Towards a More Evolutionary Theory of Property Rights

Lee Alston[*] *& Bernardo Mueller*[**]

ABSTRACT: Property rights are often referred to as "evolving," but the term is usually used to signify a gradual process of change rather than one based on Darwinian evolutionary theory. Because property rights go through processes of variation, selection and replication, a more rigorously evolutionary approach can improve our understanding of how property rights change over time. This Essay uses fitness landscapes to model the problem of searching for fit design of property rights. This approach interprets a bundle of rights as a bit string of zeros and ones that encodes for the actual property rights much like a genome encodes a phenotype. The shapes of the fitness landscapes over which the bundle of rights evolves characterize the nature of the search process. The key determinant of the shape is the number of interconnections among the different sticks in the bundle. Smooth single-peaked landscapes (no interconnections) represent easy search processes that have a good single optimal design. Random landscapes (maximally interconnected) portray a situation where there are a near-infinite number of low fitness designs. Instead of taking place at the extremes of smooth or random landscapes, property rights evolve in the interesting in-between where landscapes are rugged. This represents situations where there is a danger of getting stuck on suboptimal peaks, but where evolution (variation, selection and replication) is a particularly adept at finding good design. When the fitness contributions of the rights in the bundle are additionally affected by other laws, rules, and institutions that are coevolving, the landscape is not static but dances, changing over time. Coevolution favors property rights that are good at adapting to new conditions.

* Ostrom Chair & Professor of Economics, Indiana University; Director, Vincent and Elinor Ostrom Workshop in Political Theory and Policy Analysis.

** Professor of Economics, Universidade de Brasilia.

I. INTRODUCTION

One of the main purposes of the literature on property rights is to understand the process through which they arise and change over time. Because property rights change, it has been natural to call the process the "evolution of property rights." Yet in most cases scholars use the term "evolutionary" loosely to refer to gradual change over time and not to a well-defined process consisting of variation, selection, and heritability as in the Darwinian model of evolution. Classic papers in this literature such as Anderson and Hill's *The Evolution of Property Rights? A Study of the American West* (1975),[1] Field's *The Evolution of Property Rights* (1989),[2] Levmore's *Two Stories About the Evolution of Property Rights* (2002),[3] and Libecap and Smiths's *The Economic Evolution of Petroleum Property Rights in the United States* (2002),[4] have "evolution of property rights" in the title, but are based on an explanation of changes in property rights that is not founded on evolutionary theory, but rather on Harold Demsetz's hugely influential 1967 paper, *Toward a Theory of Property Rights.*[5] Rather than postulating a mechanism based on evolutionary theory, Demsetz's approach is grounded in neoclassical economics, with property rights changing whenever the marginal costs of altering the rights are exceeded by the marginal benefits of reducing externalities that prevailed under the previous arrangements. This approach, which has spawned a voluminous literature, was branded the evolutionary theory of property rights. So much so that, in 2001, Northwestern University hosted a symposium, *The*

1. Terry L. Anderson & P.J. Hill, *The Evolution of Property Rights? A Study of the American West*, 18 J.L. & ECON. 163 (1975).

2. Barry C. Field, *The Evolution of Property Rights*, 42 KYKLOS 319 (1989).

3. Saul Levmore, *Two Stories About the Evolution of Property Rights*, 31 J. LEGAL STUD. S421 (2002).

4. Gary D. Libecap & James L. Smith, *The Economic Evolution of Petroleum Property Rights in the United States*, 31 J. LEGAL STUD. S589 (2002).

5. Harold Demsetz, *Toward a Theory of Property Rights*, 57 AM. ECON. REV. 347 (1967).

Evolution of Property Rights, to commemorate Demsetz's seminal paper, which Demsetz personally attended.[6] On close examination it is clear that Demsetz and most of the literature that followed used "evolutionary" as synonymous with change and not to suggest a mechanism more closely associated with Darwinian evolutionary theory. James Krier notes that Demsetz:

> [H]ad not claimed to view changes in property rights (or social change in general) "as an evolutionary process." Rather, he had sought only to suggest a positive theory that property rights develop in response to costs and benefits, choosing to "avoid the different, difficult problem of how property right adjustments are actually made."[7]

Evolutionary theory is not restricted to biological processes, although that is how it originated and how it has been most frequently used. Instead evolution should be seen as a search process for fit design based on variation (recombination and mutation), selection of the fittest through greater reproduction, and replication/heritability, which can take place in many different substrates, such as culture,[8] technology,[9] language,[10] creativity/science,[11] and business strategies.[12] There are several treatments of property rights that adhere more closely to evolutionary theory such as Krier,[13]

6. *See generally* Symposium, *The Evolution of Property Rights*, 31 J. LEGAL STUD. S331 (2002).

7. James E. Krier, Essay, *Evolutionary Theory and the Origin of Property Rights*, 95 CORNELL L. REV. 139, 143 (2009) (citing Harold Demsetz, *Frischmann's View of "Toward a Theory of Property Rights*,*"* 4 REV. L. & ECON. 127, 128 (2008)).

8. *See generally* ROBERT BOYD & PETER J. RICHERSON, CULTURE AND THE EVOLUTIONARY PROCESS (1985); L.L. CAVALLI-SFORZA & M.W. FELDMAN, CULTURAL TRANSMISSION AND EVOLUTION: A QUANTITATIVE APPROACH (1981).

9. *See generally* JOEL MOKYR, THE LEVER OF THE RICHES: TECHNOLOGICAL CREATIVITY AND ECONOMIC PROGRESS 273–99 (1993) [hereinafter MOKYR, LEVER OF RICHES]; Joel Mokyr, *Induced Technical Innovation and Medical History? An Evolutionary Approach*, 8 J. EVOLUTIONARY ECON. 119 (1998) [hereinafter Mokyr, *Induced Technical Innovation*]; Joel Mokyr, *Science, Technology, and Knowledge: What Historians Can Learn from an Evolutionary Approach* (Max Planck Inst. on Evolutionary Econ., Working Paper No. 9803, 1998) [hereinafter Mokyr, *Science, Technology, and Knowledge*], *available at* http://faculty.wcas.northwestern.edu/~jmokyr/santafe.pdf.

