.

In a shifting environment, the population with no rebalancing initially grows quickly but collapses when the environment becomes hostile to the homogeneous population

Source: thesis author

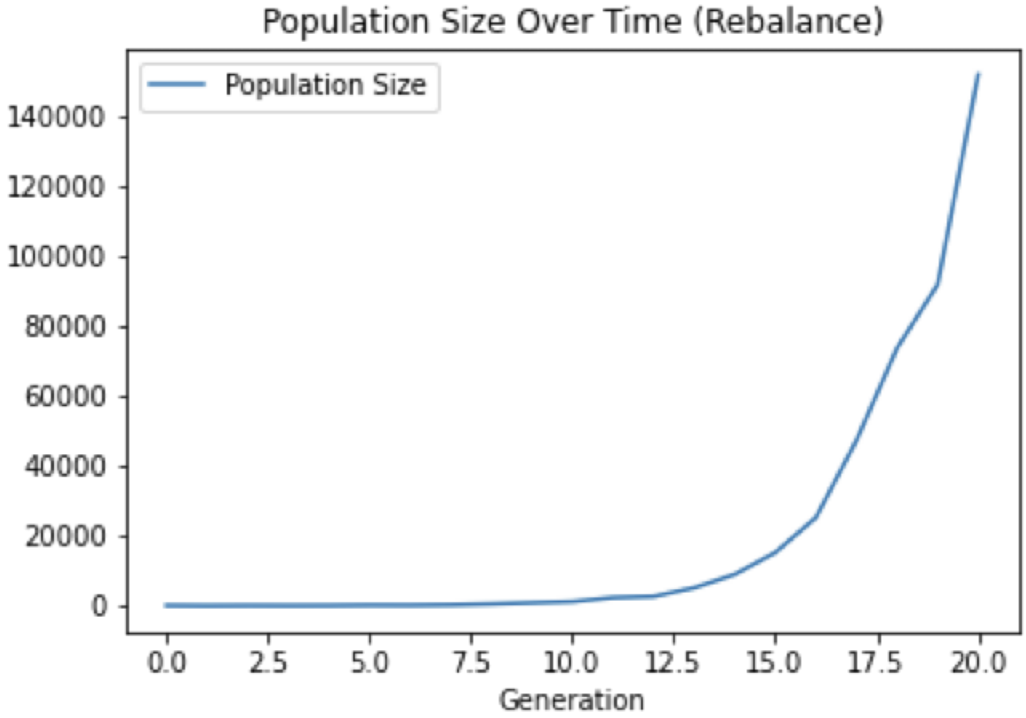


Figure 8. Population Growth in Shifting Environment: Rebalance Rule.

In a shifting environment, the population with rebalancing grows quickly and smoothly, balancing environmental fit and preservation of variety.

Source: thesis author

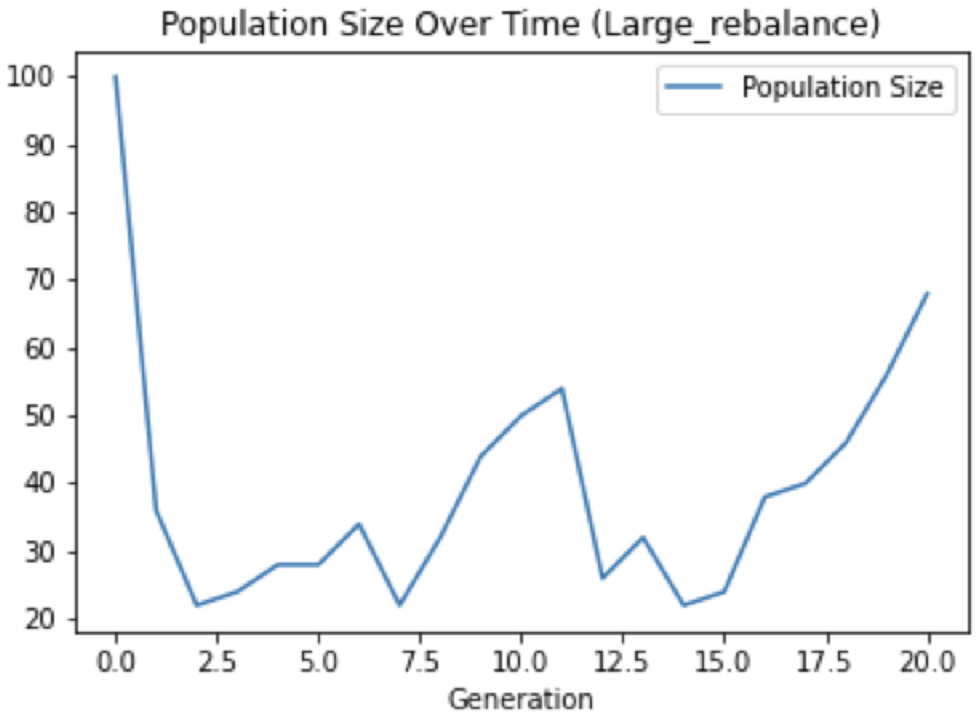


Figure 9. Population Growth in Shifting Environment: Large Rebalance Rule.

In a shifting environment, the population with large rebalancing survives with minimal growth. High variety protects against extinction but environmental fit (growth) is sacrificed.

Note: For the technical reader, the source code for these experiments is provided in Appendix 1. The code, written in the Python programming language and generated from a Jupyter Notebook, is shared in order to facilitate open interaction with and examination of the results.

