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What should policymakers know about economic complexity?

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New Thinking on Business Strategy

As the world forges ahead in its historical transformation from an industry-based to a knowledge-focused era, the context for business strategy and management is changing rapidly and fundamentally. The basic business principles of the industrial era no longer hold. An entirely new kind of management and strategy is emerging, and this section offers the comments of four of its most eloquent proponents.

These essays will obviously interest those involved or interested in business. But we believe that scholars and practitioners from other disciplines must also pay attention to the recent business literature. The best books in this field offer new models for social and economic organization based on the principles of the knowledge era, drawn from such novel sources as chaos and complexity theory. Political scientists, sociologists, military officers, and government officials should find these essays to be a rich source of fresh ideas and perspectives.
The various phenomena constituted by the interaction of many objects—such as the development of life from certain combinations of molecules or the emergence of residential segregation from the individual location decisions of families—lead one repeatedly to ask: How do complex interrelationships between many objects produce order in the aggregate, and what types of order do they produce? The new sciences of complexity suggest that we can understand and formally analyze these higher order properties through a common set of mathematical structures. For this reason, complexity has generated a great deal of excitement among natural as well as social scientists.

In this essay, I hope to achieve two things: to outline the main ideas underlying the growing study of “complexity” in the economic realm, and to suggest areas of public policy where those ideas might be important. Both goals are necessarily speculative; the study of complex systems, whether natural or social, remains in its infancy, and its long-term importance remains unclear.¹

I begin with a few definitions. In its formal, scientific use, the term “complexity” denotes something quite different from merely “complicated.” A system is said to be complex when it exhibits some type of order as a result of the interactions of many heterogeneous objects or agents. Molecules interacting and joining to produce life forms, or people interacting to produce an “economy,” are examples of complex systems. And when the properties that emerge from these interactions are of a fundamentally different character or level than the agents themselves, these properties are often called “emergent.” Thus magnetism, the result of the interaction of a large number

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of iron atoms, is an emergent property.

Economists have begun to use the theory of complex systems to help understand environments characterized by many heterogeneous actors. To take one example, a stock market consists of many traders with idiosyncratic beliefs about the future. The actors exchange information and operate with some degree of common information, but stock prices ultimately emerge from a large number of decentralized decisions to buy and sell. Similarly, the composition of residential communities owes its structure to thousands of interacting individual preferences and resultant decisions of individual families.

Notice that in each case, there is a feedback between the environment as a whole and the individual actors. Movements in stock prices influence the beliefs of individual traders and in turn influence their subsequent decisions. Families make community choices on the basis of expectations concerning community characteristics; these characteristics in turn evolve in response to the choices families make over time. This feedback process is not unique to complex environments—elementary economics teaches us about the feedback between individual demand and supply decisions and market level prices—but its effects, because of the emergence of various types of order, are quite different, and understanding its role is far more critical, in complex situations.

Complexity deepens our understanding of economic phenomena by illustrating how various types of microeconomic structures lead to particular aggregate economic phenomena. For example, booms and crashes may be common features of stock markets precisely because evolving rule-of-thumb behaviors interact to determine individual purchasing decisions. Thomas Schelling, in what is arguably the first paper on economic complexity, explained how racially segregated neighborhoods could emerge in an unplanned fashion from a collection of individuals that reflect relatively weak preferences concerning neighborhood racial composition.

