EVOLUTIONARY DYNAMICS THEORY AND EMPIRICAL METHOD

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This chapter argues that evolutionary dynamics has much to offer law and economics. By providing a frame-by-frame view of change, an evolutionary dynamics framework sheds light on the way in which law and the behavior it regulates change over time, and on the way that legal regulation might manage such dynamic change.

Mainstream theoretical work in law and economics has paid relatively little attention to the dynamics of legal activity or of the behavior that law regulates. As is true for economics generally, most law and economics analysis focuses on the equilibrium rest points to which processes theoretically converge. With some exception, scholars have largely ignored the dynamic pathways that these processes follow on their way to equilibrium.

But in real life, law and the behavior it regulates are frequently if not almost always in the process of converging rather than actually being at rest. In addition, regulatory and economic processes often do not converge to equilibrium. Indeed, legal regulation and regulated behavior spend much time out of equilibrium. For example, regulators and those they regulate are engaged in an ever-evolving game of cat-and-mouse as each side innovates in an attempt to out-compete the other. Like the economy, law is an open system.

In general, dynamic processes are central to any understanding of law and its relationship to behavior. Consider, for example, the cat-and-mouse game of regulatory avoidance. To avoid regulation, payday lenders have adopted a series of innovations, first affiliating with out-of-state banks, national banks and more recently with Indian tribes, all for the purpose of claiming immunity from state supervision. Similarly, tax shelter promoters have generated a sequence of shelters, each more convoluted than the last, to assist taxpayers in avoiding taxes. As legal actors innovate, regulators in turn have enacted a succession of new laws and regulations, each an attempt to address the latest innovation. But each regulatory innovation is rendered obsolete by the next regulated actor innovation.

These dynamics should be of great interest to legal scholars. Arms races like those described above incur increasing deadweight costs, given that improvements obtain no lasting competitive advantage. More centrally, understanding the regulatory arms race is necessary to understanding market and regulatory design. Payday lenders structure their business model primarily to avoid regulation. Firms engage in tax inversion to avoid taxes. In short, regulatory workarounds become a central component of some industry business models, and in those cases, responsive innovation must be a key feature of regulatory design. Drawing on examples like those described above, this chapter explores the usefulness of evolutionary dynamics as a method to investigate key theoretical and empirical questions about law and its relationship to the behavior it regulates.

There is reason to be optimistic that such methods will prove helpful. Evolutionary dynamics models in biology have long offered policymakers great insight into how best to manage a constantly evolving "regulated actor." For example, dynamic models convinced public health officials to adopt a low-dose, slower-paced chemotherapy regimen to treat certain kinds of tumor. Though doctors' instinct was to treat immediately at high doses, dynamic modeling showed that early high intensity chemotherapy actually decreased survival time for cancer patients with certain kinds of tumor. In fact, high intensity early treatment promoted the evolution of resistant cells.[1] Importantly, in this work, theoretical predictions were tested with empirical data.

Likewise, evolutionary dynamics models can help legal scholars to understand key dynamic relationships between law and the behavior it regulates. On the theoretical side, evolutionary dynamics approaches can shed theoretical light on the downstream and often non-linear and non-equilibrium effects of regulatory change. Dynamic models can help to describe dynamic phenomena that equilibrium theory sheds less light on—the evolution of legal rules, bubbles and crashes in a stock market, systemic risk posed by tightly networked banks, resistance to regulation. On the empirical side, just as the tumor scientists did, scholars can use dynamics models to generate testable predictions that can then be tested empirically by fitting historical data to models.

Finally, on the policy side, evolutionary dynamics frameworks can help policymakers to develop better ways of regulating. For example, such models can offer help to payday lending regulators as they decide when and with what intensity to respond to an ever-evolving lender population. Scholars can better explain the evolutionary pathway of the economic loss rule. Telecommunications regulators can draft pricing schemes that prevent pro-competitive regulation from inadvertently disrupting telecommunications networks. Banking experts can tailor regulation to manage systemic risk and stem anticipated cascades of failure in a banking crisis. These and other examples are discussed in detail below.

Dynamics-focused approaches are not really new for law and economics. Most readers of this volume will be familiar with the famous Schelling model, which mapped the evolutionary dynamics of residential segregation. Schelling's model showed that, owing to the way in which neighbor relocations trigger further cascades of relocations as people adjust to new neighbors, very segregated neighborhoods can emerge even when individuals have only a modest preference for same-race neighborhoods.[2]

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[1] Helen Monro and Eamonn Gaffney, Modeling Chemotherapy Resistance in Palliation and Failed Cure, 257(2) J. Theor. Bio 292 (2009).

[2] Thomas Schelling, Dynamic Models of Segregation, J. Math. Sociology 143 (1971); Models of Segregation, 59 Amer. Econ. Rev. 488 (1969). The Schelling model is definitely a dynamic model, but debate exists as to whether it is evolutionary. Because people often learn from others their (often bad)

Moreover, Schelling's model showed that racial integration is a stable equilibrium, but a rest point that is not reachable from most initial configurations of the neighborhood. In contrast, segregated equilibria are rest points that can be reached from a large number of initial neighborhood configurations.[3] Relocation dynamics thus operate to explain why neighborhoods are far more likely to be segregated than integrated.

This chapter suggests that, in the spirit of Schelling, evolutionary dynamics method can shed much more light on equilibrium selection, and on central questions about the relationship between law and behavior. This chapter focuses less on conventional evolutionary game theory and more on cutting-edge techniques recently deployed in the biological and social sciences. The following discussion outlines important theoretical and empirical concepts, and illustrates them using examples that are connected to law, and in the final section, are squarely within the field.

The first part of this chapter provides a high-altitude primer on modern evolutionary dynamics, with a few illustrative examples from a range of disciplines. The chapter then reviews with more specificity a number of methodological tools—both theoretical and empirical. This discussion focuses on methods that might prove useful for the theoretical and empirical analysis of law. Law and economics scholars' hesitance to address dynamic processes might be traced to the sense that investigating such processes is technically too demanding. Accordingly, this review keeps mathematical notation at a minimum, to provide relatively simple descriptions and key examples of those methods.

Finally, the chapter explores three specific areas of inquiry in legal scholarship for which evolutionary dynamics can provide useful answers. First, how does a change in the legal rules affect the unfolding patterns of behavior that law regulates? What downstream effects on those patterns will changes in the law produce? What factors determine the particular equilibrium rest point that law and behavior might evolve towards? Second, how does law itself construct the networks that shape the frequency of people's interactions? What role does legally compelled interaction or prohibited interaction play in shaping outcomes? Third and finally, how does law evolve, endogenously and in tandem, with the behavior it regulates? This chapter proposes a number of concrete payoffs that come from answering these and similar questions.