Source: thesis author

This discussion of pluralism and redistribution clearly applies to the accumulation of wealth but by no means exclusively so. The same motivations for avoiding concentration applies just as well to sectors in a national economy, party control in a government, or political ideas in a polis. The conclusion for policy makers, therefore, is

to be vigilant in guarding against excessive build-ups of wealth, influence, or institutional power. This does not mean an absolute removal of imbalance, as this would constitute a detrimental suppression of information accumulated from the environment. But multiplicative processes tend to create unstable distributions with inequality that continuously widens unless checked—either by deliberate policy or shock.

Precautionary Principle

An additional prescription for policy makers is what is commonly known as the *precautionary principle*. Several formulations have been proposed across various contexts. For our purposes, a weak and broadly unifying version of the principle may be stated as follows: to the extent that a policy intervention (or lack thereof) poses broad systemic risk, it is to be resisted in the absence of overwhelming supporting evidence.

Another characteristic formulation of the principle lays out four key components:

1. preventative measures when confronted with uncertainty,
2. placing the burden of proof onto those that would introduce uncertainty,
3. deeply exploring alternatives, and
4. expanding public participation in decision making (Kriebel, et al., 2001).

Of significance is the emphasis on extreme caution when confronted with impactful and uncertain decisions. This is particularly important with regard to the governance of complex systems. The characteristic unpredictability and non-linear behavior of such systems means that interventions often carry substantive and unpredictable risks.

Some intuition is provided by analogizing policy intervention to an investment or bet. Given a presumed positive payoff to a particular policy action (it must be expected

value positive or there would be no cause to pursue the policy), the Kelly criterion provides guidance on how much to "bet" on the action. As the volatility of the payoff goes up, the prescribed bet size goes down; greater uncertainty indicates that decision makers should be increasingly circumspect about an action.

The principle has been associated historically with environmental policy, where tampering with a complex ecology can yield disastrous unpredicted consequences. Perhaps the starkest historical example is China's 1958 Four Pests campaign, in which non-adherence to the principle led to massive ecological imbalances, created widespread famine, and contributed to the deaths of tens of millions of people. Recent authors have also applied the precautionary principle to promote skepticism regarding the widespread promotion of genetically modified organisms (Taleb, et al., 2014), as well as an extremely vigilant handling of the coronavirus pandemic (Norman, 2020).

Critics of the principle argue that it is vague and self-defeating. Certainly, we can imagine circumstances in which all outcomes are substantially uncertain. For example, policy makers considering the 2008 financial bailout had to contend with the competing risks of recession (which might be caused by withholding funds) and entrenching bad actors (which might be caused by providing the bailout). It seems clear, given the symmetry of epistemological uncertainty, that the precautionary principle cannot provide guidance in such circumstances. But more important, this shortcoming is not general. The presence of some cases in which the principle cannot provide guidance does not negate the value of the principle as a decision-making tool more broadly.

Chapter IV

Framework Comparison

To this point, we have considered how complexity theory might be applied to the analysis of political actions and institutions. It is reasonable that we should also consider its relationship to existing major frameworks of analysis. In particular, it is useful to consider the ways in which complexity theory might be regarded as complementary or contradictory to more established paradigms such as realism, liberalism, and constructivism.

Complexity and Realism

Realists argue that global politics are essentially defined by anarchy. International relations center around the largest states, which use their dominant power positions to pursue their own self-interest while others are obliged to either balance or bandwagon. The survival of individual states is regarded as essential to the analysis of behavior. This view has been developed throughout a number of key works in the tradition, which are examined in further detail.

Thucydides' *History of the Peloponnesian War* is often regarded as being the origin of realism as a theory in international relations. It begins from a theory of human nature which assumes that individuals are self-interested and that theoretical evaluation of moral norms functionally cannot supersede the draw of opportunities presented by superior strength. The international order is therefore determined by the interests of the

most powerful actors—i.e., states—which impose their will on others. It naturally follows that states will pursue power, both for its rewards and to avoid the costs associated with its absence.

H.J. Mogenthau, author of *Politics Among Nations*, makes this claim even more explicitly, arguing that universal moral principles cannot be applied to the actions of states. The overriding moral principle for the state is that of ensuring national survival. Therefore any other ethical consideration must be subordinated to the national interest (Morgenthau, 2006).

This view is expanded in *Man, the State, and War* by Kenneth Waltz, who argues that war ultimately derives from the anarchic structure of the international system. Because states cannot (credibly) appeal to any higher authority in the disputes that tend to arise among themselves, such disputes can only be resolved through the exercise of relative power (Waltz, 1992).

Perhaps the most fatalistic of the realists is John Mearsheimer. In *The Tragedy of Great Power Politics*, he argues for a theory of offensive realism in which conflict between great powers is a permanent fixture within global politics. In his conception, the means by which states seek to ensure their survival is through a tripartite strategy of pursuing regional hegemony, wealth maximization, and nuclear superiority—the latter two being strongly supportive of the first (Mearsheimer, 2003).

Where Complexity and Realism Agree

Complexity theory finds some merit in this approach, particularly with respect to the central importance of survival. Within a given complex system, the selection of subsystems is generally determined by survival competition. The system is composed of

those constituents that are adapted to persist. In this regard, the international world order could be regarded as a complex system composed of surviving states. These states are in turn composed of surviving domestic institutions, which are in turn composed of individuals, which are in turn composed of ideas.

The complexity framework tends to agree with Thucydides' notion that actors are self-interested and that they tend to pursue greater capability. Indeed, the notion that actors tend to increase their capacity to project power bears striking resemblance to the tendency of complex systems to engage in inter-temporal optimization. Any system concerned with its ability to acquire resources over time will certainly be concerned with increasing its capabilities—both in general and relative to competitors. The ability to reliably acquire resources follows directly from power which makes the pursuit of power an obvious prediction of the complexity framework.