10. *See generally* JOHN A. HAWKINS & MURRAY GELL-MANN, THE EVOLUTION OF HUMAN LANGUAGES (1992); Stephen Pinker & Paul Bloom, *Natural Language and Natural Selection*, 13 BEHAV. & BRAIN SCI. 707 (1990).

11. *See generally* Donald T. Campbell, *Evolutionary Epistemology*, *in* EVOLUTIONARY EPISTEMOLOGY, RATIONALITY, AND THE SOCIOLOGY OF KNOWLEDGE 47 (Gerard Radnitzky & W.W. Bartley, III eds., 1987); Karl R Popper, *Natural Selection and the Emergence of Mind*, 32 DIALECTICA 339 (1978).

12. *See generally* ERIC D. BEINHOCKER, THE ORIGIN OF WEALTH: EVOLUTION, COMPLEXITY, AND THE RADICAL REMAKING OF ECONOMICS (2006); RICHARD R. NELSON & SIDNEY WINTER, AN EVOLUTIONARY THEORY OF ECONOMIC CHANGE (1982).

13. Krier, *supra* note 7.

Sugden,[14] Hirshleifer,[15] and several Austrian authors, such as Mises and Hayek, who were inspired by Carl Menger's account of the emergence and evolution of money to do the same to property rights.[16]

Is there anything to be gained by adopting an approach more rigorously based on principles of evolutionary theory? Within the biological field there are controversies, even within the camp that openly accepts the basic Darwinian principles, which lead to bitter disputes over details and interpretations of concepts and mechanisms, such as the units of selection, the speed of evolution, and issues of optimality of outcomes. Applications of evolutionary theory to nonbiological areas are even more subject to criticism and dispute. In arguing for the usefulness of applying evolutionary principles to understand how technology (useful knowledge) evolves over time, Joel Mokyr warns that "applying a methodology from one field to another in a mad scramble for isomorphisms, shoehorning concepts into uses for which they were not intended seems a bad research strategy."[17] Yet in the realm of economic history, which seeks to explain long-run processes (in Mokyr's case the evolution of science and technology), Mokyr believes that "that we could vaguely characterize [such approaches] as Darwinian," and, more importantly, that the approaches could be fruitful. In a series of books and papers, Mokyr shows how a careful and rigorous evolutionary account of how useful knowledge emerges and changes over time can provide new insights, stimulate more research, and raise new questions.[18] Because the evolution of property rights is similarly a long run historical process, it stands to reason that an approach rooted in Darwinian principles, yet adapted to its singular details, can be fruitful.

We provide a brief statement of the emergence and change of property rights over time under a more rigorously evolutionary perspective. Yet that is not the main purpose of this Essay. Having argued that property rights follow a process of variation, selection, and replication, we present some models that

14. Robert Sugden, *The Role of Inductive Reasoning in the Evolution of Conventions*, 17 LAW & PHIL. 377 (1998).

15. Jack Hirshleifer, *Evolutionary Models in Economics and Law*, *in* EVOLUTIONARY ECONOMICS (Ulrich Witt ed., 1993).

16. For a review of the views of Marx, Barzel, Mises, Menger, and Hayek of the emergence and evolution of property rights, see Scott A. Beaulier & David L. Prychitko, *Disagreement Over the Emergence of Private Property Rights: Alternative Meanings, Alternative Explanations*, 19 REV. AUSTRIAN ECON. 47 (2006).

17. Joel Mokyr, *Useful Knowledge as an Evolving System: The View from Economic History*, *in* THE ECONOMY AS AN EVOLVING COMPLEX SYSTEM, III: CURRENT PERSPECTIVES AND FUTURE DIRECTIONS 309, 314 (Lawrence E. Blume & Steven N. Durlauf eds., 2006).

18. *See generally* MOKYR, LEVER OF RICHES, *supra* note 9; JOEL MOKYR, THE GIFTS OF ATHENA: HISTORICAL ORIGINS OF THE KNOWLEDGE ECONOMY (2002); Joel Mokyr, *Induced Technical Innovation*, *supra* note 9; Joel Mokyr, *Science, Technology, and Knowledge*, *supra* note 9; Mokyr, *supra* note 17; Joel Mokyr, *Natural History and Economic History: Is Technological Change an Evolutionary Process?*, NW. UNIV. (Apr. 2000), http://faculty.wcas.northwestern.edu/~jmokyr/jerusalem1.PDF (draft lecture) [hereinafter Mokyr, *Natural History and Economic History*].

are often used in evolutionary theory to address some controversies that have arisen in the more standard property rights literature. More specifically, we use Stuart Kauffmann's *NK* Model and the associated fitness landscapes to portray the evolution of property rights as a search problem over a design space of all possible bundles of property rights.[19] A fitness landscape maps each bundle to a fitness value that expresses how much those arrangements are replicated over time by contributing to that society's functionality and welfare, thus creating a large landscape over which the search for fit property rights design takes place. The model is useful because the shape of the landscape is determined by the nature of the property rights, and in particular the interconnection among the different "sticks" in the bundle of rights. Property rights with independent sticks will tend to have smooth, single-peaked (Mount Fuji) landscapes, which are easily searched and thus tend to yield optimal designs. On the other hand, property rights where the different sticks are closely interrelated will produce rugged landscapes with several local peaks that can trap a society into a suboptimal set of property rights.