These examples hint at an important fact: The value of complex system thinking in the social sciences, for either researchers or policymakers, lies in its potential for enriching our understanding of the relationships between aggregate outcomes and individual decisions. Complexity’s major contribution is the idea that these relationships can be highly nonlinear—what at first glance seem fairly simple individual choices can produce surprising outcomes.
Complexity and Economics: The Main Ideas

Economists using models drawn from complex systems theory have discovered a number of useful ideas and observations that challenge some of the traditional assumptions of the field. One involves the role of interaction and positive feedback. Many efforts to make economic theory more realistic by introducing elements of psychology and sociology amount to different ways of taking seriously the phenomenon of positive feedback.\(^4\)

Complexity theory facilitates the modeling of individual actors as decision-makers whose choices depend directly on the decisions of others—not, as in neoclassical economics, as people who interact only via the market, through prices. This focus on direct interactions allows complex systems models to accommodate a far richer class of phenomena than their neoclassical counterparts. One example is conformity effects, in which an individual's perceived benefit from a choice increases with the percentage of his or her friends who make the same choice—an effect that may be critical in determining purchases in such areas as clothing and technology. Notice, here, the general rule of positive feedback, in which one agent's choice makes it more likely that others will make similar choices. Another example is the "role model effect," in which a choice by the members of one generation influence the choices made by the next generation in such areas as education and careers.

Positive feedbacks can have dramatic results on aggregate social behavior, a connection that turns up in issue after issue. Positive feedback effects can explain how two communities with identical distributions of individuals can exhibit very different levels of drug usage, school enrollment or crime rates; these differences can be explained by such feedback processes as peer group pressures, which induce conformity effects. In the business realm, interdependent decision-making occurs for reasons such as the need to coordinate on common standards for communication or software, leading to unusual outcomes such as the sudden emergence of an industry standard despite the absence of any centralized mechanism to coordinate decisions. One example of this is the emergence of Adobe Postscript as the standard language for high-end laser printer applications.

A related feature of many complex economic environments is the presence of increasing returns to scale, turning the usual neoclassical economic assumption of declining returns on its head. Increasing returns can, for example, result from positive feedback relationships; two scientists working together can, through the interplay of different perspectives, advance more rapidly than if each works in isolation. Similarly, when many
firms are engaged in competitive research and development, successes by one firm will facilitate subsequent successes by others.

**Implications**

Complex economic environments characterized by positive feedback effects and increasing returns exhibit fascinating behavior. To begin with, complex economic systems must usually be understood as evolving processes rather than as systems residing at “equilibrium” or a “steady state.” To be clear, these terms do not imply that an economic system is somehow at rest or unchanging. But they do suggest that the dynamics that determine behavior—peoples’ basic preferences—remain steady over time. Complex systems theory points us in a different direction, toward social, economic, or political systems conceived as dynamic processes involving the interrelationships of many actors who possess limited information about the intentions and objectives of others, and whose beliefs, preferences, and opportunities therefore evolve in response to the feedback they get from that environment.

A second important feature of complex economic systems is that they are inherently nonlinear in the way in which features of the system move together. Empirical work in economics is typically highly linear, assuming that inputs and outputs—say, per-pupil school spending and test scores—are roughly proportional. Yet an important lesson from complex economic models is that, when positive feedback effects are present, nonlinearities are endemic. For example, a number of researchers have speculated that family investment in education exhibits conformity effects. Applied to the issue of whether to pay for a child’s college tuition, this could mean that the decision to send a child to college may well be determined not in linear fashion by increasing tuition costs, but by a highly nonlinear conformity effect: As the numbers of friends and neighbors who forgo sending their children to college increases, the decision for other families may become almost automatic in a much more decisive fashion than one would predict based on the roughly linear growth of tuition. As unpredictable as these nonlinear “tipping points” may seem, the existence of nonlinear effects does not make economic analysis impossible; it only requires that empirical analysis be conducted in the context of a theoretical framework that allows for interaction and feedback effects.

A third hallmark of complex systems is that “history matters” in their long run evolution—an idea encapsulated in the term “path dependence.” Path dependence refers to the permanence of seemingly random innovations; particular innovations—one example being the production of left-
hand drive cars in the United States and right-hand drive in the United Kingdom—can have permanent consequences, or a given product can dominate a market in the absence of some countervailing innovation. Path dependence is a dynamic version of positive feedback: Innovations, such as Microsoft software, become locked in through phenomena like our old friend the conformity effect ("all my friends have Microsoft Word, so I should too").

