THE EVOLUTION OF BEHAVIORAL INSTITUTIONAL COMPLEXITY

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Introduction

This essay considers how behavioral economics and institutional economics have coevolved in their development, with understanding their links central to understanding how evolutionary processes within economies dynamically develop. Key to this is that a most important function of economic institutions is to aid humans in overcoming the limits imposed by their bounded rationality. To do this we shall consider the ideas of the respective founders of institutional economics and behavioral economics, Thorstein Veblen and Herbert Simon, both of whom will also be shown to have complex evolutionary views of how the economy operates. Veblen's work was earlier (1898, 1899), however he prefigured Simon's work in many ways, with Simon tying the concept of behavioral economics, a term he coined, with that of bounded rationality, which term he also coined (1947, 1955, 1957).

Veblen not only called for economics to be an *evolutionary science* (1898), but introduced certain ideas that have since proven to be important in understanding the nature of complexity in economics, particularly that of *cumulative causation*, often thought to have been introduced later by either Allyn Young (1928) or Gunnar Myrdal (1957), with the latter making the term widely known among economists, and Nicholas Kaldor (1972) drawing out its negative implications for equilibrium economics (Rosser and Rosser, 2016). Among the various forms of complexity that are relevant to economics, cumulative causation is most obviously tied to *dynamic complexity*, which leads to increasing returns, multiple equilibria, and a variety of bifurcations in economic dynamical systems. However, it can be seen to be connected also to *computational complexity*, as well as *hierarchical complexity* due to Simon (1962).

Simon's formulation of the bounded rationality concept provided the foundation for his later views, and he developed in the context of considering problems of administrative behavior in organizations, with *Administrative Behavior* (1947) being the title of his first book where he first presented the idea, if not the term. It was thinking about the nature of human bounded rationality that led Simon into studying computer science and artificial intelligence, with this then leading into his considering the problems of computational complexity (1969). All of this was evident in his idea of hierarchical complexity, in which evolutionary emergence is a central concept.

An important issue for the matter of how evolutionary theory relates to institutional economics in its early formulation involves Veblen's relations with John R. Commons and Joseph Schumpeter. Veblen developed ideas of Darwinian evolutionary economics in the early 20th century in the United States, while Schumpeter is widely viewed as a strong supporter of an evolutionary approach to economic development, particularly regarding the evolution of technology, even as he criticized institutional economics and the application of biological ideas. Also not widely known, Commons (1924) also supported an evolutionary view, although he had more of a teleological perspective on that than did either Veblen or Schumpeter, both of whom saw no necessary direction to technological evolution and change (Papageorgiou et al, 2013). Dealing with a complexity issue, Schumpeter strongly advocated a discontinuous, or *saltationalist* view of evolution (Schumpeter, 1912; Rosser, 1992), which Veblen agreed with regarding technological change. Regarding institutional evolution Veblen mostly saw it proceeding in a more continuous manner through cumulative causation, thus being somewhat closer to Commons on that matter, even as he argued that it was fundamentally unstable and would experience crises and breakdowns.

An important element of evolutionary processes is the emergence of higher level structures out of lower level and simpler ones. This is closely links with Simon's (1962) view of hierarchical complexity, which also links to his views of bounded rationality. This fits with the issue of multi-level evolution, long controversial in evolutionary theory (Henrich, 2004). Within human systems this becomes tied to cooperation, with Ostrom (1990) developing how such cooperation can arise through particular institutions. This process of emergence is linked to deep concepts of complexity, with Simon (1962) a crucial developer of this line of thought.

The evolution of complex behavioral and institutional dynamics extends to a deeper matter of epistemic issues arising from hierarchical emergence that may show deep links between computational and dynamic complexity (Koppl and Rosser, 2002). Memes involve information structure systems that are understood by computational complexity concepts, with this form of complexity exhibiting levels. Competition between such structures in markets can see the emergence of higher order institutional forms in markets as analyzed by Mirowski (2007) that show ever expanding bounds on rationality as higher levels emerge. Thus we see a deep unification between Veblen's cumulative causation and Simon's bounded rationality as explaining profound forms of evolutionary dynamics.

