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## Introduction

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How are we to understand economic institutions that are comprised of multiple, interacting individuals who operate on various spatial and temporal scales, all of which are impacted by a myriad of factors?

Since the late nineteenth century, economics has based its efforts on the general equilibrium theory of Léon Walras and others. This dominant paradigm, however, has two fundamental flaws: First, within the theoretical models that characterize it, it has never been possible to prove that an equilibrium (which rarely exists in real economic systems) would be attained. Second, it utilizes *Homo economicus*, a fictitious being who bears little resemblance to real humans, to define preferences, behavior, and abilities. Because these assumptions deviate so drastically from reality, there is doubt as to whether incremental changes can ever render it effective. Indeed, it has become increasingly clear that Adam Smith's Invisible Hand cannot be resurrected without an important change of perspective. As a result, alternative approaches have emerged. Evolutionary theory has brought novel insight to explain the behavior of individuals and institutions, while complexity theory has provided context to understanding economies as complex adaptive systems.

The aim of this Ernst Strüngmann Forum was to explore the integration of concepts from complexity theory and evolutionary theory so as to permit greater understanding of economics and public policy. The hope was that this discourse would spur a synthesis that would lead to the creation of a new economic framework—one capable of modeling economic systems as complexly adaptive and frequently out of equilibrium, based on the preferences, behavior, and abilities of real human beings and the diverse processes involved. This overview offers insight into the main themes of the discourse, which proved both stimulating and controversial.

### Challenges of Integrating Complexity and Evolution

The study of complex systems has centered largely on physical and ecological systems in which entities interact with each other, according to certain relatively

simple rules, to produce complex and unexpected behaviors at the system level. Simple rules at the agent level result in complex behaviors at the system level. Real economic systems, however, are composed of agents that follow *simple* rules. The difference with other disciplines is that these rules are far from being static, even in the short run; they constantly change because humans and their institutions are themselves the products of fast-paced cultural evolution and slower-paced genetic evolution (e.g., Arthur et al. 1997; Kirman 2010).

To understand complex systems that are composed of multiple, rapidly adapting agents, generalities must be limited. Each system, to a large extent, is unique and must be modeled as such. Path dependence is important, in contrast to the ahistorical assumptions of general equilibrium economics. Modeling efforts must, therefore, be tightly linked to empirical measurements of the system to avoid becoming detached from reality. These constraints demand a very different modeling approach than is currently afforded by the dominant economic paradigm.

Evolutionary theory brings a number of fundamental insights to the study of complex living systems, including (but not restricted to) human economic systems. First, rules followed by agents in biological and human social systems tend to be *fitness enhancing* to the extent that they are the product of natural or artificial selection. Since fitness-enhancing rules are a small subset of possible rules, knowing how agents in a complex system evolved to enhance their survival and reproduction would greatly advance efforts toward deriving rules for their interactions with other agents, and toward understanding the behavior of the system as a whole. Second, evolution occurs on multiple levels. Adaptation at one level tends to undermine adaptation at another level: what is good for me may be bad for my family; what is good for my family may be bad for my community; what is good for my nation may be bad for the global economy. This differs profoundly from the economic concept of the Invisible Hand, which in its simplest form assumes that lower-level self-interest robustly benefits the higher-level good. A legitimate, but more subtle, concept of the invisible hand follows from evolutionary and complexity theory, but it is a form of self-organization requiring selection at the level of the whole system.

Alan Kirman and Rajiv Sethi (Chapter 2) discuss a central organizing principle in contemporary economic theory—equilibrium—which holds that all individuals make plans that are optimal, given their beliefs and mutual consistency of these beliefs. Equilibrium methodology can be extremely powerful in narrowing the set of outcomes that can arise in an economic model and in generating precise results, but it sidesteps important issues such as disequilibrium or optimality of choice. Kirman and Sethi present an alternative in which adjustment is the central theme: individuals adapt to environmental changes through incremental improvements in their behavior. These changes, in turn, alter the environment faced by others, which leads to further dynamic adjustments. Trajectories may eventually converge

to an equilibrium, but this is not inevitable. Even when convergence does occur, it may be to one of several conceivable equilibria. Adjustment dynamics operate as an equilibrium selection device. Focusing on homophily in social interactions, Kirman and Sethi argue that complexity, evolution, and disequilibrium adjustment provides a promising alternative to the prevailing equilibrium methodology.