I. An Evolutionary Dynamics Primer

Although modern evolutionary dynamics is relatively new to legal scholars, it has gained significant traction in other fields. Modern frameworks in biology trace their

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relocation heuristics and strategies—e.g., how to use race of student bodies to tell whether a public school is "good"—one could describe neighborhood location and relocation as an evolutionary process.

[3] See Alan Kirman and Rajiv Sethi, Disequilibrium Adjustment and Economic Outcomes, in Complexity and Evolution: Towards A New Synthesis For Economics (forthcoming) (exploring why a focus on the process of change sheds more light on non-equilibrium economic processes).

rigorous analysis to mathematical principles derived from Darwinian evolution and Mendelian genetics and then more recently to the central investigations of Fisher, Haldane and Wright. [4] In economics, scholars who focus on evolutionary dynamics draw from a line of argument that goes back hundreds of years, to Smith, Schumpeter, Alchian and Hayek, and then more recently, to economists as diverse as Schelling and Ostrom.[5] In social science, evolutionary dynamics traces its genealogy to theorists like Weber and Parsons, and then to the more modern scholarship of Simon (Herbert), and Granovetter.[6] Modern evolutionary dynamics has made its mark in anthropology, sociology, linguistics, epidemiology, computational science, artificial intelligence, and more.

Uniting all these frameworks is a common conceptual foundation that draws from Darwinian evolutionary dynamics to focus on the process of adaptation over time.[7] Importantly, what evolves in adaptation is not an individual or an individual strategy but rather a population of individuals or of strategies. In evolutionary adaptation, populations change over time as they adapt to their environment.

Adaptation requires three elements – variation, reproduction and selection. First, populations must vary. A heterogeneous population of payday lenders has varying strategies to avoid regulation. A homogeneous population of ants has colony-building strategies that are sometimes modified by mutants. A population of tax regulators has standard and experimental regulatory strategies. Genetic crossover and recombination, mutations, mistakes, innovations and creativity all generate differences in traits or strategies within a population.

Importantly, these sources of variation—mutation, crossover and the like—find their counterparts in social science descriptions of human behavior and decision-making. People proceed myopically, groping their way about to find alternatives. We don't experiment as randomly as biological species of course, but we are certainly blind to what happens globally and down the road. People generate new alternatives in a myriad

[4] Seminal modern work in biology develops a stochastic theory of population genetics that had its roots in Darwinian evolutionary dynamics. See R.A. Fisher, Population Genetics, 141 Proc. Royal Society London 510 (1953) (summarizing his work in the early 1930s); Ronald W. Clark, The Life and Work of J.B.S. Haldane (summarizing work on genetic linkage and its connection to evolutionary synthesis); and Sewall Wright, Evolution and the Genetics of Populations (1984) (summarizing work on genetic drift and fitness landscapes).

[5] Elinor Ostrom, Governing the Commons: The Evolution of Institutions for Collective Action (1990) (though Ostrom received the Nobel Prize for economics, some might argue that she is less an economist and more a political theorist); Thomas C. Schelling, Micromotives and Macrobehavior (1978).

[6] Herbert Simon, Models of Bounded Rationality, Vols 1 and 2 (1982); Mark Granovetter, The Impact of Social Structure on Economic Outcomes (2005) (reviewing his earlier work on social networks and the strength of weak ties in shaping outcomes).

[7] For a comprehensive view of evolutionary dynamics approaches, focusing on biology but including language and other cultural practices, see Martin Nowak, Evolutionary Dynamics: Exploring the Equations of Life (2006). The description in the text takes largely from Nowak.

of ways, combining existing alternatives, or modifying them, or experimenting with new approaches that they then try out. As the environment changes, people change rules and strategies again in response. Assuming this relatively myopic experimental but still rational search for alternatives, evolutionary dynamics in the social sciences departs from conventional economic modeling assumptions about hyperrational self-interest maximizers.

Second, this variation in the population must be copied and transmitted in some way among individuals in the population. In biology, variation is transmitted through biological reproduction or sometimes learning or imitation. In social science, people also transmit strategies and social practices by social learning or imitation. States copy other states' regulations. People adopt strategies that they learn about from the writings of other people. Individuals and organizations learn from others by imitating in many ways: following the leader, conforming to the majority, comparing payoffs and switching to another comparative strategy if the payoff differences are great enough. Cultural transmission allows social behavior and information more generally to diffuse through a population.[8]

Third, interactions between the environment and variable traits or genes in the population must "select" for those alternatives or variations with higher fitness (or "utility"). In selection, those practices that generate a higher fitness (say, social status, or material payoffs) will be copied at a higher rate than strategies with lower fitness. In Darwinian terms, those strategies that are selected because of their relatively greater fitness will outcompete via copying other less fit strategies.

So, for example, in an environment in which humans have access to and drink lots of milk, a gene for lactose tolerance will be copied more often than the gene for intolerance. A firm's strategy of dumping of assets to cover losses might be copied more often in times of financial crisis if dumping confers higher payoffs to firms in a population than other strategies. A common-law exception to a legal rule that reduces litigation frequency and conforms to the relevant precedent might be copied by other states more often than one that does not if lawmakers are paying attention to rates of litigation.

Environments "select" for traits or strategies that confer greater fitness in that environment. Assume for simplicity that the environment is unchanging. We can then picture a rugged "fitness landscape" in which populations are moving up a hill on solid ground, adapting by switching to higher fitness strategies. Environmental forces ordinarily will not select for lower fitness alternatives. Thus, on a landscape with many peaks and valleys, populations may occasionally get stuck on a local hill, unable to traverse a valley to reach nearby hills of relatively higher fitness.

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[8] Luigi L Cavailli-Sforza and Marcus Feldman, Cultural Transmission and Evolution: A Quantitative Approach (1981); Martin A. Nowak, Evolutionary Dynamics: Exploring the Equations of Life (2006); Robert Boyd and Pete Richerson, Culture and the Evolutionary Process (1985).

When populations interact with each other as they do in real life—when predators rely on prey for food, when cooperators are interacting with defectors, when banks are interacting with borrowers, when firms are interacting with legal regulators—then calculations become more complicated. Now the populations themselves are part of the environment or fitness landscape on which evolution takes place. So for example when cooperators and defectors interact in the same population, the utility of their strategies depends on how many other people are deploying the same strategy. Rather than a hill on solid ground, the hill now becomes stretchy and changes shape as the population moves over the fitness landscape.

In evolutionary processes, traits or strategies change endogenously with the patterns that these choices and strategies collectively create. Agents react locally to the overall patterns that they themselves have created. And in their reacting to that pattern, they again endogenously create patterns, to which the agents further react, and so on.