Morgenthau's notion that universal morals cannot be applied in politics is also agreeable. Because systems optimize to accommodate a particular selection function, desired moral conventions must be explicitly encoded into the incentive structure. Otherwise, behavior contrary to moral preferences will, in general, be preferred as a more efficient means of satisfying the given objective function.

Waltz emphasizes the absence of an exogenous authority in the resolution of state disputes as being of central importance. A complexity approach tends to agree that this is a significant feature of the international order. The ability of states to satisfy their interests—most essentially survival—will clearly be affected by the nature of rules enforcement. Loyal adherence to generally agreed-upon rules will only be prevalent

within the social ecology to the extent that penalties for defection are anticipated by participating actors.

Complexity finds some merit in Mearsheimer's assertion that the states' impulse to acquire security through power is likely to engender persistent conflict. So long as there exists an incentive associated with dominant power status, at least some of the various states are likely to pursue it.

Where Complexity and Realism Disagree

An approach guided by complexity science may regard realism as somewhat simplistic in its interpretation of survival and material interest. Military incursion is not the only threat that states face. The balance of power may be a relevant dynamic for any given state to consider but not necessarily a central one. Moreover, the notion that larger states will use hard power to dominate smaller states is dubious. Complexity science suggests that large powers may identify a broad range of strategies ranging from imposition of hierarchy (e.g., China in East Asia) to pluralistic cooperation (e.g., contemporary Europe). Indeed, empirical observation of world regions tends to support this conclusion. While complexity shares the realist emphasis on self-interest, it is more accommodating of cooperative behavior, which can be regarded as the enlightened pursuit of self-interest; any decision to behave pro-socially is ultimately an exercise in survival likelihood maximization.

Thucydides argues that states want to pursue arbitrary power and that those at the top will govern relations. While this may partially predict the behavior of the largest competitors, the analysis has some issues. First, it may be the case that plausible candidate hegemons see greater safety in avoiding conflict over power than in competing

for it. Second, among states destined for the periphery, devotion to the pursuit of power can do little to explain the rich ecology of national strategies.

While a complexity approach would tend to agree with Morgenthau's skepticism of morality as a generally sustainable guide to state policy, this is not to say that there are no conditions under which moral principles are sustainable. One can imagine that if a broad international consensus for the punishment of anti-social behavior were to somehow emerge, then selfish and moral behavior might be aligned in a sustainable fashion despite the absence of a strictly exogenous regulator.

Furthermore, the complexity framework gives rise to a criticism of Waltz's claim that disputes within the anarchic consortium of states will necessarily be resolved with assertions of relative power. As has just been highlighted, there are hypothetical conditions under which such assertions would be generally ineffective. Even under the prevailing environment, in which an equilibrium of mutually cooperative behavior is not in place, the ecosystem of nations is characterized by a multi-variate interdependence which disciplines certain aggressive actions regardless of relative power. For example, New Zealand has enjoyed approximately a century of national sovereignty despite comparatively limited diplomatic, economic, or military resources. It is safe from aggression not because of its own capabilities but because would-be aggressors fear disrupting a broader global equilibrium. To say that this is a demonstration of power parity would strain any reasonable definition.

A similar argument can be made against Mearsheimer's grim fatalism regarding the inevitability of power competition. It is true that there exists a plausible failure pattern in which states fall into continuous conflict over their pursuit of security through

economic and military superiority. But there is little reason to expect that this is inevitable or even likely, for two reasons. First, any state that anticipates the futility of power competition will seek to avoid it. Second, pairs of states do not exist in a vacuum wherein their conflicts are resolved in isolation. Rather, they are bound together by rich networks of interrelation. This allows for states to pursue their national interest through a variety of strategies, including, but not limited to, competition for relative power.

Complexity and Liberalism

Liberalism contends that the international system is guided by the interactions of governments and other domestic institutions within sovereign states. The theory notes that states have many common interests and opportunities for mutual benefit which will induce them to cooperate. Any mutually agreed-upon policy, action, or institution must provide a benefit to all its participants, else why would they participate? According to this logic, progress occurs through the process of individual actors pursuing an enlightened conception of self-interest by way of cooperation with others (enlightened relative to realism which apparently regards interests as fundamentally more zero-sum). As a result of this dynamic, international institutions, interdependence, and soft power are of central importance in understanding the formation of the prevailing world order.

In *After Hegemony*, Robert Keohane makes the claim that multilateral cooperation can and will occur in the absence of a political hegemon. Because global institutions are useful to states, nations can and should pursue their formation. In particular, international agreements and organizations are mutually beneficial to all participants (as evidenced by their voluntary adoption). Thus it is possible, through institutional interconnectivity, to mitigate the emergence of global conflict (Keohane, 2005).

In her work, *Who Adjusts? Domestic Sources of Foreign Economic Policy During the Interwar Years,* Beth Simmons provides an additional line of argument against the essentiality of a narrowly defined national interest in the formation of international relations. She posits, through various empirical and case study analyses, that internal political conditions have considerable influence on the external orientation of states. In particular, domestic politics were determined to have affected the extent to which governments complied with or defected from the gold standard. This specific example raises the possibility of yet more instances where limited definitions of national interest do not reasonably describe national behavior (Simmons, 2020).

In *The Choice for Europe,* Andrew Moravcsik identifies the European Union as a singularly significant example of national interest being pursued through multilateral cooperation and not power politics. Through historical analysis of the region's path towards integration, Moravcsik rejects ideology, technocracy, and national security as essential motivations for the formation of the European Union. Rather, economic advantage accrued through interconnection is determined to be the critical factor. If the analysis is to be believed, then the success of the European Union strongly recommends a broad interpretation of the national interest (Moravcsik, 2005).