This approach to understanding the evolution of property rights provides insights into some standing controversies in the literature. Many of these controversies emerged as critiques to the standard Demstez model that portrays property rights as: (1) always moving towards private property; and (2) always adjusting optimally to new circumstances without clarity on whether the new property rights developed through intentional design or as unintended consequences, and without really detailing the actual process that leads property rights institutions from the situation before to the situation after a change in relative resource values. For example, Richard Posner showed that in some circumstances common property could be optimal;[20] Terry Anderson and Peter J. Hill showed that the process through which resources are turned into private property can often lead to rent dissipation;[21] Martin Bailey provides anthropological evidence from aboriginal societies that resource scarcity does not inevitably lead to private property;[22] John C. McManus showed that even in Demsetz's example of Montagnais Indians the actual outcome was overexploitation of the beaver;[23] others criticize the black

19. *See generally* STUART KAUFFMAN, AT HOME IN THE UNIVERSE: THE SEARCH OF THE LAWS OF SELF-ORGANIZATION AND COMPLEXITY (1995) [hereinafter KAUFFMAN, AT HOME IN THE UNIVERSE]; STUART KAUFFMAN, THE ORIGINS OF ORDER: SELF-ORGANIZATION AND SELECTION IN EVOLUTION (1993).

20. *See, e.g.*, RICHARD A. POSNER, ECONOMIC ANALYSIS OF LAW (9th ed. 2014); RICHARD A. POSNER & WILLIAM M. LANDES, THE ECONOMIC STRUCTURE OF INTELLECTUAL PROPERTY LAW (2003); Richard A. Posner, *Intellectual Property: The Law and Economics Approach*, 19 J. ECON. PERSP. 57, 58 (2005).

21. *See generally* Anderson & Hill, *supra* note 1.

22. *See generally* Martin J. Bailey, *Approximate Optimality of Aboriginal Property Rights*, 35 J.L. & ECON. 183 (1992).

23. John C. McManus, *An Economic Analysis of Indian Behavior in the North American Fur Trade*, 32 J. ECON. HIST. 36, 50–53 (1972).

box nature of property rights change under Demsetz's model, which, for example, ignores institutional and political economy issues;[24] and James Krier shows that Demstez is not clear on the issue of intentionality versus unintended consequences.[25] These are just a few of the papers that added to the debate over how property rights evolve; the literature is too large to cite comprehensively.[26] The contribution of this Essay is to provide a different perspective through the use of fitness landscapes and the *NK* model. While such an approach may not fully resolve these debates, it provides a different way of perceiving and classifying the nature of the problem to be solved when societies are led to change property rights, thereby shedding new insights on the characteristics that the process of change can assume.

II. FITNESS LANDSCAPES AND BUNDLES OF RIGHTS

Perhaps the most controversial aspect of applying an evolutionary approach to any specific area is determining the unit of selection on which evolution operates. In biology, the original Darwinian theory took the unit of selection to be the individual or the organism, that is, the phenotype. This is the way that most people tend to think about evolution. An animal which, through mutation or breeding, becomes better, faster, or stronger than the others with which it competes for resources, will have greater reproductive success leading to more of its kind. But this view was eventually challenged by the notion that evolution acts instead on the genotype; that is, on an organism's set (or even a subset) of genes.[27] In this view, the individual is just the vehicle for the change. It is instead the genes, which code the information for replicating the phenotype, that should be the unit of analysis as they are the entity of which copies are made and passed along. That is, a chicken is only an egg's way of making another egg.

One of the most appealing applications of evolutionary logic to epsitemic substrates has been that of technology and technological change. In evolutionary accounts of the process of variation, selection, and amplification of technology, it is tempting to think of the artifacts that result from invention and innovation as the unit of selection. Joel Mokyr, however, proposes instead that the proper unit of analysis is the technique—"a set of instructions, much like the if-then algorithms of a computer program, that tells someone how to produce, . . . how to manipulate the forces of nature in the interest of material well-being of people."[28] In a similar manner, when it comes to analyzing property rights, we will treat the unit of selection as being not the group or

24. *See, e.g.*, THRÁINN EGGERTSSON, ECONOMIC BEHAVIOR AND INSTITUTIONS 251–52 (1990); Kirsten Foss & Nicolai J. Foss, *Organizing Economic Experiments: Property Rights and Firm Organization*, 15 REV. AUSTRIAN ECON. 297, 303 n.11 (2002).

25. Krier, *supra* note 7, at 146–50.

26. *See, e.g.*, Symposium, *supra* note 6 (dedicated to discussing Demsetz's thesis).

27. RICHARD DAWKINS, THE SELFISH GENE 11 (30th Anniversary ed. 2006).

28. Mokyr, *Natural History and Economic History*, *supra* note 18, at 6–7.

society that harbors those rules and institutions, but rather the information contained in the "set of instructions" that are the property rights, much as the genome contains a set of instructions on how to create another specimen.

This perspective of property rights as a code fits remarkably well with the notion, familiar to law school students, of property as a bundle of rights, where instead of property being a right to a thing, it is a relation between people with respect to a thing and it can be broken down into pieces that have direct consequences.[29] Examples of these pieces, or incidents of ownership, that can make up the bundle are "[(1)] the right to possess, [(2)] the right to use, [(3)] the right to manage, [(4)] the right to the income, [(5)] the right to the capital, [(6)] the right to security, [(7)] the incident of transmissibility, [(8)] the incident of the absence of harm, [(9)] the prohibition against harmful use, and liability in execution."[30] Note that in principle the number of sticks in the bundle can be quite large depending on how one disaggregates each of the more generic rights, e.g., the right to use for purpose *x* and the right to use for purpose *y*, or the right to some minerals found under the soil (in the case of land) but not the right to others.

Suppose that there are *N* different sticks in the bundle and that each component can be present or absent, so that we can write it as a zero or a one. Thus, a given bundle of rights can be represented as a string of zeros and ones that specifies that particular instruction of what can and cannot be done with the property. This is analogous to a genome, which contains *N* genes (approximately 20,000 in humans) that specify the instructions on how to render a specimen. Each gene can assume different forms or alleles (for example, for dark hair or light hair). Similarly, a stick in the bundle of rights can take many different gradations. But following the literature we simplify by assuming only presence or absence, so as to have a bit string. Given *N* sticks in the bundle, the total number of possible different bundles is 2^N. For N=3, for example, there would be the following possible combinations: 000, 001, 010, 100, 011, 110, 101, 111.