In the context of this self-recreating system, the key question that a scholar might ask is, "How does this system unfold over time? How will the agents change in reaction to the patterns of the system? How will their changes in reaction affect the pattern they have created?"[9]

Understanding the unfolding patterns of these processes sheds light on economic structures like bubbles, crashes, tipping points and their critical thresholds. Dynamic studies provide a frame-by-frame view of the dynamics of a market in free-fall, white flight, or the arms race between regulators and tax shelter promoters. Modern evolutionary dynamics focuses on the non-equilibrium processes that characterize much of real life, as well as selection of the rest points to which equilibrium processes converge.

Some scholars have questioned the usefulness of dynamics models drawn from biology to study the social sciences. After all, human decision-making is far less random and error-driven than genetic mutation. At the same time, human decision-making—real-life human decision-making – is probabilistic. As the chapter will discuss in more detail below, models that take into account both the uncertainty of experiment and the regularity of rational choice and cost-benefit analysis can describe the partially rational way in which humans navigate through the world.[10]

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[9] Much of the preceding description of evolutionary dynamics is taken from Brian Arthur's description of a dynamic conception of the economy, and the corresponding focus of "complexity economics." See Brian Arthur, The Complexity of the Economy (2014).

[10] For experimentalism in law in the face of uncertainty, see, e.g., Ana di Robilant, Property and Democratic Deliberation: The Numerus Causus Principle and Democratic Experimentalism in Property Law, 62 Amer. J. Comparative Law 367 (2014) (exploring experimental forms of property law like common interest communities, community land trust and digital servitudes); Michael C. Dorf and Charles F. Sabel, A Constitution of Democratic Experimentalism, 98 Colum. L. Rev. 267, 348 (1998) (noting in a discussion of the experimentalism of democratic government that systems for evaluating experiments "can

Likewise, some have questioned whether evolutionary models add anything to more general dynamics models. This chapter suggests that transmission of strategies—via social learning, copying, imitation, following the leader—is key to understanding how humans navigate incomplete information, and how strategies diffuse horizontally throughout a population and vertically over time. The next section takes up this claim in more detail.

II. Evolutionary Dynamics Method

Evolutionary dynamics is a fundamentally interdisciplinary project, drawing together a core of methods from several disciplines that focus on describing systems of interacting individuals and populations that adapt over time. As such, evolutionary dynamics can be said to draw from four or five key theoretical areas. We will consider each area and its contribution to evolutionary dynamics in turn.

1. Dynamics

Dynamics (and dynamic systems theory) investigates change over time. Originating in physics and mathematics, dynamics models are also common in biological and social sciences. Many dynamics models are equation based, and rely on differential equations and their solutions to describe the dynamic patterns that interacting agents create. The study of dynamics allows the scientist to see the unfolding patterns of change over time in addition to their rest points.

Research by economist Peyton Young showcases the work that differential equations can do to describe the unfolding nature of change.[11] Young investigates the particulars of three common pathways of diffusion: contagion, social influence and social learning. In diffusion via contagion, contact with adopters induces others to adopt. "Follow the crowd" social influence induces a person to adopt if some threshold of earlier adopters has already done so. And in social learning, the decision to adopt depends on the amount of information acquired by prior adopters.

Each pathway can be described using a differential equation, and each equation produces a distinctive footprint that can be useful in deciding whether certain pathways are at work in observed data. So, for example, contagion involves one-to-one transmission, of disease or ideas or innovations. When a disease diffuses through a population via contagion, the pattern of diffusion follows the standard "S" adoption curve, starting slowly, accelerating exponentially midway, and then slowing again as the population has become saturated with the innovation. More distinctively, contagious

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themselves be benchmarked, and...can be combined with random-assignment experiments and other familiar methods of evaluation").

[11] Peyton Young, Innovation Diffusion in Heterogeneous Populations: Contagion, Social Influence and Social Learning, 99 Am. Ec. Rev. 1899 (2009).

diffusion slows down exactly at the 50% mark, the point at which the population begins to contain fewer people who have not adopted the innovation than who have.

Young's study uses these characteristic footprints to analyze historical data from a landmark study on the adoption of hybrid corn between 1926 and 1945 in the Midwest. According to his analysis, hybrid corn likely spread via social learning—that is, farmers chose whether or not to adopt hybrid corn after having a look at all the information acquired by other adopters. Adopters cared much less about the identity (or number) of those who had adopted already, and much more about the evidence that those early adopters had accumulated.

Differential equations can usefully describe the specific ways in which dynamic processes unfold, and not just their stable rest points. Differential equations can also shed more light on the stability of equilibria, as we will see in the discussion below. But the ability to identify a footprint or to describe a particular pathway of change comes from understanding the way in which a phenomenon changes over time, something that static models can sometimes hide. Young's work has been extended to study the diffusion of innovations in executive compensation (stock options as a new form of compensation), legal organization (the limited liability company) and financial contracts (various forms of insurance) among other things.

2. Information Processing

Information processing theorists study the way that people organize and make sense of information about their world. Of particular interest for evolutionary dynamics is the way that people deal with incomplete information. Work by Herbert Simon and others demonstrates that under conditions of limited information, people behave in complex but patterned ways, using rough and ready "heuristics" to navigate their way through uncertainty.[12]

Recent work in psychology and sociology shows, for example, that in uncertainty, market actors often compare their payoffs with those of others around them—a market leader, their neighbors, the majority, a teacher or mentor—and will switch to the other's strategy with some probability that depends on the difference between their payoffs. Drawing from this work, evolutionary dynamics scholars have developed "pairwise comparison" models to understand the role that social learning plays in promoting public goods. For example, when people are able to compare their performance in energy conservation to others in their building, they are more likely to conserve, even in the face of incentives that promote selfish behavior. [13]

[12] See Simon, supra note 6.

[13] See e.g., Karl Sigmund, Hannelore De Silva, Arne Traulsen and Christoph Hauert, Social Learning Promotes Institutions for Governing the Commons, 466 Nature 861 (2010). See also Erez Yoeli, Moshe Hoffman, David G Rand and Martin A. Nowak, Powering up with indirect reciprocity in a large-scale field experiment, 110 Proc Natl Acad Sci 1024 (2013). For details on the pairwise comparison of payoffs, see

Copying and imitating are two strategies that people use when faced with incomplete information. People imitate their friends or follow the leader. They take straw polls on Facebook. Copying and imitation aren't limited to individuals; institutions engage in those processes as well. The national park system of Costa Rica recently decided to adopt the US national parks legal rules, rather than develop a set of legal rules from scratch. States in the US often copy each other's commercial and civil codes.