One important feature of path-dependent economies is that some shocks to the system will not correct themselves and will remain in place until pushed aside by some future shock. The output declines in the Great Depression in the United States of 1929–32 do not seem to have been self-correcting—they were, perhaps, a path-dependent situation—and were only reversed by a combination of the New Deal and World War II. The promising economic conditions in the United States today may be another form of path dependence that may suspend the business cycle until a sufficiently large shock moves the economy to an alternative configuration.

**Examples: High Technology**

Increasing returns are especially common in high technology industries, for a variety of reasons. High-tech firms conduct research and development on an intense and continuous basis, for example, and R&D is subject to strong increasing returns—companies that capture market share can afford more of it, and employ larger workforces that generate larger amounts of innovation. Increasing returns can also emerge through a phenomenon known as "lock-in of demand," which is particularly noticeable in computer-related industries. Consider, for example, the demand for betamax versus VHS videotapes: Once consumers have purchased a video cassette recorder that uses one format or the other, those consumers are locked into using that type of videotape—unless they are willing to buy a second machine. And the important implication of this fact is that the desirability of a particular videotape standard will depend on the level of use of the same standard by others—if one's friends use the same standard, or if all video stores rent tapes in one format alone, then that format will have an advantage. If such effects are strong enough, then unplanned forces—the interaction of many agents, the heart of complex systems analysis—will lead the economy to choose a single standard.
Computer operating systems are an example of how lock-in is especially likely in high technology contexts. The desirability of a particular operating system by a given consumer depends, to a very large extent, on the availability of products which are compatible with that system. The demand for computer operating systems by consumers exhibits strong interdependencies, factors that differ widely from the textbook model of consumer demand.

Therefore, such interdependence in demand can, through the lock-in effects associated with the need to commit to one standard or technology, create the potential for a single firm to dominate an industry simply because of the ubiquity of use of its products. In a world of VHS and Microsoft, this may sound unsurprising; but it challenges a cherished notion of economics—the idea that, with free exchange, superior products will drive inferior ones from the market. In the presence of lock-in, new market entrants—young companies struggling to gain market share—have immense difficulty generating a level of demand to make a profit. Because of increasing returns and lock-in, then, market choices—and the equilibria they create, such as the steady dominance of one product over another—can be highly inefficient, either because of the unhealthy market dominance acquired by some firms or the mutually reinforcing adoption of inferior technologies.

The existence of such inefficiencies hints at the policy relevance of the increasing returns phenomenon. Increasing returns make it especially likely that high technology sectors will exhibit noncompetitive market conditions, because average cost per unit of production decreases with the level of production. Firms that can produce at high levels—generally the biggest firms—will have a big edge. And in the presence of the substantial fixed costs to production that exist in the high-tech field, market entry requires a minimum scale of production. Taken together, increasing returns create conditions under which a single firm or small number of firms can dominate a market.

**Examples: Inequality**

Economists also use interactions-based models to understand the emergence of persistent inequality and poverty. Their insight begins with the recognition that one's memberships in various groups strongly influences individual preferences, beliefs, and opportunities. Such groups may be fixed, such as race, or may be determined by the economy or society, such as neighborhoods, schools, or firms. When [positive] interaction effects occur between members of a given group, group level influences generate common outcomes among group members. For example, social pathologies of the inner city—out of wedlock births, drug use, and crime, among others—appear to
Economic Complexity systems are inherently nonlinear. 

be explained not just by lack of economic opportunities, but by the direct interdependence of these decisions through peer group, role model, and social norm influences. Similar explanations may be used to help explain how some historically disadvantaged groups have experienced unusual success—an obvious example here being Jewish immigrants from Eastern Europe. The characteristics of other members of the groups to which an individual belongs, therefore, mediate the relationship between an individual’s characteristics and his or her economic outcomes. Whereas the way in which groups form and the way in which intragroup interactions occur will vary greatly in different cases, the implications for inequality can be quite powerful.