If the three sticks in the bundle are (1) the right to use; (2) the right to sell; and (3) the right to manage, then 000 represents the absence of each of these rights, 100 the right to use but not to sell or to manage, and so on.

If *N* is large then the total number of bundles will be too large to consider each possibility case by case. If one considers only the nine sticks cited above, then the total number of combinations would be 512. If each of the nine definitions were further disaggregated into three more specific rights, then the total number of bundles would be 2^{27}—over 134 million combinations. If more than two alleles are considered the number rises even faster: for A=3,

29. For a discussion on the use of the bundle-of-rights metaphor, see Daniel B. Klein & John Robinson, *Property: A Bundle of Rights? Prologue to the Property Symposium*, 8 ECON J. WATCH 193 (2011).

30. Richard A. Epstein, *Bundle-of-Rights Theory as a Bulwark Against Statist Conceptions of Private Property*, 8 ECON J. WATCH 223, 224 n.3 (2011) (ascribing this list of nine incidents of ownership to Tony Honoré, a Roman–Dutch lawyer).

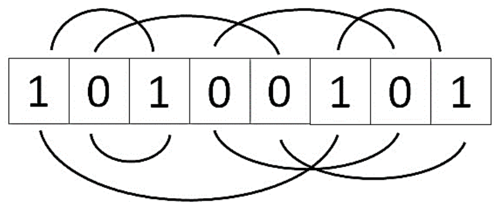
there would be 3^{27}—7.6 trillion combinations. The power of combinatorics means that the number of possibilities rises very fast.[31] Even if we could easily calculate the fitness (according to some criterion) of each bundle, so as to compare and choose among them, it is clear that the task of finding the best (or even good) alternatives is not trivial. In order to be more precise on what is involved in this task, we will use the notion of fitness landscapes, as their shapes impart information on how likely it is that a good solution will be found. Furthermore, we will show how the shape of the landscape is determined by the characteristics of the property and the environment it is in.

A further complication that must be considered before going to the landscapes is that the contribution of each of the sticks in the bundle towards the total fitness under that bundle might not be independent of the state of the other sticks. This is analogous to the phenomenon of epistasis in genetics, where the effect of one gene depends on the presence of one or more other genes. Since the usefulness of a given phenotypic trait (e.g., the size of the wing) controlled by one gene may depend on the state of another trait (e.g., the weight of the bones) controlled by another gene, the genes are epistatically coupled. In a similar manner, the different sticks in the bundle of rights can be related in a network of epistatic interactions. For example, if the contribution to total fitness of the right to use is affected by the right to the capital.

A bundle of rights with its epistatic couplings can be represented with arrows showing which sticks affect other sticks, as in Figure 1. The number of couplings is referred to as *K*. In this example there are eight sticks in the bundle (*N*=8) and each is linked to two other sticks (*K*=2). More generally, *K* can vary from 0 to *N*-1. These couplings are conflicting constraints, so as *K* increases from a situation where each stick is independent from the others to a maximally constrained situation where each stick is coupled to every other, the problem of finding high fitness combinations becomes harder and, as we shall see, the level of attainable fitness decreases.

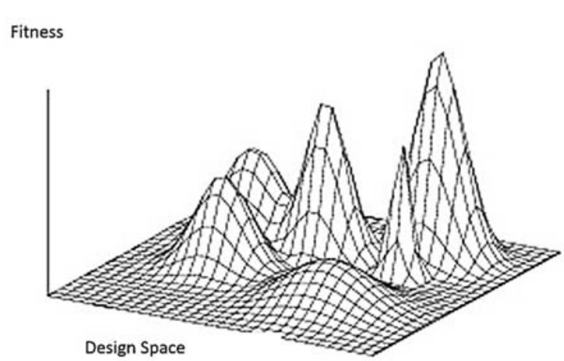
31. Where the *numerus clausus* principle operates, the number of ways of owning property may be limited to reduce information costs and allowing for an easier search for fit design. *See* Yun-chien Chang & Henry E. Smith, *The* Numerus Clausus *Principle, Property Customs, and the Emergence of New Property Forms*, 100 IOWA L. REV. 2275 (2015); Thomas W. Merrill & Henry E. Smith, *Optimal Standardization in the Law of Property: The* Numerus Clausus *Principle*, 110 YALE L.J. 1, 40–42 (2000).

Figure 1. Bundle of Rights with *N*=8 and *K*=2



A fitness landscape starts off with a design space of all possible combinations of the set of instructions laid out along a horizontal plane. Each bit string has *N-1* neighbors that are one-bit mutations; that is, each neighbor is identical to itself except for one bit that is flipped from 0 to 1 or vice-versa. As we have seen, even moderately small values of *N* imply that the design space will be very large, and in many applications, including property rights, it may be astronomical. For each bit string in the design space a corresponding level of fitness can be plotted on the vertical axis, thus creating a fitness landscape, where the peaks represent the most-fit designs (see Figure 2, which plots a section of a fitness landscape). In biological applications, fitness refers to the capacity of that design reproducing faster than others so as to prevail in the population. The fact that fitter designs replicate more than less-fit designs implies that the species will tend to climb towards higher peaks. Most designs will typically provide very low or null fitness so the landscape is flat at zero. But in some regions the designs will yield higher levels of fitness and peaks and valleys emerge. Because neighboring bit strings are very similar to each other, though not identical, they will tend to display approximately similar levels of fitness, thus producing smoothly rounded hills. If an essential bit is flipped, however, abrupt precipices and sharp spikes can result. As we will see, the shape of the landscape gives us information concerning the characteristics of the search problem we are investigating and the ability of different search strategies to find good solutions to those problems.