As suggested earlier, probabilistic models are well suited to describing these kinds of human information processing practices. Early work by the legendary Chicago-school economist Armen Alchian suggested that because population dynamics models describe behavior probabilistically, they might be suitable to describe human decision-making in uncertainty.[14] As Alchian pointed out, human beings often experiment with a wide range of rational approaches, making rational behavior appear random to an outside observer even though the decision maker pays close attention to cause and effect. In addition, behavior that appears rational is sometimes in fact random, appearing rational only because the selected strategy improved utility.

Given that rational behavior can look random, and random behavior can look rational, Alchian concluded that investigation should focus on the probability of particular decisions or strategies rather than their motivation. Probabilistic principles of biological evolution and natural selection can be used to describe the economic system as an adaptive mechanism that chooses among a distribution of exploratory actions undertaken in the pursuit of payoffs.

3. Path Dependence, Economic History and Geography

Not surprisingly, in an evolutionary dynamics approach, the study of time and space (history and geography) plays a central role in determining outcomes. Space often affects the likelihood that people or biological species will interact with each other. A well-mixed population gives everyone an equal chance of interacting; people interacting on a network have far more uneven probabilities of meeting.

The timing (sequence) of events can also shape evolutionary outcomes. "Path dependence" is a concept that explains how early events might determine later outcomes far downstream. When processes are self-reinforcing (say, when a market exhibits increasing returns), outcomes can depend on random historical events early in the history of the process. These small historical events—a random surge in market demand, or

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Arne Traulsen, Jorge M. Pacheco and Martin A Nowak, Pairwise Comparison and Selection Temperature in Evolutionary Game Dynamics, 246(3) J. Theor. Biol. 522 (2007).

[14] Armen Alchian, Uncertainty, Evolution and Economic Theory, 58 J. Pol. Econ. 211 (1950). See also Armen Alchian, Biological Analogies in the Theory of the Firm: Comment, 43 Amer. Econ. Rev. 600 (1953).

victory in a brand contest – can sometimes confer a first-mover advantage in economic, political or social competition that then becomes locked in.[15]

So, for example, by some accounts, path dependence explains why VHS won its competition with Betamax in the US. Early in the competition, a small surge in popularity in the VHS market gave VHS a first-mover advantage. Video stores stocked VHS because carrying two copies of the same movie in different formats seemed wasteful. And even if Betamax were to have become more popular, store owners would have had to incur significant costs for switching out one set of videos for another.[16] Path dependence can help to explain why history matters--why VHS won in the US but Betamax won in Europe, for example.

Space can also play an important role in shaping the outcomes of dynamic processes. Economists like Paul Krugman and Brian Arthur have developed a dynamic account that explains why industries cluster unevenly in places like Silicon Valley. Larger concentrations of industry bring with them larger markets and better sources of supply. In turn, larger markets and better sources of supply attract even more industry. As a result, a relatively greater concentration of manufacturing in a particular place becomes self-reinforcing.[17]

Likewise, spinoffs can make early location choice self-reinforcing for later firm location. Early random historical events determine which locations and concentrations are the first to generate spinoffs, which by and large tend to stay in the same area. Because spinoffs beget more spinoffs in a process of self-reproduction, geographic location becomes self-reinforcing.[18]

4. <u>Networks and Graph Theory</u>

The analytical work that location in space does can be analyzed using network and graph theory.[19] Graph theory studies networks mathematically, creating nodes to represent individuals (people, species, institutions) and edges to represent the

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[15] For an in-depth look at path-dependence, see Brian Arthur, Increasing Returns and Path Dependence in the Economy (1994).

[16] W. Brian Arthur, Increasing Returns and Path Dependence in the Economy 112 (1994). See also Paul David, Understanding the Economics of QWERTY: The Necessity of History, in W. Parker (ed.), Economic History and the Modern Economist (1986).

[17] See id.; Masahisa Fujita, Paul Krugman and Anthony Venables, The Spatial Economy: Cities, Regions and International Trade (1999).

[18] See W. Brian Arthur, Urban Systems and Historical Path Dependence, in Cities and Their Vital Systems (Jessie Ausubel and Robert Hermans eds. 1987).

[19] Mark Newman, Networks: An Introduction (2010); Matthew O. Jackson, Social and Economic Networks (2010).

relationships among them. Graph theory enables scholars to investigate evolutionary dynamics that flow along networks. Network flows feature heavily in the study of infectious diseases, gang violence and interbank systemic risk, for example.

Network theory has been particularly helpful in understanding the cascades of failure that helped plunge the country (and now the globe) into crisis. Shortly before the crisis, in 2006, the National Academies/ National Research Council and Federal Reserve Bank of New York jointly commissioned a study of the architecture of the network along which payments flowed between banks in the US. Most banks engaged in interbank payments via the US Fedwire service, a real-time electronic settlement system operated by the Federal Reserve. [20]

Mapping the network, scholars discovered that the overall "connectivity" of the banks was low—the average bank was only connected to 15 others. At the same time, a small core of 65 banks served as network hubs; these hub banks maintained thousands of connections to a significant fraction of other banks in the network. This core created significant risk for failure cascades, and indeed experts correctly identified what would become a major source of fragility in the impending collapse.

Such studies shed light on ways to more appropriate regulate systemic risk. Andrew Haldane (the Chief Economist and Executive Director of Bank Research at the Bank of England) has proposed ways of restructuring bank network topology in order to reduce the kind of risk that comes from interbank payment networks.[21]

Haldane and biologist Robert May have suggested two key prescriptive policies. First, financial institutions must pay attention to diversity, not at the level of the individual bank but at the level of the population. Distributing inter-bank connections more widely among the population reduces the risk associated with big hub institutions. Second, the financial system should invest in creating modularity—setting up sectors of the system with firewalls of some kind that can reduce the contagion of failure characteristic of the 2008 crash. The Volcker rule, which quarantines risky activity from the rest of the system is one such example.

5. <u>Dynamic Evolutionary Game Theory</u>

Dynamic evolutionary game theory ("EGT") studies the dynamics of behavioral strategies that change over time in large populations of interacting individuals. Introduced as a way to deal with large populations in biology, John Maynard Smith and George Price developed evolutionary game theory models of animal behavior in the 1970s. Early "ESS"

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[20] Kimmo Soramaki, Morten L. Bech, Jeffrey Arnold, Robert J. Glass and Walter E. Beyeler, The Topology of Interbank Payment Flows, Fed. Res. Bank of N.Y. Staff Reports, Report No. 243 (March 2006).

[21] Andrew G. Haldane and Robert M. May, Systemic Risk in Banking Ecosystems, 469 Nature 351 (2010).

versions of evolutionary game theory continued to focus primarily on equilibrium analysis. [22]

More recently, theorists have devoted significant energy to charting non-equilibrium dynamics—dynamics that display cycles, arms races or other more complex patterned behavior that does not converge to a rest point. Non-equilibrium dynamics allows scientists to study novel phenomena.