Forms of Complexity

A discussion regarding the relationship between "complexity" and something else clearly requires some discussion of what is meant by this term, or at least what this observer means by it. Indeed, this is arguably a weasel term, one that has no clearly agreed-on meaning more generally. The MIT engineer, Seth Lloyd, some time ago famously gathered a list of various different meanings, and this list was at least 45 before he stopped bothering with this effort, or at least making it publicly known (Horgan, 1997, p. 303). It may be useful therefore to refer to the broadest possible view of complexity that includes all of these and any others as being *meta-complexity*. The definition of this may simply amount to listing all possible meanings that any have ever claimed should be on the list.

If one seeks general definitions or concepts, something often appears in such general definitions is the idea that somehow something that is complex involves a whole that is "greater than the sum of its parts," as the old cliché puts it. Such an idea can be traced as far back as Aristotle, with many since contributing to it. We shall see below that not all the items on Seth Lloyd's list might agree with this, particular the many that relate to *computational complexity*, arguably the sub-category of complexity with more variations than any other. That those concerned with this sub-category might not have such a view might explain why John von Neumann (1966) did not distinguish complexity from mere *complicatedness*. While some may not wish to make this distinction, many do, with Israel (2005) noting that the two words come from different roots in Latin, *complecti* and *complicare* respectively, the former meaning "to enfold" and the latter "to entangle." Thus, while close and possibly from an identical deeper origin, the former implies some completing in a higher order whereas the latter implies more simply "to confuse" due to the bringing together of many different elements.

In any case, perusing Lloyd's list allows one to lump many of his definitions into higher order sub-categories. Arguably the sub-category with the most items on it can be considered forms of *computational complexity*, with at least as many as 15 of them fitting in this category, possibly more. If there is a linking concept through this set of definitions, it involves ideas of size or length, how long a program is or how many distinct units there are within the object such as bits of information. However, the many variations on this do not map onto each other readily. Nevertheless, many of these definitions have the virtue of being clearly measurable, even if there are many such definitions. Thus, if one gloms onto one of these, one can argue that it may have a stronger claim to being "scientific" due to this specific clarity than some other fuzzier alternatives. Interestingly, among those fuzzier alternatives listed by Lloyd is the *hierarchical complexity* concept introduced by Herbert Simon (1962), which is relevant to several disciplines.

Within economics and arguably several other disciplines the strongest rival to the varieties of computational complexity can be called *dynamic complexity*, although no item called precisely this appears on Lloyd's list, with perhaps the closest being "self-organization" and "complex adaptive systems." More precisely, Day (1994) defined (dynamic) complexity as arising in nonlinear dynamical systems that due to endogenous causes do not asymptotically approach a point, a non-oscillating growth or decline, or two-period oscillation. Thus such a system will exhibit some form of erratic dynamic behavior arising endogenously from within itself, not due to an erratic exogenous driver. Rosser (1999) adopted this definition for his "broad-tent" complexity that is clearly dynamic.

Within this broad-tent form of dynamic complexity one can observe four well-known sub-categories that were identified as being "the four Cs" of *chaoplexity*, according to Horgan (1997, Chapter 11). These were cybernetics, catastrophe theory, chaos, and "small-tent" or agent-based or Santa Fe complexity. Horgan argued that these have all constituted a succession of intellectual fads or bubbles, beginning in the 1950s with Norbert Wiener's cybernetics and moving on successively, with agent-based complexity simply the latest in this succession that was overhyped and then discarded after being shown to be overhyped. However, an alternative view is that these represent an accumulating development of knowledge regarding the nature of nonlinear dynamics, and that students of this development should take Horgan's ridicule and turn it on its head, much as such art movements as Impressionism were originally named critically, only to have them become widely admired. Let the "four Cs" be the focus of a successful ongoing intellectual system.