Figure 2. A Fitness Landscape



In the case of the evolution of property rights or other social constructs, the concept of fitness is not as clear as it is in biology. Here, fitness also refers to the capacity of a design of property rights to replicate and persist over time. Note that given that the unit of selection is the design of the property rights and not the group that uses those rights, fitness refers to the tendency of that design being kept in place rather than being changed for another bundle of property rights. Of course, if the extant bundle is highly dysfunctional, this will affect the welfare of the group, which may grow and prosper at a slower rate, or may even be conquered by other social groups. So the fitness of the property rights is related to the welfare of the society, but it is important to keep in mind that when we mention fitness in this Essay it will refer to the fitness of the *bundle* for the sake of its own perpetuation over time.

Suppose that Figure 2 represents a fitness landscape for property rights for a given good in a specific society. The original set of rights will emerge by spontaneous order at a given point in the landscape. Even though there might be some purpose and intentionality in the design, what actually emerges does so in a nonteleological fashion as the process is subject to error, surprise, and serendipity. Joel Mokyr shows that even in the case of technological evolution, where there is obviously purposeful action, the innovations that emerge cannot be seen as the result of a closely controlled process.[32] For property rights the effect of unintended consequences should be even stronger. Thus variation in property rights evolution takes place through a process of deductive tinkering that involves intention but is subject to "serendipity, opportunism, and the 'King Saul effect' (which occurs when the search for the solution of a specific problem inadvertently leads to a totally new opportunity set)."[33]

The original bundle of rights that emerges can only appear in a section of the landscape that exhibits at least a minimal level of fitness. This is one of the main points of Stuart Kauffman's *At Home in the Universe*, which highlights the difference and complementarity of spontaneous order and natural selection. He states that:

> Evolution may be impossible without the privilege of working with systems that already exhibit internal order, with fitness landscapes already naturally tuned so that natural selection can get a foothold and do its job. And here, I think, may be an essential tie between self-organization and selection. Self-organization may be the *precondition* of evolvability itself.[34]

Note then, that the position on the landscape where the original bundle emerges will define in many ways the nature of the task that the system faces

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32. *See* MOKYR, LEVER OF RICHES, *supra* note 9, at 286.

33. *Id.*

34. KAUFFMAN, AT HOME IN THE UNIVERSE, *supra* note 19, at 185.

to find fit design. If the original bundle happens to emerge near a high peak, and the search strategy is an adaptive walk that always takes the steepest path available, then the task will be relatively easy and the result will be highly fit. If the starting point is near a low peak, that same strategy will get the system stuck in a suboptimal solution from which it will be hard to escape, even in the presence of nearby better solutions. Thus the process is highly path dependent.

There are a large number of strategies for searching large landscapes for fit design, such as random jumps, adaptive walks, greedy algorithms, and simulated annealing, among others. In many real world applications, evolution—a process of variation, selection, and replication—turns out to be the dominant strategy. Evolution is ubiquitous because it is particularly well suited for search in rugged landscapes such as that in Figure 1, which characterize the problem typically faced in biology, culture, language, technology, and property rights. Evolution can be seen as a combination of an adaptive walk that seeks to move uphill, with short random jumps produced by recombination and mutation, which allow the system to escape from inferior peaks so as to explore other sections of the landscape for superior designs. The strength of evolution is its ability to balance exploration with exploitation.[35] Whenever a system has reached a relatively high point in its fitness landscape it would want to perpetuate the current design in order to exploit that fitness to the environment. There is, however, a tradeoff that must be considered. It is possible that the current point is a local maximum and there may be preferable peaks nearby that can be reached through some viable variation. It would thus be wise to dedicate some efforts to exploring the landscape for fitter designs. Exploitation takes place as fit designs that have been selected by the environmental pressures replicate. Yet, because this replication happens with errors, i.e., mutations and other processes, there is continual exploration. Mutation and sexual recombination can be seen as a jump from one point in the landscape, possibly a local peak, to another noncontiguous point. Furthermore, evolution is such that this balancing act dynamically adjusts itself to circumstances, exploiting more when the current set up is particularly fit for the environment and exploring more when fitness decreases.[36]

III. SMOOTH, RUGGED, AND RANDOM FITNESS LANDSCAPES

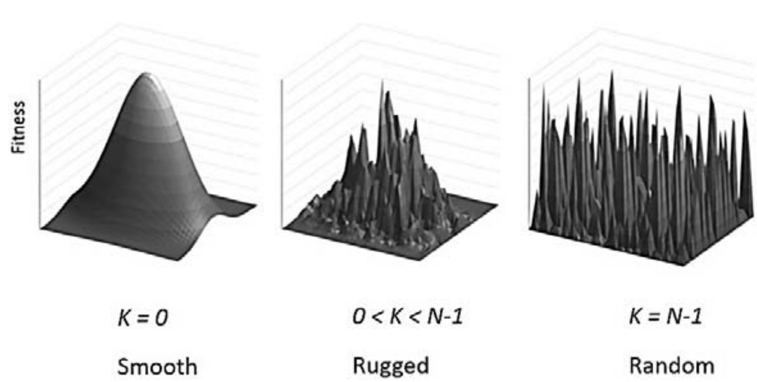
Now we are in the position to ask what determines the shape of the landscape (the number, heights, and disposition of the peaks) in the systems we are concerned with. When will there be a landscape with a single smooth

35. *See, e.g.*, BEINHOCKER, *supra* note 12, at 211–12, 216; JOHN H. HOLLAND, ADAPTATION IN NATURAL AND ARTIFICIAL SYSTEMS 11–12 (1992) [hereinafter HOLLAND, ADAPTATION IN NATURAL AND ARTIFICIAL SYSTEMS]; JOHN H. HOLLAND, HIDDEN ORDER: HOW ADAPTATION BUILDS COMPLEXITY 78–80 (1995); SCOTT E. PAGE, DIVERSITY AND COMPLEXITY 122–24, 151–58 (2011).