To be sure, equilibrium theory is a profoundly important tool that permits analytical, generalizable precise study of economic processes. Often, it is the right tool to describe economic processes in ways that are useful for the policymaker. Sometimes, equilibrium theory obscures features of the economy that play an important role in a particular problem. For example, equilibrium models do not easily illuminate the dynamics of a bubble in the mortgage market.

A metaphor may be useful to underscore this subtle point. Sometimes equilibrium theory sheds light on useful features of the ocean. Forces of gravity and the pull of the moon on tides affect seal levels. To study the movement of the ocean in terms of sea levels, equilibrium theory is essential and extremely useful.

For a sailor, however, the interesting features of the ocean are on the surface. Here, departures from equilibrium create novel problems for the sailor to navigate—swells, waves, whirlpools and so on. Some features of the ocean surface are patterned: disturbances lead to more disturbances, waves come in sets and so forth. Like the ocean, when it comes to the economy, the money gets made on the surface, where things are out of equilibrium, or on their way to equilibrium. [23]

All versions of evolutionary game theory share some common characteristics. Payoffs or utility are synonymous with reproductive fitness. Higher-fitness strategies

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[22] John Maynard Smith and George Price developed a concept very much like the Nash equilibrium called the "evolutionarily stable strategy" (ESS). Assume a large population of players who are randomly paired to play a finite symmetric game with the standard payoff matrix. Assume also that all players play the same pure or mixed strategy. Now assume that a very small number of the population "mutates" and switches to play another strategy. If on average the residents do better than the mutants, the resident strategy is an evolutionarily stable strategy against that mutation. A strategy is evolutionarily stable if it does better on average than all other strategies: its fitness will be driven by competition with other strategies but also by interaction with itself.

An ESS is a Nash refinement (every ESS is a Nash equilibrium, though not every Nash equilibrium is an ESS). An ESS isn't necessarily the winner of every contest with another strategy—it does better on average than any other strategy when these are the only two present and the latter is sufficiently rare. John Maynard Smith and George R. Price, The Logic of Animal Conflict, 246 Nature 15 (1973). ESS analysis resembles classical game theory far more than does the more dynamics-focused and equation-based replicator dynamics and pairwise comparison adaptive dynamics. See generally Jorgen Weibull, Evolutionary Game Theory (1997); Nowak, Evolutionary Dynamics, supra note 5.

[23] See Arthur, Complexity and the Economy (2014).

spread in the population, and less successful strategies diminish or go extinct. In the most promising versions of dynamic EGT developed over the last decade or two, differential equations are used to describe the way in which the distribution of strategies changes over time. These equations are useful because they describe with precision the magnitude, direction and type of change over time.[24]

In replicator dynamics, for example, the central insight (and corresponding equation) is quite simple: the frequency of a strategy increases when the strategy is above average, that is, when its fitness exceeds the average fitness of the population.[25] Consider an infinitely large population of n types. Assume that individuals play only pure strategies to correspond with their type. Assume also that individuals meet randomly and pair off to play a symmetric game with the standard payoff matrix. Payoffs for each strategy can be calculated by (weightedly) averaging across the different opponent types that each strategy will randomly play. The average payoff for the whole population can also be calculated in a similar way.

Replicator dynamics assumes that a strategy with a fitness that is higher than the average fitness of the population will be copied more frequently over time. RD also assumes that best responses (as determined locally in competition) will have the highest long-term growth rate. In particular, replicator dynamics assumes that the per capita growth rate is given by the difference between the payoff of that strategy and the average fitness of the population. Best responses have the highest difference.

Replicator dynamics has proved quite useful to understand pro-social behavior and its relation to selfish behavior in populations. For example, Martin Nowak and Karl Sigmund have studied cycling replicator dynamics in the context of repeated prisoner's dilemma games to gain insight into real-world non-equilibrium cycles of cooperation and defection.[26] Nowak and Sigmund ran computer simulations to randomly generate strategies and then let them compete against each other in virtual tournaments.

Simulations began with Tit-for-Tat, a strategy that famously won several tournaments against hundreds of other strategies, including Always Cooperate (AC) and Always Defect (AD). But as Nowak and Sigmund discovered, TFT had a vulnerability. TFT does quite poorly if a player makes a mistake, and two mistakes can lead to mutual defection. Nowak and Sigmund's computers then evolved a new strategy, Generous Tit-for-Tat (GTFT), in which the first mistake is forgiven. GTFT outcompeted TFT because it avoided the potential for mutual defection that a less forgiving strategy risks.

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[24] LA Imhof, Drew Fudenberg and Martin A. Nowak, Evolutionary cycles of cooperation and defection. 102 *Proc Natl Acad Sci USA* 102 10797 (2005).

[25] Peter D. Taylor and Leo B. Jonker, Evolutionarily Stable Strategies and Game Dynamics, 40 Mathematical Biosciences 145 (1978).

[26] In the children's game of rock-paper-scissors, rock beats scissors, scissors beats paper and paper beats rock.

But GTFT had an Achilles heel. In a population of all GTFTs, Always Cooperate was able to invade, slowly over time, as a “neutral” mutant. GTFT’s payoffs were essentially the same as, if not a little less than, Always Cooperate. As a result, Always Cooperate could eventually “drift” to take over more of the population by chance. Of course, a homogenous population of Always Cooperate was vulnerable to Always Defect.[27] And the cycle would repeat. Nowak and Sigmund point out that these dynamics are cyclical and non-equilibrium. In theory, populations can cycle from cooperation to defection to increasingly generous forgiveness and then to cooperation again, with no rest point, let alone a stable equilibrium.

A close relationship exists between the rest points of the replicator dynamics equation and Nash equilibria.[28] The so-called “folk theorem” of evolutionary game theory specifies that if a population state is (asymptotically) stable, or if an interior solution trajectory converges under some “selection” process based on the underlying payoffs of the game, then the population state or limit point is a (strict) Nash equilibrium.[29] Beyond the rest points and their stability, replicator dynamics allows us to map the dynamic trajectories of equilibrium formation. Those trajectories cannot be mapped as easily (if at all) with standard game theory.

One other version of dynamic game theory should be mentioned: agent-based models. Analytical solutions aren’t always possible in evolutionary dynamics analysis. In agent-based simulation models, scholars describe the underlying mechanisms of interaction with simple fixed rules that operate at the level of the individual agent rather than equations that describe population behavior.[30] Agent-based models simulate the evolution of agent interactions under particular conditions.