In *Liberal Leviathan,* John Ikenberry analyzes the liberal order led by the United States beginning in the latter half of the twentieth century. Ikenberry concludes that this arrangement has been uniquely successful in providing both security and economic well-being to many throughout the West. While the liberal order has faced challenges—American unilateralism, disputes over national roles and responsibilities, and the ascendency of non-Western states—these challenges are indicative of its evolution rather

than its collapse. Thus, Ikenberry identifies the pursuit of national interest through multilateral cooperation as both desirable and broadly practiced (Ikenberry, 2011).

Where Complexity and Liberalism Agree

Complexity science and liberalism certainly have some areas of overlap in their approach to understanding the prevailing order. In particular, a complexity-oriented analysis would agree forcefully with liberalism's broad interpretation of states' interests. To the extent that cooperative behavior and the formation of regional institutions advances the interest and survivability of state actors, such behavior is expected to be the norm. In his book (and earlier paper of the same name) *The Evolution of Cooperation*, Robert Axelrod discusses research in which participants were invited to submit strategies for a tournament of iterated Prisoner's Dilemma. The strategies were pitted against one another in order to understand which strategies might be successful and in what environments. Axelrod noted that while unconditionally cooperative strategies floundered, strategies that sought to cooperate while retaliating against non-cooperation tended to be the most successful. Further analysis indicated that this "friendly" behavior was an evolutionary stable strategy, and that within a population of practitioners of such a strategy, there is no adaptive benefit to deviating. Even though widespread cooperation may seem antithetical to a system of thought predicated on adaptive selection, there is actually a strong evolutionary argument for the emergence of cooperative behavior. In this regard, complexity theory and liberalism are aligned in an expectation of cooperation.

The complexity approach would share Keohane's view that cooperation is likely to occur in the absence of political hegemony. The usefulness, to all participants, of

multilateral institutions is all that is required to effectively guarantee their formation, and the value of these institutions may well serve to stifle the emergence of conflict which might disrupt them.

Complexity theorists would applaud Simmons' rigorous critique of the notion that a narrow conception of national interest could be used to anticipate state behavior or that that behavior might be consistent across entities. States are complex systems, which means their specific behaviors are inherently unpredictable. They are composed of subsystems which include their citizenry, and therefore it should be expected that state actions should be a function of domestic considerations.

Moravcsik's analysis of the European Union is largely compatible with a complexity-oriented approach. That member states might perceive an advantage in tight integration is not controversial. Indeed, given the diversity of conditions under which world governments operate, it is absolutely to be expected that some of them would seek sustained cooperative arrangements.

The same logic applies to Ikenberry's analysis of the US-led liberal order. Economic and security collaboration among countries in the West has been generally advantageous relative to a more confrontational approach. It is to be expected that it would occur.

Where Complexity and Liberalism Disagree

There is not perfect overlap between the two paradigms. While a complexity approach sees value in, and would anticipate the emergence of, cooperative dynamics, it would not necessarily identify sovereignty, institutions, or soft power as being of fundamental significance. These notions persist to the extent that they are pro-adaptive to

institutions that use them in the political ecology within which they operate. But institutions may shirk the liberal order as soon as there is a perceived advantage to doing so.

While complexity theory is sympathetic to Keohane's view that useful global institutions will reliably emerge, and that this will tend to dampen the impulse toward conflict, it would also regard Keohane as too optimistic. Institutions of common interest are a double-edged sword: not only does interconnectivity confer benefits to the participants, it also represents a source of dependency which may be exploited by unscrupulous agents. Indeed, the more valuable a cooperative institution is, the less favorably inclined its participants will be toward the disruptions that may be required to punish anti-social behavior. Such a dynamic seems to explain, for example, the interwar process of appeasement; Europe's (justifiable) attachment to collective security created the adaptive niche for Hitler's exploitation of concessions.

Simmons makes the empirical case that states do not reliably conform to a narrow and specific concept of self-interest. This does not exclude the possibility that states are driven by complex and multi-faceted conceptions of self-interest. Indeed, the conditions of the various states are distinct, so the strategies by which they maximize their own welfare would be expected to differ. That there is some correlation between domestic politics and outward orientation does not undercut the essentiality of state self-interest. Rather, it simply underscores the hierarchical network structure of the states; the behavior of the macroscopic system is, unsurprisingly, a function of its components.

Complexity theory is not surprised by the observation of self-interest through cooperation, as outlined in Moravcsik's *The Choice for Europe*. But that does not mean

that such cooperation should be expected to occur in general. Interconnectivity may be advantageous given the particular context of the European Union. However, states in differing political and economic situations may well find advantage in more adversarial behavior.

The concerns with Ikenberry's analysis are similar. That the liberal order led by the United States has tended to be successful in a particular geo-political context offers no guarantee that this arrangement will continue to be efficacious indefinitely. The broad scope for cooperative behavior offered by evolutionary processes has limits. To the extent there is a contextual advantage to rivalrous behavior, it is likely to occur.

Complexity and Constructivism

Constructivism holds that the international system is shaped by ideas, culture, and norms, all of which are contestable. Outcomes can either be cooperative or conflictual as a function of context as shaped by the underlying ideas. This stands in contrast to the previously discussed frameworks of realism and liberalism which emphasize the importance of material interests relative to ideas. This paradigm also places a strong emphasis on the significance of non-state actors in its analysis of world order.

Social Theory of International Politics by Alexander Wendt advances the constructivist approach to international relations in which the role of common norms and ideals are central to the formation of state behavior. Wendt charges that both realism and liberalism are unduly preoccupied with material considerations. Rather than debating the means by which states might most effectively pursue their interests—assertions of power according to realists versus multilateral cooperation according to liberals—scholars of global politics ought to focus on the shared values among the various national

populations. Because collective norms differ across populations, the governments of those populations will differ in their approach to the essential anarchy among states (Wendt, 1999).