Norbert Wiener (1948) introduced *cybernetics*, which strongly emphasizes the role of positive and negative feedback mechanisms. Wiener emphasized issues of control, which made cybernetics popular in the Soviet Union and other socialist planned economies long after it had faded from attention in western economies. While Wiener did not emphasize nonlinear dynamics so much, certain close relatives of cybernetics, *general systems theory* (van Bertalanffy, 1950) and *systems dynamics* (Forrester, 1961) did so more clearly, with Forrester particularly emphasizing how nonlinearities in dynamical systems can lead to surprising and "counterintuitive" results. However, the discrediting of cybernetics and its relatives may have come most strongly from the failure of the limits to growth models based on systems dynamics when they forecast disasters that did not happen (Meadows, Meadows, Randers, and Behrens, 1972). Much of the criticism of the cybernetics approaches, which emphasized computer simulations, focused on the excessive levels of aggregation in the models, something that more recent agent-based models are not guilty of, with these arguably representing a new improved revival of the older cybernetics tradition.

Catastrophe theory developed out of broader bifurcation theory, and to the extent that formal catastrophe theory may not be applicable in many situations due to the strong assumptions required for it to be applied, broader bifurcation theory can analyze the same fundamental phenomenon, that of smoothly changing underlying control variables having critical values where values of endogenous state variables may change discontinuously. Formal catastrophe theory, based on Thom (1972), provides generic forms for these bifurcation conditions on equilibrium manifolds according to the number of control and state variables, and Zeeman (1974) provided the first application in economics to the analysis of stock market crashes using the cusp catastrophe model that has two control variables and one state variable. Empirical analysis of such models requires the use of multi-modal statisitical methods (Guastello, 2009). A backlash developed as critics argued that the theory was applied to situations that did not fulfill the strict assumptions necessary for the application, but Rosser (2007) has argued that this backlash was overdone, with many avoiding its use who should not do so.

While *chaos theory* can be traced back at least to Poincaré (1890), it became prominent after the identification of sensitive dependence on initial conditions, aka "the butterfly effect," by the climatologist, Edward Lorenz (1963), probably the most important idea associated with the phenomenon. Applications in economics followed after an important paper by May (1976) that initially suggested some of them. Debates over empirical measurements and problems associated with forecasting have reduced some of the earlier enthusiasm for chaos theory in economics, which probably peaked during the 1980s. However, the fundamental insights derived from it continue to influence economic thinking as well as that in other disciplines.

Coming on the heels of the popularity of chaos theory would be agent-based (or "small tent") dynamic complexity, strongly associated with the Santa Fe Institute. However, its origin is generally traced to the urban segregation model of Schelling (1971), who used a go board rather than a computer to work out the dynamics of a city starting out racially integrated and then segregating with only the slightest of incentives through nearest neighbor effects. Such systems are famous for exhibiting self-organization and do not generally converge on any equilibrium, also showing cross-cutting hierarchical interactions and ongoing evolutionary change (Arthur, Durlauf, and Lane, 1997). Substantial active research in economics using such models is ongoing.

We note that these are only a small subset of the full array of complex dynamics that nonlinear systems can exhibit. Others include *non-chaotic strange attractors* (Lorenz, 1982), *fractal basin boundaries* (Abraham, Gardini, and Mira, 1997), *flare attractors* (Hartmann and Rössler, 1998; Rosser, Ahmed, and Hartmann, 2003)), and more.

A central point that should be clear is that the presence of such dynamic complexities in economic systems greatly complicates the problem for economic agents of forming rational expectations regarding the future path of such systems. In their presence, it becomes highly unlikely that agents can fuflill the conventional assumption of full information and complete rationality in their decisionmaking. Complexity is a foundational source of bounded rationality.