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[27] See Martin A. Nowak, Evolutionary Dynamics, supra note 5 at 91; Martin A. Nowak and Karl Sigmund, Oscillations in the Evolution of Reciprocity, 137 J Theor Biol 137 (1) 21-26 (1989); Martin A. Nowak and Karl Sigmund, The Evolution of Stochastic Strategies in the Prisoner's Dilemma, 20(3) Acta Appl Math 247 (1990).

[28] For each player role (e.g., Row or Column), assume that there are infinitely large populations of players. The game is repeatedly played, each time by players randomly drawn from the appropriate population. Individuals in their respective populations learn from experience to avoid the suboptimal actions. A mixed strategy for a player role (Row/Column) is just the statistical distribution of the actions available in that role. Nash claimed that if players avoided suboptimal responses, and the population distribution of actions was stable, this distribution was the Nash Equilibrium. An unpublished version of John Nash’s thesis on the Nash equilibrium reveals that he had motivated the Nash equilibrium with both the conventional hyperrational player explanation and a “mass action” explanation that relied on evolutionary game theory. See Robert J. Leonard, Reading Cournot, Reading Nash: The Creation and Stabilization of the Nash Equilibrium, 104 The Economic J. 492 (1994).

[29] Josef Hofbauer and Karl Sigmund, Evolutionary Game Dynamics, 40 Bull. Amer. Math Soc. 490, 494 (2003).

[30] Scott Page, Agent Based Models in New Palgrave Dictionary of Economics (2d ed. 2008).

For example, the agent-based model depicting the famous Schelling model of segregation described above specifies the rule that agents should relocate when the fraction of same-race neighbors around them drops below some critical threshold. Agent-based models use rules of interaction, and particular trajectories of change, rather than differential equations (these models are discussed more at length below).

Some critics argue that agent-based models are too sensitive to arbitrarily chosen parameters or initial conditions and more subject to confusion about what drives outcomes. But practitioners point out that equation-based methods often require assumptions and abstractions that are highly unrealistic, to make the method tractable.[31] Agent-based modeling supplements such tools, with an eye towards improving both the realism of the assumptions and of the outcomes.

6. Empirical methods to fit the model to the data

Just as computers have revolutionized much of the theoretical modeling that lies behind modern evolutionary dynamics theory, so too has it revolutionized empirical methods for empirical evolutionary dynamics work. The explosion of cheap computing power enables scientists to easily engage in customized analysis that formerly would have taken months. Computer power helps scientists to navigate the difficulty of analyzing dynamic processes. Most statistical models are static, which makes fitting dynamic models a challenge. But modern techniques have now begun to meet that challenge.

In practice, dynamics scholars use all statistical methods for curve-fitting (e.g. least-squares, maximum likelihood, Bayesian) to fit dynamic deterministic models to data – the only difference is that the function being fit to data is the numeric solution of a differential equation rather than a (potentially) analytic expression. If what is being fit is a highly stochastic process, or has a complicated experimental error function, the statistical model could be more complicated. For most ordinary differential equations, a least-squares model is generally sufficient to fit a few parameters.

For more complicated solutions, some evolutionary dynamics scholars have begun to use Bayesian statistical modeling, and to exploit fast and inexpensive computing power. Markov Chain Monte Carlo Sampling (MCMC) is a Bayesian computing technique that evolutionary dynamics scholars occasionally use to map the probability distribution of a set of parameters. MCMC works by randomly and sequentially sampling from the distribution in order to efficiently explore and map that distribution. MCMC has a set of rules for randomly sampling – for generating new proposed parameter values (candidate distributions)—and also for accepting parameter values as part of the mapped distribution.

[31] For the basic arguments of this debate, see W. Brian Arthur, Out of Equilibrium Economics and Agent-Based Modeling, in 2 Handbook of Computational Economics (Judd and Tesfatsion eds. 2005).

For example, under Metropolis-Hastings rules, if a new randomly sampled set of parameters has a higher probability than the previous parameters, then the algorithm accepts the new parameters with probability 1. If the new set has a lower probability, the algorithm accepts them with a probability equal to the weighted ratio of probabilities. With the right rules and appropriate "burn in sampling" (sampling that is discarded), in the long run, the sampling process spends more time in high probability areas of the posterior distribution, and less time in low probability areas.[32]

III. The Evolutionary Dynamics Analysis of Law

So what might an evolutionary dynamics approach to law (and the relationship between law and behavior) look like? It should be clear by now that an evolutionary dynamics framework enables scholars to analyze distinctively dynamic features of legal and social change, like bubbles and crashes. But the method is even more powerful than that. In particular, evolutionary dynamics allows us to ask three types of questions of particular interest to legal (and law and economics) scholars:

- How does a change in legal or institutional rules affect the unfolding patterns and equilibria of the behavior that law regulates? What factors determine the selection of a particular equilibrium from multiple possibilities towards which law and behavior might evolve? As the following discussion will elaborate, recent work shows that simple rule changes can produce unexpectedly intricate dynamic patterns that are more difficult to describe via standard analysis.

- How does law itself construct the networks that shape the frequency of people's interactions? Law compels some people to interact, and prohibits others from interacting. As the following discussion demonstrates, regulatory requirements that compel interaction can sometimes have unexpected effects on legal outcomes.

- What is the co-evolutionary relationship between law and behavior? How does law evolve, endogenously and in tandem, with the behavior it regulates? Just as law shapes and structures the unfolding patterns of regulated behavior, so too is law shaped by those patterns. What is the nature of this co-evolutionary relationship between law and society?

The following discussion considers each of the three categories of inquiry in turn. Along with a description, each category will include an example of work by legal scholars (or scholars of regulation) who use evolutionary dynamics method to find answers to these kinds of inquiries.

[32] The description of empirical methods comes largely from Benjamin M. Bolker, Ecological Models and Data in R (2008).

1. How does law affect the unfolding patterns of behavior that law regulates?

Though law and economics scholars have long used classic game theory and the equilibrium versions of evolutionary game theory, legal scholars are only now beginning to make use of evolutionary dynamics to shed light on the dynamics of legal change. This section argues that dynamic methods can help us to predict the complex unfolding patterns of behavior that legal change can produce.

ED's potential usefulness might be best illustrated in this regard with a relatively simple and intuitive example: traffic. Traffic is regulated. It involves a complex system of interacting heterogeneous agent drivers. These agent drivers adapt their behavior to the environment of other agent drivers. They copy strategies that they think are the highest-fitness strategies. Traffic is a hot subject of conversation around water coolers in Los Angeles. (I personally have been given the gift of a shortcut from the West Side to downtown, from a colleague who inherited it from another colleague before my time.)

Traffic spends much of its time out of equilibrium, in complex patterns that are difficult to predict in advance. Given the combinatrics of traffic, it becomes very difficult to completely analyze in advance all the effects of a given rule change. With no model to guide analysis, policymakers (and drivers themselves) might come up with a very wide range of guesses about how to optimize traffic either at the global or individual level to avoid congestion and gridlock.