In the similarly titled, *Social Construction of International Politics*, Ted Hopf continues this argument. International policy is born of shared ideas within society because policy makers are of and bound to society. To demonstrate the point, Hopf draws connections between various sources of mass consumption media and the views of contemporary decision makers (Hopf, 2002).

The Justice Cascade by Kathryn Sikkink advances the evidentiary case for constructivism by examining the effects of human rights trials. She notes that state leaders becoming subject to public trials with visible consequences has resulted in widespread behavioral shifts among the political elite. She quantifies the effects that more pervasive human rights norms have had on repression, democracy, and more (Sikkink, 2011).

Paternalism Without Borders, a collection of writing edited by Michael N. Barnett, applies the lessons of constructivism to the compelling interconnection between power and global acts of compassion. Humanitarianism, development aid, and other projects ostensibly aimed at improving the lives of those less fortunate necessarily involve those with power exercising it over those who do not. In this way, external actors isolate themselves from local actors, privileging general over local knowledge. Thus, humanitarian practice frequently involves acts of paternalism in which a well-meaning agent substitutes their judgment for that of the subject of their beneficence. Because of this obvious conflict, in which the subjects of paternalistic care may have undesirable

outcomes imposed on them, the multi-author volume is unable to reach conclusions as to whether paternalism can be justified at all (Barnett, 2016).

Where Complexity and Constructivism Agree

Complexity theory does have overlap with this approach. In particular, the constructivist emphasis on the importance of ideas is appropriate. In treating states as hierarchical complex systems, ideas are the basic building block at the bottom level. Governments are composed of branches, composed of people, composed of ideas. Complexity science also tends to agree with constructivism's willingness to accommodate non-state actors. In interpreting world order, the significance of states is that they have historically been the most powerful institutions. There is no reason to expect that this is an immutable property that cannot or will never change.

Wendt's focus on broadly shared ideas of a population has a natural affinity with complexity theory. While realists and liberals might tend to treat the state an agent entity independent of its population (Simmons being a notable exception), Wendt distinguishes constructivism by emphasizing the connection between pervasive memes and governance. This wholly coheres with the hierarchical network structure which is central to complex systems. Memes will tend to be represented in governance to the extent they successfully endure survival competition.

Hopf's work has similar strengths in the eyes of the complexity framework. The state is ultimately composed of political ideas which are contained within the population. Therefore, an understanding of highly prevalent political memes is useful to understanding the behavior of the state.

Sikkink's results should be no surprise to the complexity theorist. A policy that raised the prevalence of certain political memes—various human rights norms in this case—increased the likelihood of associated political actions. It is to be expected that the behavior of the network shifts with the alteration of its components.

Finally, a concern for the perils of interventionism, expressed in *Paternalism Without Borders*, is strongly aligned with the complexity framework. The framework is highly skeptical of the capacity for external actors to exercise superior judgment relative to that of internal actors with local information and subject to adaptive pressure. This is expressed in the normative framework's admonition against attempting to design systems top-down (Barnett, 2016).

Where Complexity and Constructivism Disagree

There are some obvious objections to constructivism. In particular, a complexity theorist may contend that the framework underemphasizes material considerations and the role of survival. It is true that ideas are the fundamental building block of complex social systems and warrant significant attention. But ideas, economic welfare, and security are interdependent considerations which must be examined accordingly.

A practitioner of the complexity approach might regard Wendt's analysis of collective ideas as both unduly static and unconcerned with material conditions. The pervasive memes of a population are not a constant from which governance directly flows. Rather, the requirements of the state impose pressure on constituents who, in turn, apply selective pressure to the population of memes that underlie their political behavior. Subsequent iterations of the meme pool in turn beget iterations of the state. Importantly, the state is mutually interdependent with both material conditions and the pervasive ideas

of its population. This implies that those ideas must also be a function of material conditions.

Hopf's work raises similar concerns. It is certainly true that domestic identity has a great effect on how the state conducts its international relations. But domestic identity is not an exogenous variable. The content that flows through mass media and achieves public consensus is bound to economic and security concerns.

Sikkink's work further highlights the connection between the material and intellectual domains. It is true that increasing prevalence of human rights norms served to change the behavior of political elites. But the means by which ideas changed, i.e., public and consequential trials for offenders, are clearly material. The meme population shifted because the behaviors associated with retired memes were perceived to have deleterious impact on their practitioners' ability to preserve power.

While the complexity framework is highly sympathetic to the intervention hesitancy expressed in *Paternalism Without Borders*, this should not be interpreted as a proscription of humanitarian action. The framework rejects the external imposition of specific behavior but not the enabling of individual agency (one obvious manifestation being direct cash grants or loans). The framework is skeptical of large-scale bureaucratic designs (e.g., the Millennium Villages Project) but not of small-scale experiments which might be locally adapted or else discarded at low cost. Efforts toward the promotion of pluralism, as detailed in the normative framework, are to be viewed favorably as well.

Framework Comparison: Conclusions

The complexity framework shares points of both harmony and contention with each of the three major frameworks, ultimately offering an attractive synthesis. In

realism, we embrace the essentiality of material interests but reject the narrow and adversarial means by which they are presumed to be pursued. We find merit in liberalism's more expansive conception of cooperative self-interest but caution against belief in the fundamental significance or sustainability of shared institutions. While we share the constructivist appreciation for the importance of common ideas, we note that such ideas are interdependent with and shaped by material considerations.

This apparent harmony between complexity and each of the three frameworks evaluated suggests that they may not be as mutually incompatible as some of their proponents suppose. It also suggests that the complexity framework might appropriately be viewed as a moderate compromise in the broader landscape of analytical paradigms.