Veblen, Simon, and Complexity

At the time when Thorstein Veblen was writing his most important works when the 19th century was turning into the 20th, there was no clear or general awareness of what we now call *complexity*, even as many ideas we now associate with it had been floating around in various disciplines for many years, especially in mathematics and even somewhat in economics (Rosser, 2009). We have no reason to believe that Veblen was particularly aware of these strands, although evolution itself is now viewed as a complexity process par excellence (Hodgson and Knutsen, (2006), which Veblen would strongly advocate. In any case, central to Veblen's approach to economic evolution was his invocation of the idea of *cumulative causation*, which he was the first to introduce. What is important is to note that cumulative causation can lead to such dynamic complexities through increasing returns, which Veblen recognized as present in industrial technology.

Computational complexity has long been argued that there are levels of this, with linear programs that can be solved in a short time often labeled as not complex, and ones that involve polynomial or non-polynomial time being viewed as higher levels of complexity. Highest of all are problems or programs that cannot be solved, that suffer from a halting problem that leaves them running for an infinite time, the highest order of computational complexity. The greater precision involved in these computational complexity definitions has led some economists to advocate focusing on this sort of complexity in economics (Velupillai, 2000; Axtell, 2005), with Simon's work a great inspiration for this. Like Simon later, Veblen was concerned with information systems and we shall argue that computational complexity may be involved in behavioral institutional evolution.

Finally among the broader categories of complexity that are relevant to economics we have hierarchical complexity, initially formulated by Herbert Simon (1962). This is concerned with decomposability of systems and also ultimately of the emergence of new levels of hierarchy in systems whether through evolutionary or physical processes. We shall argue that indeed this is centrally tied to institutional evolution as emergence of higher levels of institutions (and also organizations) is a key part of the dynamics of institutional evolution.

Herbert Simon and Bounded Rationality

The late Herbert A. Simon is widely considered to be the father of *modern behavioral economics*, at least it was his work to which this phrase was first applied. He was also an early theorist of complexity economics, if not the father per se, and also was one of the founders of the study of artificial intelligence in computer science. Indeed, he was a polymath who published well over 900 academic papers in numerous disciplines, and while he won the Nobel Prize in economics in 1978 for his development of the concept of *bounded rationality*, his PhD was in political science and he was never in a department of economics. We must use the term "modern" before "behavioral economics" because quite a few earlier economists can be seen as focusing on actual human behavior while assuming that people do not behave fully in what we would now call an "economically rational" manner (Smith, 1759; Veblen, 1899).

We must at this point be clear that by "behavioral economics" we are not assuming a view similar to that of "behavioral psychology" of the sort advocated or practiced by Pavlov or B.F. Skinner (1938). The latter does not view studying what is in peoples' minds or consciousness as of any use or interest. All that matters is how they behave, particularly how they respond to respond to repeated stimuli in their behavior. This is more akin to standard neoclassical economics, which also purports to study how people behave with little interest in what is going on inside their heads. The main difference between these two is that conventional economics makes a strong assumption about what is going on inside peoples' heads: that they are rationally maximizing individual utility functions derived from their preferences using full information. In contrast, behavioral economics does not assume that people are fully rational and particularly does not assume that they are fully informed. What is going on inside their heads is important, and such subjects as *happiness economics* (Easterlin, 1974) are legitimate topics for behavioral economics.

In any case, from the beginning of his research with his path-breaking PhD dissertation that came out as a book in 1947, *Administrative Behavior* and on through important articles and books in the 1950s (Simon, 1955, 1957), Simon saw people as being limited in both their knowledge of facts as well as in their ability to compute and solve the difficult problems associated with calculating optimal solutions to problems. They face unavoidable limits to their ability to make fully rational decisions. Thus, people live in a world of *bounded rationality*, and it was this realization that led him into the study of artificial intelligence in computer science as part of his study of how people think in such a world (Simon, 1969).