Modern evolutionary dynamics methods have enabled policymakers to regulate traffic with great precision. Work by Carlos Daganzo uses dynamics to model traffic gridlock, and then draws from those models to generate optimal regulatory strategies.[33] Daganzo's work is offered to illustrate the potential for evolutionary dynamics to provide similar regulatory insights in law, helping policymakers to understand the downstream and horizontal effects of changes in the law.

Daganzo develops a simple model of traffic that divides the city up into "reservoirs," and the reservoirs into smaller linked routes through which external traffic arrives and leaves and flows internally. Daganzo's model shows that the key to avoiding gridlock lies in the exit rate of cars from a link. When exit rates are low, traffic becomes self-reinforcing over time because more cars reduce the rate at which cars can exit. Specifically, when the number of cars in a link exceeds some ideal threshold number, traffic flow in a link begins to drop, and the exit rate begins to drop as well. In turn, lower exit rates mean more cars still on the road, which again lowers the exit rate, and so on. The departure curve begins to drop precipitously as gridlock becomes self-reinforcing.

Traffic has entered the death spiral. That is, once the number of cars triggers a feedback loop, the process decays automatically until it reaches gridlock. At some point, as traffic continues to snarl, the exit rate nears zero and traffic flow comes to a halt.

[33] Carlos Daganzo, Urban Gridlock: Macroscopic modeling and mitigation approaches, 41 Transp. Research Part B 49 (2007).

Conversely, reducing cars on the road creates a virtuous feedback loop, increasing exit rates, which would reduce the number of cars and increase exit rates even more, thereby restoring the flow.

Regulators can optimize the system to prevent gridlock by taking steps to reduce the number of cars and allow cars to exit at rates that are close to ideal. First, regulators can meter the entry of cars, holding some outside the link while others inside the link exit, which lowers the number of cars in a link. Regulators can calculate the precise metering frequency to hold the number of cars in the link to the ideal level, which will in turn optimize the departure curve and traffic flow.

Second, to optimize traffic citywide, assuming that some congestion is inevitable, regulators should confine pockets of congestion to neighborhoods in which exit rates are low, and ensure high flow rates of traffic rates in locations where exit rates are high. Regulators can do this by routing traffic away from pockets of congestion with high exit rates, and by maintaining high departure curves (via metering and other methods) in neighborhoods with a high density of destinations—places like Hollywood, for example, in Los Angeles. Daganzo's traffic models have been extended to optimize low emissions and coordinate transport, parking and congestion pricing, among other things.

Evolutionary dynamics analysis offers scholars an opportunity to use data to understand and manage the hard-to-predict downstream effects of changes in legal rules. Many regulatory challenges resemble the challenge of regulating traffic. Securities regulation must manage quickly evolving trades and trading strategies, evolving even more quickly now on computers engaged in high frequency trading. Cybersecurity regulation governs quickly evolving populations of hackers.

Further afield, procedural rules on summary judgments and dismissal are meant to manage an evolving population of actual and potential claims. Tax regulation, corporate governance, and banking regulations are all fields for which evolutionary analysis potentially holds great promise. In the newly emerging digital "underground economy," mediated by "smart" digital connections rather than humans, the need for dynamic approaches becomes all the more pressing.

2. <u>How does law structure the very field of interaction on which the dynamic patterns of regulated behavior unfold?</u>

At a deeper level, evolutionary dynamics can highlight the way in which law actually constructs the field of interaction that gives rise to dynamic patterns. In the most foundational sense, law often controls the architecture of social interaction. Law sometimes requires that people interact with each other; other times law prohibits such interaction (as with antitrust law). In contrast to the traffic example from above, in which law affected the traffic that was flowing through a network, in this line of inquiry, law constructs the network itself, and legal changes affect the architecture of the network.

Changing the location of network "nodes" or "edges" (links) shapes outcomes by changing the frequency with which people interact. Creating a new node or removing an edge in one place might create a bottleneck in another, for example. Evolutionary dynamics helps to predict the frequently unexpected effects of these changes.

An example from telecommunications is instructive. In a telecommunications network, network operators form a network of access on which consumer traffic flows. In an effort to promote open access and competition, the 1996 Telecommunications Act required that an incumbent network operator's emerging competitors have access to the network, on terms that the competitor was largely free to decide. Under the Act, incumbent network operators are not allowed to decide where on the network competitors gain access; the law specifies that the competitors can choose their point of access at any technically feasible point. In addition, compelled access rules only require price to be calculated on the basis of the local impact of access, and not on impact on overall network performance.[34]

Brilliant work by Daniel Spulber and Christopher Yoo shows that requiring competitor access on a link of the competitor's own choosing can unexpectedly reduce the capacity of the entire network and render this pricing system incoherent. [35] All global networks have a sort of weakest link of vulnerability, some set of critical links through which all or most traffic must flow. If a competitor chooses to access capacity on one of the weakest links, or if access on a link now pushes the link to be one of the weakest link set, then adding the competitor at that spot will potentially reduce the overall performance of the network.

Even when the link appears to have sufficient local capacity to add a competitor, adding a competitor at that location changes the global architecture and potentially reduces capacity at the global level, harming everyone on the network. As Spulber and Yoo demonstrate, these unexpected effects can render pricing schemes inefficient, as prices do not reflect the global spillovers, and as market actors compete on those prices. Evolutionary dynamics modeling can help scholars and policymakers to spot such problems.

4. <u>How does law evolve, endogenously and in tandem, with the behavior it regulates?</u>

Perhaps most noteworthy, evolutionary dynamics helps scholars to investigate how law itself evolves in tandem ("co-evolves") with the behavior it regulates. Just as legal rules regulate behavior, behavior also shapes the formation of legal rules designed

[34] 47 U.S.C. § 251(c) (3) (2004). The statute requires that the accessed elements be "necessary" and that "the failure to provide access to such network elements would impair the ability of the telecommunications carrier seeking access to provide the services that it seeks to offer." Id. § 251(d) (2)(A) & (B).

[35] Daniel F. Spulber and Christopher S. Yoo, On the Regulation of Networks as Complex Systems: A Graph Theory Approach, 99 Nw. U L. Rev. 1687 (2005). See also, Daniel Spulber and Christopher S. Yoo, Networks in Telecommunications: Economics and Law (2009).

to regulate behavior. This reciprocal relationship seems obvious when one considers the impact that lobbyists have on lawmakers. But law and behavior can reciprocally shape each other in a much more fundamental way—by creating the very problems that each is required to solve.