Chapter V

Policy Notes

Up to this point, we have been concerned with cultivating the body of abstract theory that constitutes the main contribution of this document. Having thus developed a framework of analysis grounded in complex systems theory and relating it to major alternatives, we can now turn to the matter of policy applications. What follows is a collection of brief policy notes which touch on economic, security, and climate issues. The scope of this analysis is purposefully broad, aiming to demonstrate the wide applicability of the framework. These policy notes serve to establish select political viewpoints suggested by the framework, lay a foundation for deeper analysis of the topics addressed, and guide future application of the framework to other policy questions.

Coordinating Climate Action

There exists, at the time of this writing, a broad understanding that Earth faces a shared risk associated with rising temperatures which are caused, to a significant degree, by human emission of carbon. How policy makers, and society more broadly, ought to respond to this is a matter of significant contention. Candidate responses run the gamut. Some advocate de-industrialization, renewable energy investment, or technological innovation. Others suggest that minimal response is required; the costs of emission are acceptable, unavoidable, or nonexistent (i.e., disputing the connection between emission

and climate change). In the face of such uncertainty and contention, how does our framework suggest that global policy makers approach this challenge?

First, we can refer to the precautionary principle which dictates that the existential nature of the threat requires it to be addressed forcefully, even if epistemic doubts regarding the effects of climate change are to be taken seriously. The asymmetry of the risk profile makes the primary concern obvious. The costs associated with overreacting are extremely low relative to the alternative. If the association between human activity and climate change turned out to be entirely spurious, then societies will have squandered whatever resources they invest in divesting from carbon. If the association holds, societies face unbounded and continuous ecological disaster. Importantly, de-carbonization is still prescribed *even if the expected value of carbon divestiture is lower than the alternative*. There is only one Earth, which means that the ecological process in question is non-ergodic, and extreme caution must be practiced.

Having established the need for a global program of reducing carbon emissions, we can turn to questions of implementation. Our framework tends to suggest that carbon taxes or so-called “cap and trade” programs are preferable to a highly directed global strategy (e.g., pre-determined levels of energy consumption or mandates for specific means of energy production). Such policies create the structure for evolutionary adaptation by appropriately shaping payoffs rather than attempting predictions of complex causality. Any given policy regime or energy source may have convincing support but predicting realized outcomes is prohibitively difficult. Note that this line of reasoning does allow for concentrated national strategies so long as, globally, nations are diversified in approach.

Given the epistemological challenges to any particular intervention, the ideal implementation strategy is almost certainly mixed. Allowing various nations to make carbon reductions without prescribing specific implementation details seems ideal. This serves to achieve both the desired strategic diversification and allows for accommodation of national idiosyncrasy. A scenario in which Germany pursues wind power, France produces nuclear energy, and Saudi Arabia uses solar (even while exporting limited amounts of oil to others who pay a steep surcharge) seems perfectly tenable.

Of course, all of this assumes a solution to the global coordination problem, that is, a successful response to climate change requires broad international commitment. Our previous examination of cooperative dynamics in an evolutionary context provides some guidance on how the necessary global action might be achieved. Each nation would prefer to emit carbon without constraint (defect) while others reduce their emissions (cooperate). If each country chooses to defect, the collective outcome is worse for each than if they had cooperated. This represents a clear instance of a prisoner's dilemma. This would tend to suggest that the outline of a solution can be found in the tit-for-tat strategies of Axelrod's previously discussed study (friendly but retaliatory and occasionally forgiving strategies represent the baseline for candidate policy). To the extent that some critical mass of countries consistently acts in accordance with such a strategy (adherence to collectively specified emissions targets with retaliation against non-compliant states), then each country would find itself effectively participating in an iterated prisoner's dilemma with a supranational block. The dynamics of a such a game are both well understood and in accordance with desired outcomes.

Nuclear Weapons and Security

The emergence of nuclear weapons clearly marked a phase shift in international security. Through transitions from nuclear unipolarity, to bipolarity, to the current multipolarity, the world has enjoyed a hiatus from the use of nuclear weapons since their initial deployment at the end of the Second World War. Conventional conflict among the great powers has also diminished, presumably out of concern for the ladder of escalation. While the various nuclear powers have different public and private positions regarding the conditions under which they might deploy nuclear weapons, the long-running nuclear standstill suggests the existence of some equilibrium. Debates regarding the durability of this equilibrium, its relationship to conventional conflict, and the impacts of shifting technology are both ongoing and of clear significance. While our complexity framework cannot resolve these debates, it can support some useful observations.

Not only are we unable to articulate something like a general theory of security policy, in fact our complexity analysis would tend to suggest that such a result is not achievable. Importantly, security policy is defined within an ecology of adaptive agents. Optimal policy for one actor is a function of policies followed by others; the practice of salami tactics[1] is likely to achieve more against a target proclaiming a policy of "no first use" than it is against one proclaiming a willingness to use tactical nuclear weapons. Thus, ideal security practice should be understood as necessarily being evolutionary and in flux, a function of shifting policies and capabilities. Notably, this observation would tend to undermine the significance of the "nuclear revolution"; the set of actions that

[1] A divide-and-conquer approach that aims to split up the opposition.

might be deterred by credible second-strike capability will depend on a shifting set of other capabilities.

Given the tendency of complex systems to optimize for growth in resource ownership, the framework here maintains a realist cynicism regarding the risks of likely power competition. Thus, any international security institutions or agreements must confer verifiable material benefits to all participants if they are to be regarded as credibly sustainable. Culture, tradition, and good will can support transient cohesion but are likely to be eventually exploited where possible.