This led Simon to the concept of *satisficing*. People set targets that they seek to achieve and then do not pursue further efforts to improve situations once these targets have been reached, if they are. Thus a firm will not maximize profits, but its managers will seek to achieve an acceptable level of profits that will keep owners sufficiently happy. This idea of satisficing became the central key to the behavioral study of the firm (Cyert and March, 1963) and entered into the management literature, where it probably became more influential than it was in economics, for quite a long time.

Some economists, notably Stigler (1961), have taken Simon's position and argued that he is actually a supporter of full economic rationality, but only adding another matter to be optimized, namely minimizing the costs of information. People are still optimizing but take account of the costs of information. However, Stigler's argument faces an unavoidable and ineluctable problem: people do not and cannot know what the full costs of information are. In this regard they face a potential problem of infinite regress (Conlisk, 1996). In order to learn the costs of information, they must determine how much time they should spend in this process of learning; they must learn what the costs of learning what the costs of information are. This then leads to the next higher order problem of learning what the costs of learning what the costs of information are, and there is no end to this regress in principle. In the end they must use the sorts of *heuristic* (or "rule of thumb") devices that Simon proposes that people facing bounded rationality must use in order to answer the question. Full rationality is impossible, and the ubiquity of complexity is a central reason why this is the case.

Simon (1076) distinguishes *substantive rationality* from *procedural rationality*. The former is the sort of rationality traditionally assumed by most economists in which people are able to achieve full optimization in their decisionmaking. The latter involves them selecting procedures or methods by which they can "do their best" in a world in which such full optimization is impossible, the heuristics by which they manage in a world of bounded rationality. In this regard it is not the case that Simon views people as being outright irrational or crazy. They have interests and they generally know what those are and they pursue them. However, they are unavoidably bounded in their ability to do so fully, so they must adopt various essentially ad hoc methods to achieve their satisficing goals.

Among these heuristics that Simon advocated for achieving procedural rationality were trial and error, imitation, following authority, unmotivated search, and following hunches. Pingle and Day (1996) used experiments to study the relative effectiveness of each of these, none of which clearly can achieve fully optimal outcomes. Their conclusion was that each of these can be useful for improving decisionmaking, however, none of them is clearly superior to the others. It is advisable for agents to

Imitation and the Instability of Markets

While this list of procedures that can support a boundedly rational pursuit of procedural rationality, a point not clearly made is that excessive focus on one of these rather than others can lead to problems. Clearly following authority can lead to problems when the authority is flawed, as many unfortunate examples in history have shown. Any of these can lead to problems if too intensively followed, but one that has particularly played an unfortunate role in markets is imitation, even though it is a widely used method by many people with a long history of being evolutionarily successful. The problem is particularly acute in asset markets, where imitation can lead to speculative bubbles that destabilize markets and can lead to much broader problems in the economy, as the crisis of 2008 manifestly shows.

A long literature (MacKay, 1852; Baumol, 1957; Zeeman, 1974; Rosser, 1997) has recognized that while agents focusing on long term fundamental values of assets tend to stabilize markets by selling them when their prices exceed these fundamentals and buying when they are below those, agents who chase trends can destabilize markets by buying when prices are rising, thus causing them to rise more, and vice versa. When a rising price trend appears, trend chasers will do better in returns than fundamentalists and imitation of those doing well will lead agents who might have followed stabilizing fundamentalist strategies to follow destabilizing trend chasing strategies, which will tend to push the price further up. And when a bubble finally peaks out and starts to fall, trend chasers can then push the price down more rapidly as they follow each other in a selling panic.

That such a tendency to engage in trend chasing speculation is deeply rooted in the human psyche was initially established by Smith, Suchanek, and Williams (1988), with many subsequent studies supporting this observation. Even in situations with a finite time horizon and a clearly identified payment that establishes the fundamental value of the asset being traded, in experimental markets it has been repeatedly shown that bubbles will appear even in these simplified and clearcut cases. People have a strong tendency to speculate and to follow each other into such destabilizing speculation through imitation. Procedures that can support procedural rationality in a world of bounded rationality can lead to bad outcomes if pursued too vigorously.