36. HOLLAND, ADAPTATION IN NATURAL AND ARTIFICIAL SYSTEMS, *supra* note 35, at 12.

peak that can easily be climbed, and when will there be a large number of distributed smaller peaks confounding the search for the best combination? Stuart Kauffman's *NK* Model shows that the crucial determinant of a fitness landscape's shape is the extent to which the *N* features of the system are correlated, which is represented as *K*.[37] When *K=0*, each feature is independent of all the other *N-1* features so that the search process can experiment with different values of a given feature without affecting the contribution of the other features to total fitness. Because a change of a given feature by flipping one bit in the bit string affects only that feature's contribution to fitness, which is only approximately *1/N* of the total fitness, the neighboring bit strings have similar levels of fitness and the landscape will be smooth, single-peaked and tall, as in the left-hand picture in Figure 3. As *K* increases, some of the features are coupled with other features, so that the total fitness contribution of one is determined by its own contribution as well as the indirect contribution of the *K* other features. This means that there are constraints and trade-offs in changing any single bit. The effect on the landscape is that it becomes increasingly rugged as *K* increases, with more peaks and lower levels of fitness all around, as in the middle picture in Figure 3. It turns out that, in practical applications, even low levels of *K* are already sufficient to cause ruggedness with all the obstacles it creates for the search of fit design. If *K* reaches very high levels, close to *N-1*, then the landscape becomes so intertwined that it is effectively random, as in the right picture in Figure 3. In random landscapes the flip of a single bit can lead the level of fitness to vary dramatically as a bit string's fitness will be effectively unrelated to that of its close neighbors.

Figure 3. Change in Landscape as *K* Increases[38]



37. *See generally* KAUFFMAN, AT HOME IN THE UNIVERSE, *supra* note 19, at 170–76.

38. Figure modified from Thomas Shafee, Evolvability of a Viral Protease: Experimental Evolution of Catalysis, Robustness and Specificity 12, fig.A-7 (Sept. 2013) (unpublished Ph.D. thesis, University of Cambridge), *available at* https://www.repository.cam.ac.uk/handle/1810/245207.

The key to understanding the fitness landscape's shape, and thus the immense task of finding the best design, is the extent to which the different features that make up the system (in our case, the different sticks in the bundle of rights) are interrelated.

> It is these conflicting constraints that make the landscape rugged and multipeaked. Because so many constrains are in conflict, there is a large number of rather modest compromise solutions rather than an obvious superb solution. There are in other words, many local peaks with very low altitudes. Because landscapes are more rugged, adaptation becomes harder.[39]

This result reflects the typical characteristic of complex adaptive systems that most complex phenomena (such as the evolution of property rights) take place neither at the extreme of fixed equilibria nor at the extreme of chaos, but rather in the "interesting in between," at the edge of chaos. As put by Kauffman, "Real landscapes are neither as simple as the Fujiyama landscapes nor fully random. All organisms—and all kinds of complex systems—evolve on" rugged landscapes.[40]

IV. INTERACTIONS OF STICKS IN THE BUNDLE

Henry Smith, in a critique to the bundle-of-rights metaphor, has made the point that property rights are a complex adaptive system, in which the whole is more than the sum of the parts:

> [T]he bundle theory leads to a fallacy of division. Just as water molecules don't have to be wet for water to be wet, so each stick in the bundle or doctrine of property need not have the desirable features we want the system to have. Wetness is an emergent property of water. So with property.[41]

His critique is that the bundle-of-rights view implicitly assumes that $K=0$, whereas he believes that in actual fact $K > 0$ so that:

> [A]dding or subtracting a stick to the bundle affects the rest of the sticks. In principle the bundle theory could take this into account, but it typically does not. Instead, the metaphor of the bundle of sticks is used to imply precisely the opposite. In a bundle of sticks the sticks do not interact; you can add or subtract them at will, and still you will have a bundle with roughly the same properties. Not so with property: giving the right-to-roam stick to a neighbor or to the public

39. KAUFFMAN, AT HOME IN THE UNIVERSE, *supra* note 19, at 173.

40. *Id.* at 175–76.

41. Henry E. Smith, *Property Is Not Just a Bundle of Rights*, 8 ECON J. WATCH 279, 286 (2011); *see also* Yun-chien Chang & Henry E. Smith, *An Economic Analysis of Civil Versus Common Law Property*, 88 NOTRE DAME L. REV. 1, 21–26 (2012) (arguing property is a structured bundle of relations as opposed to a simpler bundle of independent sticks).

> affects the value of the remaining property, including "sticks" like the ability to grow plants, to eat dinner in peace, etc.[42]

This contrast between smooth landscapes, where $K=0$, and rugged landscapes, where $0>K>N-1$, provides a useful perspective to make sense of the critiques to the Demsetz theory of the evolution of property rights listed earlier. In the Demsetz view, property rights always adjust optimally given the circumstances (relative prices) through more-or-less intentional design, moving from open access to commons to private property with clear directionality. A moment's reflection reveals that such properties are compatible only with a situation where the landscape is smooth and single-peaked, where the search for fit design is simple and controllable. Thus, Demsetz implicitly assumes that the bundles of rights have no epistatic couplings, i.e., $K=0$. Assuredly, there may very well be many cases in which the different features of the bundle are focused and detachable so that the evolution of property rights would be optimal and predictable. But as a general rule it is probably the case that several sticks in the bundle are interconnected, so that the problem of evolving property rights is complex and doomed by its very nature to reach only compromise solutions through often tortuous paths. This fits the description of the evolution of property rights in the United States by Anderson and Hill,[43] as well as that of the United States, Australia, and Brazil by Alston, Harris, and Mueller,[44] all of which experienced significant rent dissipation and suboptimal solutions.