The precautionary principle would clearly suggest that, given the existential nature of the risks, the primary consideration in any security analysis is the avoidance of nuclear conflict. Therefore, the pursuit of minor advantages through measures that might lead to escalation is generally inadvisable. Such aggression should be pursued only with high confidence of reward and limited by the uncertainty in outcomes.

The non-linearity of complex systems further recommends caution; inability to forecast outcomes increases uncertainty and raises the threshold for taking risks. States would be well-advised to consider this in evaluating novel cyber-capabilities; while new vectors of attack have been opened, the enormous uncertainty that surrounds their use recommends extreme reservation.

Nuclear action among states is correlated by dynamics that clearly support a fat-tailed distribution. Non-use from one party begets non-use from another, while any use may trigger cascading escalation. The interdependence of behavior suggests that extreme outcomes will be comparatively likely. Bearing this in mind, international security institutions should seek to limit correlations in the behavior of nuclear actors. Of

particular concern are highly interdependent security arrangements, in which many actors are mutually committed to each other's nuclear defense. Such arrangements may reduce the likelihood of nuclear incidents but dramatically increase their expected magnitude.

Our analysis of redistribution and pluralism suggests that maintaining a degree of parity in military capability is highly desirable. To the extent that military capacity disproportionately accrues to a single actor, the risk of concentrated mis-deployment increases. This concern is punctuated by the exponential nature of technology accumulation. Novel innovations that disrupt the security equilibrium, such as offensive cyber-capabilities, should be expected to occur with regularity. Therefore, international institutions that seek to share military technology and strategic innovations in order to maintain balance are recommended by the framework. Of course, this depends on verifiable mutual interest. Any such cooperation requires a mechanism of credible incentives.

Our analyses of system design that is process-based and incremental, as opposed to top-down, also suggest some high-level guidance on how to approach the construction of useful security institutions. Clearly, the ideal international security institution (i.e., a set of rules and associated regulatory bodies) cannot be pre-specified; managing the complexity of the underlying system of actors would require a regulator that is itself prohibitively complex. Moreover, any regulatory institution would be required to adapt over time, to shift with the evolving security ecology. So, it is clear that appropriate security institutions must be incrementally adapted over time. Ideally, the process for this adaptation should leverage the previously discussed mechanisms of selection and entropy. By selection, we mean a well-specified objective function against which to

evaluate candidate security resolutions. The degree to which any candidate resolution credibly confers material security benefits to all participants, which seems a reasonable standard. By entropy, we mean wide variation in the candidate rules and associated regulatory bodies to be considered.

We have specifically highlighted limiting inter-state nuclear correlation and technology-sharing agreements as strategic avenues recommended by the framework; there are no doubt many more. Maintaining a broad and multifaceted approach to achieving collective security goals maximizes the likelihood of successfully navigating the uncertain and changing landscape.

Evaluating Macroeconomic Policy

It is a reasonable, if somewhat extreme, simplification to say that macroeconomic policy discourse draws on ideas advanced by a relatively small number of economic theorists. Policy makers of the conservative right have historically been associated with names like Adam Smith, Milton Friedman, and the Austrian School. Alternatively, the progressive left has drawn from Karl Marx, John Maynard Keyes, and the more recent Modern Monetary Theory. Given the contradictory policy prescriptions of these various intellectual schools, some guidance on how to resolve their disputes is clearly valuable. By applying the complexity framework, we can perhaps make progress toward a more coherent view of economic policy analysis.

Conservative economic thought tends to emphasize personal freedom and agency, arguing that self-interested individuals have the best view into how to achieve their own ends. Because it is profitable to provide what is widely demanded, the free expression of individual wants will tend to be satisfied in an open market. This was most famously

articulated in Adam Smith's notion of an "invisible hand," and developed through various threads including the Austrian School (often associated with libertarianism) and the more technical theory of rational expectations. Associated policies include a broad skepticism of regulation, government action more generally, and a preference for lower taxation.

By contrast, progressive economic thought is associated with a large and active government. While Karl Marx imagined the spontaneous emergence of an economic system allocating "from each according to his ability, to each according his needs" (Marx, 1875), the most notable practitioners of Marxism (i.e., Soviet and Chinese Communists) have historically stressed the importance of the central government in directing the economic activity and rewards of system participants. Keynesianism is decidedly more friendly to markets but emphasizes the need for government expenditure to create demand in times of recession. Modern Monetary Theory (MMT) goes further in arguing that governments that print their own currency can do so freely in pursuit of policy objectives; the associated risk of inflation can be managed with demand-limiting increases in taxation.

There are some clear points of agreement between the conservative economic view and the complexity framework. Our analysis supports the conservative position that economic activity should largely be delegated to private interests. There is a shared belief that individuals have better information and incentives regarding their circumstances. Therefore, regulatory action, which centralizes economic decisions, should be viewed with skepticism.

But there are important disagreements between the complexity framework and the conservative view. We have previously discussed that there is a natural tendency toward resource concentration, and that this concentration, if left unaddressed, can have highly undesirable consequences (and this says nothing about common moral intuition regarding the possible unfairness of such inequality). Where the complexity view favors antitrust and redistributive taxation as antidotes, conservative economic theory tends to favor inaction.

There is yet more overlap between our framework and the progressive view. Our analysis clearly allows for several categories of market failure, which warrant policy action. First, in analyzing the dynamics of fat tails, we noted that correlation in the behavior of individual actors can lead to extreme aggregated behavior of the super-structures they compose. In particular, correlated economic contraction (i.e., one person restricts spending/lending/borrowing in the expectation that the next person will do the same) results in aggregately contractionary events far beyond what might be expected by conventional statistical measures. Such a situation evokes the Keynesian demand trap and seems to recommend similar responses.