We note that such patterns regularly take three different patterns. One is for price to rise to a peak and then to fall sharply after hitting the peak. Another is for price to rise to a peak and then decline in a more gradual way in a reasonably symmetric manner. Finally, we see bubbles rising to a peak, then declining gradually for awhile, finally collapsing in a panic-driven crash. Kindleberger's classic *Manias, Panics, and Crashes* (2001) shows in its Appendix B that of 47 historical speculative bubbles, each of the first two have five examples, while the remainder, the vast majority, follow the final pattern, which requires heterogeneous agents who are not fully rational for it to occur (Rosser, 1997). This shows that complexity is deeply involved in most speculative bubbles.

All of these three patterns described above happened during the runup and beginning of the Great Recession (Rosser, Rosser, and Gallegati, 2012). The first is for oil, which peaked at $147 per barrel in July 2008, the highest nominal price ever observed, and then crashed hard to barely over $30 per barrel in the following November. It seems that commodities are more likely to follow this pattern than other assets (Ahmed, Rosser, and Uppal, 2014).

The second pattern was followed by the housing bubble, which peaked in mid-2006. This sort of pattern historically is often seen with real estate market bubbles. The more gradual decline than in the other patterns, nearly symmetric with the increase, reflects certain behavioral phenomena. People identify very personally and intensely with their homes and as a result tend not to easily accept that their home has declined in value whey they try to sell it during a downturn. As a result they have a tendency to offer prices that are too high and then refuse to lower their prices readily when they fail to sell. The upshot is a more dramatic decline in volume of sales on the downswing compared to the other patterns as people hang on and refuse to lower prices.

The third case was followed by the US stock market as exhibited by the Dow-Jones average, which peaked in October 2007, only then to crash in September 2008. Such patterns seem to be more common in markets for financial assets. Such patterns show heterogeneity of agents with different patterns of imitation, a smarter (or luckier) group that gets out earlier at the peak, followed by a less smart (or less lucky) group that hangs on hoping the price will return to rising, only to panic later en masse for whatever reason.

The Discontinuity Debate in Evolutionary Theory

It was Leibniz who initially coined the phrase *natura non facit saltum*, or, "nature does not take a leap." It would be picked up by Darwin himself who repeated it and applied it to his theory of natural selection, and Marshall would follow Darwin in applying to economics, repeating it in the Prefaces of all eight editions of his *Principles of Economics*. For Darwin (1859, pp. 166-167):

"Natura non facit saltum…Why should not Nature take a leap from structure to structure? On the theory of natural selection we can clearly understand why she should not: for natural selection can only act by taking advantage of slight successive variations; she can never take a leap, but must advance by the shortest and slowest steps."

This was a strong statement for Darwin to make given that he did not understand the underpinnings of how the process of mutation through changes in genes worked, but indeed many evolutionary theorists since Darwin have been impressed by the idea that only minor changes in genes can occur at a time for species to be viable and survive and reproduce, thus setting up at least most evolutionary processes to be slow and gradual as asserted by Darwin. However, until the understanding of genetics was fully integrated into Darwinian theory with the neo-Darwinian synthesis in the 1930s, there was more of an opening for more noticeable discontinuous change in the Lamarckian perspective that allowed for the inheritance of acquired characteristics, and thus more rapid evolutionary change.