In Chapter 3, David S. Wilson reviews two meanings of a complex adaptive system: CAS1 denotes a complex system that is adaptive as a system (e.g., the brain, the immune system, and social insect colonies); CAS2 refers to a complex system of agents that follow adaptive strategies (e.g., multispecies ecosystems, the biosphere). He explores the relationships between CAS1 and CAS2 using multilevel selection theory. For a complex system to qualify as CAS1, the general rule is that selection must occur at the level of the complex system (e.g., individual-level selection for brains and the immune system, colony-level selection for social insect colonies). Below the level of the system, selection tends to undermine system-level functional organization. Wilson applies this general rule to human social systems as well as biological systems and concludes with a call for a science-to-narrative communication chain: Science is necessary but insufficient to solve the problems of modern existence. Thus ways must be found to communicate information to large numbers of people who may lack expert knowledge.

In a discussion of evolution and market complexity (Chapter 4), John E. Mayfield argues that complexities originate from the use of preexisting purposeful information. Structured in numerous ways (e.g., instructions, recipes, algorithms, rules of thumb, business plans), this information, if followed, can result in the formation of something unique. Mayfield argues that preexisting purposeful information is the output of an evolutionary computation, and thus an evolutionary process underlies most everything that characterizes human existence, including economics and markets. He discusses how an understanding of the fundamental role of evolutionary computation for enabling human and biological complexity offers useful insight into market behaviors.

Robert Axtell et al. (Chapter 5) examine the inherent challenges of integrating complexity and evolution theories into economics. They review different notions of equilibrium and how these evolved in biological systems and their complex counterparts. They look at major transitions normally attributed to exogenous shocks in modern macroeconomic models and discuss how such transitions are integral to evolving biological and complex systems. Emphasizing the importance of information in economics, they provide examples which show that the aggregate outcomes in a market or an economy can be equally well attributed to the structure of the system as well as to the behavior of the individuals within it. They find methods of evolutionary analysis and of complex systems to be extremely useful in capturing the open-ended, evolving nature of an economy composed of interactive agents, and stress that utilizing these

methods will permit more realistic models—with simple individuals whose interaction leads to the often complicated and unstable dynamics—of real-world markets and economies.

### Evolutionary Behavioral Economics

Behavioral economics is widely regarded as posing a strong challenge to the dominant rational actor paradigm in economics. Grounded in more realistic assumptions about human preferences and cognitive abilities, behavioral economics utilizes more empirical research and experiments to inform theory than neoclassical economics. Nonetheless, behavioral economics has been unable to escape completely the conceptual orbit of the dominant economic paradigm. Often, when actual human preferences and abilities depart from the abstract assumptions of *H. economicus*, they are typified as irrational, anomalous, or paradoxical. In addition, although behavioral economics attempts to describe the properties of individual economic agents, it seldom addresses how these agents interact in complex economic systems that are frequently out of equilibrium. Furthermore, the evolution of economic and social systems can be determined, at least in part, by the perceptions that agents have of how these systems work (e.g., Woodford 1990).

How should we account for the properties of individual agents that make up economic systems? This necessitates a consideration of our own evolutionary history as a primate species that evolved to be highly cooperative in small groups of largely unrelated individuals. Although the genetic nature of *H. sapiens* is largely shared, important individual differences exist both within and between populations. This includes the capacity for individual and cultural change, which qualifies as an evolutionary process in its own right. Human genetic and cultural traits have been coevolving for so long that it is hard to disentangle them. Cultural evolution directs the course of genetic evolution at least as much as the reverse. In addition, the timescales of genetic and cultural evolution overlap with each other: genetic evolution can take place within a few generations whereas cultural evolution can require centuries.

The concept of *mismatch* is crucial in the study of economic systems and difficult to understand from anything other than an evolutionary perspective. Species that are adapted to a given environment can behave maladaptively when placed in another. Only a period of subsequent evolution or an environmental intervention can cause the species to behave adaptively again. Consider the immune system, which has evolved over hundreds of millions of years in the presence of a diverse ecosystem comprised of microbes, worms, and other species inside our guts and on the surface of our skin. Such “fellow travelers” were not always beneficial, but they were always there with us. Now, for the first time in human evolutionary history, humans can rid themselves of such species. Conventional medical wisdom holds that germs are bad, so the fewer

the better. The idea that excessively hygienic environments might trigger immune system dysfunction was not proposed until the late twentieth century (Rook 2012). Successful interventions require a sophisticated knowledge of the immune system in relation to past and present environments.