This dynamic is visible in the cat-and-mouse games described at the beginning of this chapter. Regulators and those they regulate are engaged in a sort of arms race of innovation, each side innovating in an attempt to work around the obstacles that the other has created. Many areas of law display this phenomenon. Taxpayers innovate to avoid tax regulation by creating progressively more convoluted tax shelters. Media pirates avoid intellectual property regulation by inventing new versions of file-sharing technology. Payday lenders innovate to avoid regulation. In each case, regulators respond with innovations of their own, which triggers another round of innovation.

Recent work in legal scholarship uses evolutionary dynamics to investigate this co-evolutionary relationship in the context of payday lending and payday lending regulation. Insight into this question comes from an unexpected place: models of drug resistance. Drugs and pathogens often engage in an arms race, in which pathogens mutate, health experts come up with a new drug and the pathogens mutate again. Dynamic modeling has helped health officials to manage ever-evolving pathogens and tumor cells. For example, modeling has helped experts to develop a "time machine" that transforms resistant bacteria by way of a sort of crop rotation scheme to wild-type bacteria susceptible to drug treatment.[36]

Roithmayr, Chin and Levin draw from these models of regulation and resistance to map the cat-and-mouse game between payday lenders and regulators.[37] In our model, lenders mutate with some probability to adopt a strategy that evades regulators, and regulators mutate with some probability to adopt a strategy that is able to re-target payday lenders. The model highlights the trade-off that regulators face when deciding how quickly to respond to lender innovation. A speedy response eliminates more payday lenders but also triggers another round of innovation, requiring a costly return to the drawing board.

To advise regulators, we map the Pareto frontier of responses that optimize this tradeoff between costly retargeting and effective regulation. Our work makes two recommendations, both counterintuitive. First, regulators should not respond as quickly as possible to an innovating payday lender, but should instead calculate an optimal response time, one that balances the need to minimize predatory lending with the need to minimize costly repeated innovation. Just as chemotherapy can be administered too

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[36] Robert E. Beardmore and Rafael Pena-Miller, Rotating antibiotics selects optimally against resistance in theory, 7(3) Math. Biosciences and Engin. 527 (2010). But see Sebastian Bonhoeffer, Pia Abel zur Wiesch and Roger Kouyos, Rotating antibiotics does not select optimally against resistance, 7(4) Math.Biosciences and Engin. 919 (2010).

[37] Daria Roithmayr, Justin Chin and Bruce Levin, The Cat and Mouse Dynamics of Payday Lending (available at SSRN).

quickly after the tumor has developed resistance, so too can the regulator respond too quickly after payday lenders have mutated.

More surprisingly, we recommend that a regulator that cannot easily adapt its regulation should weaken regulatory strength and reduce the rate at which it closes lenders. Above a key threshold, any lender closure will unnecessarily trigger more lender innovation, and non-adaptive regulators cannot retarget those innovators. Weakening regulation limits lender innovation. Our model suggests that sometimes, doing nothing and letting the market help regulate is the most efficient regulatory response.

A co-evolutionary model can help us understand the endogenous change that characterizes the legal system. Regulatory actors navigate uncertainty by experimenting, exploring a wide range of "search space" among legal rule prototypes, copying from successful jurisdictions and then adapting the rules to better fit the local environment. Regulators induce change in the strategies of regulatory subjects, who reciprocally induce change in the regulators. Evolutionary dynamics methods can help scholars and practitioners to understand and map such endogenous forces.

Conclusion

Evolutionary dynamics offer a range of flexible tools that scholars interested in a dynamic analysis of law can use. Most notably, the evolutionary dynamics framework allows us to see agents react to the patterns they create, and then to create new patterns or recreate the old ones. For policymakers, who usually work at a scale in which history and time matter, the ability to describe the dynamics of law and society is quite useful. Recall the possibility, for example, that evolutionary dynamic approaches might provide insight to those who regulate the ever-evolving tax shelter.

More generally, these dynamic models offer scholars the ability to describe the relationship between law and regulated behavior. Such models can potentially incorporate both the way in which legal rules and regulatory regimes compete with each other and affect citizen behavior, which in turn affects the creation of legal rules themselves.

Importantly, evolutionary dynamics might give legal scholars a framework for studying innovation. Innovation is not imposed from the outside but endogenously generated. New legal rules generate new unmet legal needs ("How do we price competitor entry into a network?" "How do we evade payday lending rules?") that then give rise to new strategies and new legal technologies to meet those needs, and so on. Innovators tweak old legal rules and recombine their parts with other parts of other rules (using a disability framework to analyze racial or religious discrimination, for example).

Evolutionary dynamics enables observers of legal evolution to say things about the patterns of co-evolution that are in formation, by drawing on regulatory and behavioral history and constructing models of legal change that explain observed patterns.

Evolutionary dynamics might help to explain why law doesn't appear to evolve to some efficient rest point, as rational choice theorists would predict.

Standard law and economics analysis predicts efficient evolution. Notwithstanding that prediction, Richard Posner, Anthony Niblett and Andrei Shleifer recently published a paper in which they found the opposite. The authors conducted an empirical review of the economic loss rule over a period of fifty years to investigate the long-standing hypothesis that the common law evolved to efficiency.[38] The authors found no evidence that the states converged on the efficient version of the economic loss rule (either a general rule with no exceptions, or a general rule with well-accepted or statutory exceptions).

At the same time, they did find a pattern in the data. States converged towards the efficient versions of the rule until 1995, and then states began to adopt a range of idiosyncratic exceptions, many having to do with independent (non-statutory) duties for builders and architects that permitted (in theory, and in fact) plaintiffs to recover outside contract causes of action.

Evolutionary dynamics might give us a framework with which to investigate this evolutionary pattern. A closer reading of the cases before and after 1995 (and then more broadly) might provide sufficient information to construct a model, and then try to fit the model to the data, to discern the trajectory and origins of this pattern. Perhaps some economic event triggered experimentation by judges to carve out exceptions to the rule in order to reach pro-plaintiff rules.

Alternatively, the diverging exceptions might be understood as mutations that differentially confer advantage among particular states. Whatever the actual explanation, a dynamic model might be well positioned to attempt to make some sense of the patterns that Niblett et al. observed.

More broadly, evolutionary dynamics methods offer legal scholars the opportunity to draw useful insights not just from economics and the social sciences but also from a wide range of other bodies of knowledge like biology and epidemiology. As the earlier discussion illuminates, evolutionary dynamics draws from the sciences and from the social sciences – history, information theory, economic geography, economic sociology, political theory and many other disciplinary traditions. Legal scholars in general, and law and economics scholars in particular, have much to gain from collaborating across such a wide range.

[38] Richard A. Posner, Anthony Niblett and Andrei Shleifer, The Evolution of a Legal Rule, 39 J. Legal Studies 325 (2010).

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