After the 1930s the more dramatic reassertion of the possibility for rapid change in the form of *punctuated equilibrium* would come with Eldredge and Gould (1972), whose arguments remain controversial among evolutionary biologists. However, the groundwork for their arguments was laid in the development of the neo-Darwinian synthesis itself during the 1930s, even if it was not clearly recognized at the time. A central part of the neo-Dawinian synthesis, especially as formulated by Fisher (1930), involved focusing on the gene, with natural selection operating at the level of the gene, which contrasted with theories that saw natural selection operating at higher levels on wholes. Changes at the level of a gene must be fairly small to be viable, but a method of studying this through fitness landscapes as introduced by Sewall Wright (1932) opened the door for a broader perspective, one that can be carried over to the study of institutional evolution (Mueller, 2014).

A piece of groundwork always there regarding Wright's fitness landscape framework that opened the door to such saltationalist discontinuities or punctuations was that Wright from the beginning allowed for multiple local optima or equilibria within those landscapes. While he himself did not see a dramatic discontinuities happening at the genetic level, he recognized that rapid environmental changes could shift the landscapes so that a former peak could fairly quickly become a valley with the nearest peak reachable by a gradient might be some distance away, which would imply some rapid evolution, if not necessarily discontinuous in genotype and phenotype.

Regarding the application of these ideas to economic evolution and more specifically institutional evolution, it is generally accepted that while Marshall may have agreed with Leibniz and Darwin that *natura non facit saltum*, Veblen tended to accept the idea that institutional evolution could be discontinuous, or at least that institutional equilibria were not stable and could change suddenly. Thus he declared (Veblen, 1919, p. 242-243):

"Not only is the individual's conduct hedged about and direct by his habitual relations to his fellows in the group, but these relations, being of an institutional character, vary as the institutional scene varies. The wants and desires, the end and the aim, the ways and the means, the amplitude and drift of the individual's conduct are functions of an institutional variable that is of a highly complex and unstable character."

Curiously while Schumpeter strongly supported the idea of discontinuous technological change and used the language of evolution in the context of economic development, he rejected the use of biological analogies in such discussions, declaring that (Schumpeter, 1954, p. 789), "no appeal to biology would be of the slightest use." He dismissed selective mechanisms whether of a Darwinian or Lamarckian sort, using the word "evolution" in a simply developmental way (Hodgson, 1993).

While Wright did not spell it out, a key to the existence of multiple local equilibria in his fitness landscapes is the presence of some sort of increasing returns. This brings in Arthur's (1994) emphasis on increasing returns and its link to the existence of multiple equilibria and dynamic complexity, which carries over to institutional evolution. Minniti (1995) used a variation of the Arthur, Ermoliev, Kaniovski (1987) urn model to show how low and high crime equilibria can arise in a society, with social interactions providing positive feedbacks the key to such an outcome, with potential discontinuities arising as the amount of crime can shift very suddenly from one state to another. Rosser, Rosser, and Ahmed (2003) applied this model informal economies in transition economies, with their also being multiple equilibria as seen by large differences in this variable among the transition economies of

Eastern Europe, with the degree of inequality of income feeding into the determination of where an economy ends up.

Institutions, Organizations, and the Locus of Economic Evolution

If economies are evolutionary systems, then the question of what is the locus of that evolution is important. Hodgson and Knudsen (2006) argue that there are three crucial characteristics involved in truly Darwinian evolution: variability, natural selection, and inheritance. For something to qualify as a locus of evolution it must exhibit all three of these. In biological evolution the gene certainly fulfills all of these: mutation provides random variability, natural selection determines whether an organism containing a gene will survive or not, and genes pass from one organism to another through reproduction if the organism is able to survive and attract mates to effectuate this. Critics of evolutionary economics argue that there is no definitive unit or element in economies that fulfill all three of these, even if many fulfill some of them.

Given the long advocacy by institutionalist followers of Veblen for making economics an evolutionary science, these issues have been central to debates within this area. A focus on organizations has long attracted attention, with this arguably more important to Commons than to Veblen. For Commons, directed or artificial selection was more important than strictly random natural selection, and he noted that Darwin himself spent much time discussing both random natural selection as well as artificial breeding (Commons, 1934, p. 657; Vanberg, 1997). Commons saw organizations as being subject to direction and thus appropriate objects for this sort of directed evolution, which had a goal of general human improvement. In his argument for evolution as the fundamental force in microeconomics, Armen Alchian (1950) emphasized the competition of firms, with the survival of the fittest involving which firms can come closest to maximizing profits, even if they do not know precisely how they are doing so, with firms clearly the locus of evolution.