Current social and physical environments are often so different from human ancestral environments that dozens of mismatches analogous to immune system dysfunction are possible. Evolved genetic influences on our preferences may not be aligned to current economic opportunities. Mismatches may adversely affect our economic decisions or otherwise cause economic systems to behave pathologically. Cultural evolution may solve some mismatches but it can also generate others. A sophisticated knowledge of human behavioral and cultural systems in relation to past and present environments is required.

Paul Glimcher (Chapter 6) reviews the proximate mechanisms involved in individual decision-making behavior. He tracks the development of economic theory beginning in the first half of the twentieth century, when neoclassical economists put forth mathematically beautiful theories of human decision making to describe how *optimal* human agents (subject to no internal computational resource constraints) made choices. In the second half of the century, empirical work exposed the limitations of this neoclassical approach: human decision makers were often observed to fail to achieve maximization of their utility, as formally defined, in domains ranging from health to happiness to wealth. Psychologists working during this period responded by largely abandoning holistic theory in favor of large-scale multiparameter models that retained many of the key features of the earlier models. He then describes ensuing work over the last two decades that combined neurobiology, psychology, economics, and evolutionary approaches. Data suggest explanations for some of the failures of neoclassical approaches and have opened up new theoretical avenues for exploration. While neurobiologists have largely validated the economic and psychological assumption that decision makers compute and represent a single-decision variable for every option considered during choice, their data also make it clear that the human brain faces severe computational resource constraints which force it to rely on very specific modular approaches to the processes of valuation and choice.

Herb Gintis (Chapter 7) discusses human morality based on gene–culture coevolution, the rational actor model, and behavioral game theory. He argues that human morality is the product of an evolutionary dynamic in which evolving culture makes new behaviors fitness enhancing, thus altering our genetic constitution. Human morality is also predicated on an evolved set of human genetic predispositions and consists of the capacity to conceptualize and value a moral realm governing behavior beyond consequentialist reasoning. Gintis provides evidence for a model of human behavior based on the rational actor model, in which individuals have both private and public persona, and their

preferences range over personal, social, and universal modes of private persona and in most activities in the public sphere.

Terence C. Burnham et al. (Chapter 8) analyze what types of modification are needed in economic theory of individual decision making and why. Their premise is that the economic model of individual behavior could be improved through insights from evolutionary theory and complex systems theory (e.g., to ground individual behavior in more psychologically and socially informed decision making, along lines already followed in experimental and behavioral economics), just as insights from psychology, the neurosciences, and behavioral economics may be better understood from an evolutionary and complexity perspective. To integrate disciplinary knowledge, key concepts at the heart of economic theory—preference and choice—are clarified. Burnham et al. present ideas on how behavioral science can be used to understand economic behavior, reviewing the current status of research and discussing potential trajectories. Their report takes an inspirational view, as they hold that the creation of evolutionary behavioral economics will take years to realize, as well as the concerted effort of many scholars.

### **Evolution of Institutions**

Thousands of generations of gene–culture coevolution have equipped humans with the ability to function as corporate units, at relatively small social and spatial scales, and shaped the genetic architecture of our minds. The invention of agriculture, for instance, enabled the formation of larger social groups, but the mechanisms that had previously supported small groups to function as corporate units were not necessarily applicable at this higher scale. New culturally derived mechanisms were required to interface with older genetic and cultural mechanisms. Human history provides a fossil record of how cultural evolution resulted in the mega-societies and economic systems in place today (Turchin 2010; Johnson et al. 2013; Mullins et al. 2013; Stoelhorst and Richerson 2013; Witt and Schwesinger 2013).

Human social institutions provide intermediate levels of functional organization in large-scale human socioeconomic systems. They provide norms to govern groups and social processes, which in turn form the basis of large-scale societies that are comprised of multiple institutions. Social institutions are the products of cultural evolution, and their histories cannot be ignored given the deep historical roots of economic development. Often the roles of geography, institutions, and technology are used to explain the variation in the ability of different human societies to nurture productive economies. Because institutions and technologies are cultural elements, we can profitably study them by formulating theories in evolutionary terms and using historical data to test theories, in much the same way that evolutionary biologists use the paleontological record.

Why have some complex societies, with their elaborate governance structures and extensive division of labor, collapsed while others have persisted? What is it about complexity that makes it adaptive?