V. COEVOLUTION AND DANCING LANDSCAPES

But there is a further complication. Until now we have assumed that the fitness landscape is fixed, so that a given bundle of rights always produces the same level of fitness. But this is clearly not realistic. As exogenous shocks change relative prices and open up new opportunities, the old bundle of rights might no longer be a good way of organizing property. It is these shocks that drove the changes in the Demsetz model: new demand for beaver pelts led to a strain on the population's carrying capacity that could not be prevented by the old rules. If the fitness of each potential bundle of right changes when a shock occurs, then the fitness landscape dances, with former peaks potentially plunging and what were valleys possibly rising to new heights. When this happens, what was a good design may no longer be able to deal with the new conflicts that arise and a new fitter bundle may or may not evolve. Consider, for example, the disruption brought about to intellectual property by the arrival of the Internet and easy digitalization of content.

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42. Smith, *supra* note 41, at 286.

43. *See generally* Anderson & Hill, *supra* note 1.

44. *See generally* Lee J. Alston, Edwyna Harris & Bernardo Mueller, *The Development of Property Rights on Frontiers: Endowments, Norms and Politics*, 72 J. ECON. HIST. 741 (2012).

In biological systems the landscapes also dance in response to exogenous shocks, such as a giant meteorite, or global warming, but they also do so for endogenous reasons. Because each species can have several predators and prey, as well as a host of symbiotic relationships, the fitness of any given design depends on the designs of these related species. Therefore, when one species undergoes variation to climb in its own landscape, the related species will find that their own landscapes shift, as their current design now yields a different level of fitness. If hawks evolve better eyesight, rabbits will find that their camouflage no longer contributes as much towards their survival and replication as it originally did. The rabbit's landscape moved down for the current design, prompting the species to evolve a new design, say greater speed, which will move it up to a higher peak, while causing the hawk's landscape to shift down. This process of coevolution repeats continuously. At times it can lead to periods of stasis, in a sort of equilibrium where each species has reached an evolutionarily stable strategy ("EES"), which is a refinement of a Nash Equilibrium.[45] But, in other cases, it will lead to chaotic Red Queen Races in which coevolution results in frantic dancing landscapes and continuous change.[46]

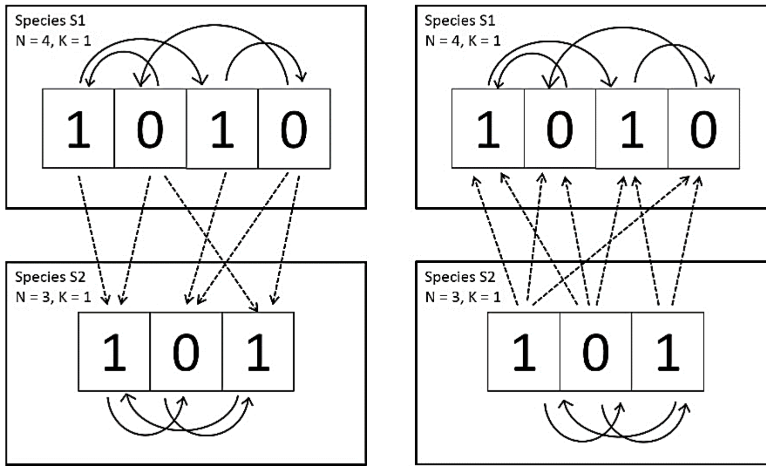
Coevolution is modeled in the *NK* approach by allowing some bits in the bit string of a given species to be coupled to some bits in the bit strings of other species. Thus, besides having *N* bits and *K* internal epistatic couplings within the same bit string, there are now *C* external couplings with other species, and this can be the case for *S* other species. This extension is known as the *NK(C)* Model.[47] Figure 4 shows an example for two species (S=2), the first with $N=4$ and $K=1$, and the second with $N=3$ and $K=1$. Note that each trait in the first species is affected by two traits in the second species and vice versa. Thus, the fitness contribution of the first trait in species 2, for example, is determined by itself, by the third trait in its own string, and by the first two traits in species.

45. *See generally* JOHN MAYNARD SMITH, EVOLUTION AND THE THEORY OF GAMES (1982).

46. Red Queen Races refer to the game played in Lewis Carroll's book, *Through the Looking-Glass and What Alice Found There* where it takes all the running you can do to stay in the same place. LEWIS CARROLL, THROUGH THE LOOKING-GLASS AND WHAT ALICE FOUND THERE (1871).

47. *See generally* KAUFFMAN, AT HOME IN THE UNIVERSE, *supra* note 19, at 224–35.

Figure 4. Coevolution in the *NK(C)* Model: S=2, C=2, N_1=4, K_1=1, N_2=3, K_2=1[48]



Whereas *K* determines the ruggedness of the landscapes, *C* and *S* affect the extent and rate of the dancing of the landscape. The more species that are coupled (higher *S*) and the greater the extent of external epistatis (greater *C*) the more the landscapes will dance, with changes in one bit sending tectonic shifts across all the landscapes thus linked. It is counterintuitive that under coevolution the greater the number of internal couplings *K*, the more static the dynamics of the landscape will be. This is counterintuitive because in the simple *NK* Model, where we considered a single landscape, increases in *K* lead to an increasingly rugged and chaotic landscape, and in the extreme of $K=N-1$, to a random landscape. But in the *NK(C)* Model, the result is inverted. For a given level of *S* and *C*, that is, for a given rate of dancing of the landscape, low values of *K* in a given landscape are associated with chaotic behavior in the form of continual change of the bit string, and high values of *K* lead to stable behavior. To understand this result visualize a simple Mount Fuji landscape that arises when $K=0$. If the landscape starts to dance, with the single peak becoming a single valley, heaving up and down in different regions of the landscape, the species is never able to evolve a good solution. When a peak pops up in a given region of the landscape, the species starts evolving in that direction, but, before the peak is reached, the landscape changes and the peak pops up somewhere else. So the species is always chasing the elusive peak in a chaotic fashion. The peaks are high, but are never reached, so the average fitness of the species is relatively low. When *K* is high, the landscape is random and full of spikes. If

48. Adapted from Richard Vidgen & Julian Padget, *Sendero: An Extended, Agent-Based Implementation of Kauffman's NKCS Model*, J. ARTIFICIAL SOCIETIES & SOC. SIMULATION, Oct. 31, 1999, fig.2, *available at* http://jasss.soc.surrey.ac.uk/12/4/8.html.