Economists have so far applied these abstract ideas mainly in studying the evolution of community formation and education. The belief that the interaction of three factors determines an adult’s occupation, and hence his or her economic status, drives this strand of the literature of inequality. These three factors are the level of human capital investment received as a child through formal education; a range of role model and peer group effects that influence aspirations, efforts, and opportunities; and luck. As wealthier families segregate themselves from poorer families through some combination of zoning restrictions and housing price differentials, rich and poor families become isolated. Their children are exposed to very different schools and labor market opportunities, and initial differences in income between adults can become magnified between their children. Ghettoes or other types of poverty traps may emerge and perpetuate themselves as a consequence of this stratification, and family income across generations can exhibit path dependence when the economic status of parents has a sufficiently strong influence on offspring.

The application of complexity to the question of how different ethnic or cultural groups fare in our society has two implications. First, positive interaction effects can produce socially undesirable as well as socially desirable outcomes. Hence there is nothing intrinsically good or bad about tightly knit communities. Second, the common claims that either the culture of poverty or the lack of economic opportunities can in isolation explain group-level inequality are wholly unsatisfactory. Lack of economic opportunities produces conditions under which small differences in group-level conditions can, through interaction effects, produce very disparate outcomes. Hence the conventional explanations by the left and right of social pathologies turn out to be complementary.
With respect to policies designed to promote equality, the lesson of complexity-based approaches in this case is that policies designed to promote equality should focus on the importance of group memberships in determining economic success. In this context, policies such as affirmative action may have value because of the presence of strong positive spillover effects from distributing key jobs more widely across socioeconomic and racial boundaries. Additional policies that might achieve what I have termed "associational redistribution" include school busing to achieve integration, charter and magnet school programs, and the location of public housing projects.

Conclusions

Complex economic systems have several messages that policymakers may find useful. First, interdependence among various actors can, without anyone planning or intending it, generate many varieties of aggregate or emergent behavior. As a result, economic environments can become stuck in undesirable steady states, such as the existence of high levels of social pathologies like inequality or the predominance of inferior technology. Second, the consequences of policies will depend critically on the nature of the interdependencies; the effects of different policies may be highly nonlinear, rendering history a poor guide to evaluating policy effectiveness. Even though many complex economic environments seem to be particularly likely situations in which there exist social welfare-enhancing policies, it may prove especially difficult to identify such policies. Detailed empirical studies that underlie conventional policy analysis should prove to be even more valuable in complex environments.

The importance of detailed empirical work relates as well to the long-term importance of complexity in the social sciences. Complexity theory has helped to enrich economic theory along many dimensions and in a number of cases has challenged conventional wisdom. Yet, it would be a great exaggeration to say that complexity has revolutionized economics. Such a revolution, if it ever comes, will require that empirical economic research show how complex systems thinking extends our ability to explain and predict actual economic phenomena. Efforts to link theory and empirical analysis will ultimately determine the importance of economic complexity, as is appropriate for any methodological advance in social science.

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Notes


2. See the essay by W. Brian Arthur, John Holland, Blake LeBaron, and Richard Palmer in Arthur, Steven Durlauf, and David Lane, eds., The Economy as an Evolving Complex System II (Menlo Park: Addison-Wesley, 1997).


4. In addition to the introduction of psychological and sociological elements to economic theory, endogenous growth theory, which has dominated macroeconomic research for the last decade, is based on understanding how these positive types of productivity feedbacks can generate sustained growth. The seminal article is Paul Romer, “Increasing Returns and Long Run Growth,” Journal of Political Economy 94 (1986), pp. 1002–1037.


6. On a more technical note, it is worth mentioning that technology development, like the production of knowledge in general, involves many uncompensated positive feedbacks. A technological breakthrough in one area may stimulate breakthroughs in others, without any compensation accruing to the first innovator. This is a textbook case of production externalities; complexity theory suggests that connections between different technologies may make these externalities very large.