Enrico Spolaore and Romain Wacziarg (Chapter 9) explore the fundamental drivers of economic development and political institutions, providing a novel empirical analysis of the determinants of institutional differences and the diffusion of institutional innovations across societies. They present a critical discussion of recent literature to document how economic and political outcomes are affected by traits that have deep historical and geographic roots which are passed on generationally. Spolaore and Wacziarg put forth the hypothesis that intergenerationally transmitted traits affect current outcomes by acting as barriers to the diffusion of technological and institutional innovations: a longer historical separation time between populations creates greater barriers. Hence, the degree of ancestral distance between a given society and the society at the frontier of institutional and technological development should be associated with higher barriers and lower adoption. They provide empirical support for the proposition that long-term historical distance from the frontier affects both current institutions and development.

Jenna Bednar (Chapter 10) discusses different theories of institutional dynamics. She reviews how institutions are defined, explains the need for adaptation, and discusses the difference between robustness and resilience. She presents current theories of institutional change and applies them to describe the system features that lead to robustness, with particular attention to diversity, modularity, and redundancy. Using work on federal system robustness, Bednar illustrates the theory of robust design and highlights open questions regarding adaptive efficiency of institutions and robust system design.

What can a synthesis of complexity theory and evolutionary theory contribute to our understanding of the evolution of organizations and institutions? To approach this overarching question, John F. Padgett (Chapter 11) explains how the emergence of organizations and markets can operationalize the blending of evolutionary theory (autocatalysis) with complexity theory (dynamic multiple networks in regulatory feedback). These two theoretical building blocks, taken together, can explain the sudden emergence or invention of novel forms of organizations, previously unobserved in history. Padgett illustrates this using an empirical case study of the emergence of international finance in medieval Tuscany.

Thomas Currie et al. (Chapter 12) discuss the need to understand better how and why institutions emerge and change. They present a conceptual framework, informed by evolutionary theory and complexity science, which views institutions as part of a nongenetic system of inheritance. Using this framework, they examine how broader historical factors, not just economic factors, influence present-day institutional arrangements and economic outcomes, and analyze how noninstitutional aspects of culture (e.g., values, beliefs) interact with institutions to shape behavior in particular contexts. They emphasize the

need to develop explicit models of the processes of institutional evolution and argue that this framework holds promise to bring together and synthesize findings and insights from a range of different disciplines.

### Shaping the Evolution of Complex Societies

Complex systems are inherently difficult to predict. Take the weather as an example: forecasts of this complex physical system can only be attempted based on enormous amounts of real-time data and an array of computer simulation models. The challenges inherent in predicting policy outcomes in complex human socioeconomic systems are similar. Theory can only outline plausible alternatives; these, in turn, must be tested using real-world system parameters. For the management of ecological systems, such an approach, known as adaptive management, has already been developed (e.g., Allan and Stankey 2009; Swenson 2010). For economic policy, a complexity approach has been outlined by Colander and Kupers (2014).

In Chapter 13, Sander E. van der Leeuw argues that adaptation and maladaptation are best viewed as different phases of the relationship between a society and its (social and natural) environment. He analyzes this relationship on millennial and centennial scales, and attributes transitions (“tipping points”) to the unintended consequences of human actions. Such transitions occur when a society’s “value space” (i.e., the total set of values that keep a society functionally together) is unable to expand rapidly enough to keep pace with the growth of the society’s population. This appears to be linked to a second-order dynamic that is exhibited when a society’s focus turns inward (due to being overwhelmed by the consequences of their own earlier actions) and becomes short-term (tactical instead of strategic). This dynamic, van der Leeuw argues, is active in today’s Western-dominated global system. He suggests that the global economic system might be able to be reenergized if the flow of global information is reversed; that is, if information is spread rather than concentrated in the West. This reversal, which he terms *green growth*, must be achieved in concert with a respect for the environment. It also requires rephrasing the current economic and political debates from “burden sharing” to “opportunity creation,” both for the developing and for the developed world.

Mariana Mazzucato (Chapter 14) postulates that successful innovation policies are those which actively seek to create and shape markets, not just fix them. In the past, this has often been accomplished through “mission-oriented” policies. Mazzucato argues that innovation policy must concentrate on building symbiotic innovation “ecosystems” that are capable of directing, evaluating, structuring the necessary organizational changes, and creating tools to socialize risk and enable rewards. Key issues to be addressed include:

1. How can public policy be understood in terms of setting the direction and route of change? What can be learned from the ways in which directions were set in the past, and how can we stimulate more democratic debate about such directionality?
2. How can an alternative conceptualization of the role of the public sector in the economy translate to new indicators and assessment tools for evaluating public policies, beyond the microeconomic cost-benefit analysis? How does this alter the crowding-out narrative?
3. How should public organizations be structured to accommodate risk taking and exploration? What capabilities are needed to manage contemporary challenges?
4. How can a conceptualization of risks and rewards be put into practice to frame investment tools, where the goal is to socialize risk and rewards, and to enable “smart growth” to be “inclusive growth”?