the landscape starts dancing, with the spikes stabbing up and down all over the place, the species will not be prompted to evolve very far from where it already is, as there is always a nearby peak. But the peaks are relatively low given all the internal constraints. The evolutionary behavior thus resembles an evolutionary stable strategy. On average the species' fitness will also be relatively low as the random nature of the landscape means that it will be as likely to find itself on a high peak as on a low peak, or any other. It is when $0<K<N-1$ (or better, for relatively low values of K) that the average fitness will be higher. In this situation there is a rugged, but not random landscape, with several rolling peaks. When the landscape dances, the species finds that its previous design is no longer fit and it tries to evolve towards a higher peak. Contrary to the single-peak case, several peaks pop up relatively nearby, such that it can actually reach and climb before the landscape changes again. Thus, the fitness when K is intermediate is on average relatively high. Kauffman describes this result as follows:

> The highest average fitness occurs precisely at the transition from order to chaos. Deep in the ordered regime, fitness peaks are low because of conflicting constraints. Deep in the chaotic regime, fitness peaks are high, but there are too few and move too rapidly to be climbed. The transition regime occurs precisely at that point on the axis where the peaks can just be climbed on the time scale available. Here the peaks are simultaneously the highest possible and still attainable in the time available.[49]

The importance of this result is that it implies that coevolutionary relationships themselves evolve. If there is a combination of *K*, *S*, and *C* that tends to result in higher average fitness, then it must be the case that those sorts of relationships will tend to predominate. Evolution leads to webs of relationships between predators, prey, and other interrelated species that are fitter than other possible relationships given the environment.

VI. COEVOLUTION OF PROPERTY RIGHTS

How can coevolution be understood in the context of the evolution of property rights? In this context, it is not readily apparent what or whom *S* are, the different "species" that coevolve. Given that the notion of a bundle of rights was in part created to allow property to be simultaneously held by multiple parties, it is tempting to think of different holders of the attributes of a given bundle as the participants of the coevolution; actions by one might affect the welfare of the other. But this would not be a proper analogy, for what is being evolved—the unit of selection—are not the owners but rather the property rights themselves; that is, the information contained in that set of instructions of how to act towards the property.

49. KAUFFMAN, AT HOME IN THE UNIVERSE, *supra* note 19, at 230.

Consider instead that in the context where property rights exist there are other laws, rules, and institutions that coexist affecting the same society. Property rights do not exist in a vacuum, but rather in a body of law, and the rights are influenced by a large set of formal and informal institutions that establish the "ground rules" within which the property rights function and play out. Rule of law, such as contract law, codes of conduct, institutions for resolving conflicts, and many others, can all be thought of as evolving units that can similarly be expressed as a set of instructions and consequently be portrayed as having their own fitness landscapes. It is reasonable to assume that the functioning of any bundle of property rights will be influenced by many of these other rules. In other words, property rights not only have internal epistatic links, but also external epistatic links, *C* to *S* other rules, which therefore coevolve with the property rights in an institutional ecosystem.

If this coevolution is in fact taking place, then the main result from the *NK(C)* Model should carry over to the case of property rights. This result would be stated as follows: The evolution of property rights in a context where these rights are embedded in a web or ecosystem of laws and institutions will tend to give rise to property rights that have intermediate levels of interrelatedness among the sticks in the bundle. Because property rights with moderate levels of interrelatedness have higher fitness than either the bundles of independent rights or the bundles of maximally connected rights, we should expect bundles with these characteristics to prevail over time. By giving the means for societies to better deal with conflicts and change, this class of property rights will be replicated and should dominate. The logic of dancing landscapes implies that the property rights we observe are not optimal, in the sense that higher peaks exist and may have been reached at certain points in time. Similarly, in many instances the property rights will be at points of low fitness. But in a context of continuous and unpredictable change, the process through which the bundles adapt and change is perhaps the best that can be done, and is itself quite remarkable.

VII. CONCLUSION

We used fitness landscapes and the classic theory of evolution to suggest that the evolution of property rights is highly complex and contextual. It is not as simple as changing relative prices lead unilaterally to a better set of property rights. It depends on the relationship across the attributes of the property rights along with the belief structure in which they are embedded. The fitness landscapes provide a heuristic for understanding the process through which property rights evolve as a process of search for designs that are better able to mediate the issues and conflicts encountered given the environment and context. This model accounts for the fact that property rights change when shocks affect relative prices, but it also allows for current arrangements getting stuck in suboptimal solutions, which is a feature that seems to characterizes many property rights around the world.

The number of interdependencies between the different sticks in the bundle of rights is the key determinant of the difficulty in changing property rights optimally and the optimality of the available solutions. The model shows that because property rights coevolve with other institutions as well as with technological arrangements, in societies where there are neither too few nor too many interdependencies property rights will tend to replicate more and thus prevail over time.

In this Essay, we have only sketched out theoretically how property rights evolution can be analyzed through the fitness landscape framework. The next step is to test this approach against actual historical events to see if our implications are confirmed; for example, by comparing the evolution of property rights to land in colonial America to the evolution of property rights within the United Kingdom. It is not straightforward how this could be done because there is no obvious way to establish the relevant design space of property rights for measuring the fitness of each bundle. The key is to infer which sticks compose the bundle of rights and associate the bundle within a society to a measure of how well the extant property rights mediate and coordinate the use of resources. Importantly, it is necessary to ascertain the interrelationship among the different sticks in the property rights bundle to each other and to external coevolving institutions and technologies. With suitable measurements or proxies for these variables, the analyst then needs to track the changes in the property rights arrangements over relatively long periods of time to see if they follow the evolutionary process described in the model. Property rights bundles that have moderate amounts of internal and external interdependencies should prevail over time. A successful application of the model involves both depicting the process of spontaneous order through which the initial set of property rights emerges and the evolutionary process of change that follows thereafter.