Additionally, we have previously established that sufficiently mature complex systems (such as large corporations) tend to identify pathological behaviors that confer benefits to themselves at the expense of others. This closely maps to the economic notion of negative externalities, for which explicit regulation and fines are canonical means of remediation. Our framework suggests that these are both perfectly reasonable but could be augmented by less frequent but more punitive crackdowns on instances of malfeasance.

In our discussion of ergodicity, we have seen how the possibility of ruin incentivizes extreme risk aversion. The mere possibility of a severe regulatory crackdown may thus serve as a highly efficient inducement to compliance.

The framework does have criticisms of the progressive view. First, there is the clear rejection of anything like central planning. Our analysis would also suggest strong suspicion of MMT as a more subtle version of the same; arbitrary public expenditure effectively constitutes a replacement of private economic activity with public. Even Keynes is somewhat open to this same critique (although the decision to crowd out the idleness of recession with carefully chosen public works has a risk profile that would tend to justify it). Rather than viewing centralized interventions, such as regulations or public project expenditures, as the norm, they should be evaluated in the context of the Kelly criterion or precautionary principle.

Specific interventions ought to be pursued only in high confidence of reward and limited by the degree of uncertainty in outcomes. Instead, it is preferable to maintain demand and constrain inequality through redistributive taxation (i.e., redistribution that is relatively but not absolutely egalitarian). Importantly, this is not synonymous with "big government." The complexity framework would suggest a preference for *both redistribution and a higher private wealth share* relative to public.

In short, the framework can be regarded as supporting a synthesis of conservative and progressive economic views. It is conservative in its preference for individual agency and skepticism of central controls. It is progressive in its desire to actively constrain inequality and its allowance for selective intervention.

Appendix 1.

Pluralism Experiment Source Code

```
#!/usr/bin/env python
# coding: utf-8

# In[1]:

import random
import pandas as pd
import numpy as np

# In[2]:

def noise(num, degree=0.1):
 # return a weighted avg of given number and a random value
 return ((1 - degree) * num) + (degree * random.random())

def neighbor(a, b, delta=0.1):
 # determine whether two values are “close” to each other
 return abs(a - b) < delta


class Agent:

 def __init__(self, p=None):
 # initialize agent action parameter p
 self.p = p or random.random()


 def offspring(self, rule):

 if rule == ‘copy’:
 # a near copy of the parent parameter, with minor entropy
 p_ = noise(self.p, 0.01)

 if rule == ‘rebalance’:
 # a meaningful incorporation of entropy to the parent parameter
 p_ = noise(self.p, 0.15)

 if rule == ‘large_rebalance’:
```

```
    # mostly randomness, with some residual of the parent parameter
    p_ = noise(self.p, 0.75)

    return Agent(p_)


class Environment:

    def __init__(self, p, rule, n_population=100):
    # initialize environmental action parameter p
    self.p = p

    # intialize agent offspring rule
    self.rule = rule

    # initialize a population of agents with random action parameter
    self.population = [Agent() for i in range(n_population)]
    self.generations = []

    # catalog the initial population
    self.add_generation()


    def add_generation(self):
    # store the agent action parameter for each member of a generation
    self.generations.append([a.p for a in self.population])


    def run_generation(self):
    # the optimal action is in a random neighborhood of environmental parameter
    env_action = noise(self.p)

    # each agent which is near the environmental action survives
    survivors = [a for a in self.population if neighbor(env_action, a.p)]

    # each survivor replicates itself for the next generation
    next_gen = [a.offspring(self.rule) for a in survivors] + survivors

    # update and catalog the new population
    self.population = next_gen
    self.add_generation()


    def run_simulation(self, n_generations, env_noise=0):
    # simulate behavior for each of a given number of generations
    for i in range(n_generations):
```

```
self.run_generation()
# update environment action parameter
if env_noise > 0:
self.p = noise(self.p, env_noise)

def render_population_size(self):
# render population size over time
df = pd.DataFrame(
[len(g) for g in self.generations]).reset_index()
df.columns = [‘Generation’, ‘Population Size’]

df.plot(
x=‘Generation’,
y=‘Population Size’,
title=f’Population Size Over Time ({self.rule.capitalize()})’
)

def render_population_param(self):
# render action param of population over time
df = pd.DataFrame(
[np.mean(g) for g in self.generations]).reset_index()
df.columns = [‘Generation’,
‘Mean Action Parameter’,
]
df.plot(
x=‘Generation’,
y=‘Mean Action Parameter’,
title=f’Mean Action Parameter Over Time ({self.rule.capitalize()})’
)

# ### Stable Environment
# In[3]:

# given environmental parameter, run experiments for different decision rules
p = 0.6

# copy simulation
env = Environment(p, ‘copy’)
env.run_simulation(n_generations=15)

env.render_population_size()
env.render_population_param()

# rebalance simulation
env = Environment(p, ‘rebalance’)
env.run_simulation(n_generations=15)
```

```
env.render_population_size()
env.render_population_param()

# large rebalance simulation
env = Environment(p, ‘large_rebalance’)
env.run_simulation(n_generations=15)

env.render_population_size()
env.render_population_param()


# ### Shifting environment

# In[4]:
# repeat in the context of a shifting environment (second experiment)

# copy simulation
env = Environment(p, ‘copy’)
env.run_simulation(n_generations=20, env_noise=0.2)

env.render_population_size()

# rebalance simulation
env = Environment(p, ‘rebalance’)
env.run_simulation(n_generations=20, env_noise=0.2)
env.render_population_size()

# large rebalance simulation
env = Environment(p, ‘large_rebalance’)
env.run_simulation(n_generations=20, env_noise=0.2)

env.render_population_size()
```

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