Much of what standard economists understand about complexity economics are summaries of abstract analysis, which are generally viewed as having little direct impact on the cut-and-dried policy analysis that most economists do. In Chapter 15, David Colander argues that the complexity vision—which pictures an economy as a complex evolving system undergoing continual evolutionary change—has significant implications for workaday economic policy. He reasons that good applied policy is not applied science but rather more akin to engineering. Complexity policy opens up economics to a wide range of policies that go beyond the standard allocation policies, and can be supplemented by policies designed to influence the ecostructure within which individuals operate: formation policy is added to allocation policy. The market and government are not viewed as opposing forces but rather as coevolving institutions. Formation policy is designed to influence that coevolution. One example of how complexity policy differs from standard policy can be seen in distribution policy: the standard approach tends to focus on redistributive taxes (e.g., progressive income and wealth taxes) whereas the complexity policy approach focuses more on modifying the length and nature of evolving property rights as embedded in patent and copyright law.

In Chapter 17, Joshua M. Epstein and Julia Chelen advance an agent-based computational model known as *Agent\_Zero*. *Agent\_Zero* is an explicit computational actor that can generate important, but insufficiently understood, social dynamics from the bottom up. This novel theoretical entity possesses emotional, deliberative, and social modules that are grounded in contemporary neuroscience. In contrast to the canonical rational actor, *Agent\_Zero*'s behavior results from the interaction of these internal modules. When multiple *Agent\_Zeros* interact, a wide range of important, indeed disturbing, collective dynamics emerge. Epstein and Chelen review a range of fertile research directions: the use of realistic geographies and population levels, the exploration of new internal modules and interactions among them, the prospects for

empirical testing, the replication of historical episodes, and various practical applications.

Scott E. Page sets forth a fundamental issue for consideration in Chapter 17. In his view, modern economics is catholic in orientation: no reasonable assumption has gone unmodeled. In addition, assumptions from evolutionary theory and complexity theory can be incorporated without having to abandon core models or standard techniques. In fact, ideas from evolution and complexity have already become add-ons. The current field of economics contains many useful models and ideas. Thus, Page sees little justification for claims to toss out the old paradigm and replace it with one based on ideas from evolution and complexity. He advocates the construction and advancement of a set of new economic models based on complexity to complement and challenge the existing approach. Complexity models should not be seen as competitors to the standard models; they also need not be predicated on being better or even having the potential to be better. They only need to be sufficiently different in order to add value.

In Chapter 18, John Gowdy et al. call for an approach to economic policy that takes evolutionary and complex systems theory into account. This is necessary to alter the way that economic policy is framed and how policy co-dependes on understanding markets as outcomes of nonmarket interactions, incomplete information, path dependency, and coordination failures. In policy considerations, modern economists strongly focus on allocation mechanisms, with far fewer formation mechanisms than called for by evolutionary theory and complex nonequilibrium dynamics. Gowdy et al. argue for an increased focus on formation mechanisms. They explore how evolutionary and complexity thinking can be applied to policy criteria, goals, instruments, and policy assessment in the following examples: transition to a low carbon economy, the use of multilevel selection to inform group design in human organizations, policy making as shaping and creating markets, government failures in Greek farm policy, and the protection of the Sudd Wetland in South Sudan. These examples point to key issues that an evolutionary and complexity approach must consider when informing public policy.

## **Concluding Remarks**

The aim of any Ernst Strüngmann Forum is to subject a central theme to critical review from multiple perspectives: to unpack it so that what is known, or thought to be known, about its component parts can be scrutinized and critically evaluated. This process lays bare areas where understanding is lacking and uncovers issues for future inquiry.

It is important to emphasize that consensus is never a goal at a Forum. In fact, areas or issues where consensus is lacking often function to spark future

investigation better than anything else. Equally, it must be recognized that different disciplines and individual researchers have varying ways of approaching problems or understanding concepts, as well as interests and motivations. This diversity needs to be embraced, for it has the potential to lead to a greater, eclectic understanding.

This Forum did not produce a succinct new economic framework, as some might have hoped. It did, however, reveal insights and laid the groundwork for further cooperation and research. Whether this ultimately leads to a new synthesis or a paradigm shift can only be assessed later. In this spirit, we turn over this discourse to you in the hope that the various perspectives presented will spur you to consider how complexity theory and evolutionary theory can add value to the study of economics and public policy.