A criticism of the idea of firms, or more generally organizations, serving as the key locus of evolution in economics is that while they are subject to random variability as they experience shocks from the system, and natural selection clearly operates in their competition with each other, with unprofitable firms failing to survive, the missing piece is that of inheritance. Firms and organizations do not essentially reproduce themselves. All they do is survive, although they may change while doing so. These changes may reflect these evolutionary forces of natural selection, but the inheritance element of their doing so must be operating at some lower level than that of the firm or organization itself.

The leading alternative for serving as the evolutionary meme, an idea due initially to Dawkins (1976), is habits or practices within an organization. While they were not driven to this argument by trying to fit new institutional economics into an evolutionary framework per se, this is how North (1990) and Williamson (2000) define institutions. They are habits or practices, not organizations. This is also what Nelson and Winter (1982) came to in their search for the key to evolutionary economics, although they labeled these memes to be "routines." But prior to any of these and prior to Commons and his emphasis on organizations, Veblen identified habits, including habits of thought, as the central locus of evolution in economic institutions, declaring (Veblen, 1899, pp. 190-191):

> "The situation of today shapes the institutions of tomorrow through a selective, coercive process, by acting upon men's habitual view of things, and so altering or fortifying a point of view or a mental attitude handed down from the past."

Given that as he put it the individual's conduct is "hedged about by his habitual relations with his fellows in the group," with these relations of an "institutional character," it is habits and habitual relations that are at the foundation of the evolution of institutions, even if he sees these institutions as being higher order social structures. It is the habits that are at the foundations, and habits can change, leading to new habits that may be inherited by the individuals and organizations using them.

Emergence and Multi-Level Evolution

Among the ideas most strongly associated with complexity is that of *emergence*, that a higher order entity arises out of a lower level one that is not simply the sum of the parts of the lower level one, that the emergent entity is something qualitatively different. While the idea of a whole being greater than the sum of its parts has been around for a long time, a scientific formalization of it is probably due to J.S. Mill (1843) in his discussions of logic in which he characterized situations where something qualitatively different from its parts appears as representing *heteropathic laws*. His original examples involved chemistry such has how salt appears when one combines sodium with chlorine, with salt not being at all like either of them separately. Lewes (1875) applied the term *emergence* to such phenomena. This led to the "British Emergentist" school of thought that especially in the 1920s (Morgan,1923) would apply this concept to evolution, in particular to such problems as how multi-cellular organisms arose out of uni-cellular ones. It would be applied to how larger social groups would organize themselves to act together out of previously smaller separate groups, an idea clearly important in the evolution of institutions.

In biological evolutionary theory this view fell out of favor in the 1930s with the rise of the neo-Darwinian synthesis, which put the focus on the gene as the locus of evolution, the meme, as Dawkins (1976) labeled it. The idea that natural selection occurred at levels above the gene, at the level of "wholes" or groups, was specifically rejected (Williams, 1966). The obvious counter to this in biological evolution involves the social insects (Wilson, 2012), in which individuals are subordinated to the good of the colony, with the colony becoming the vehicle of evolution. Most attribute the mathematical understanding of how this can arise to the work of Price (1970) and Hamilton (1972). However, in fact, the original formalization of this understanding in terms of within-group versus between group selection was due to Crow (1955).

Let B_w be the within-group genic regression on the fitness value of the trait as defined by Wright (1951); B_b be the between-group genic regression to the fitness value; V_w be the variance among individuals within a group, and V_b be the variance among means across groups. For an *altruistic gene* one would expect B_w to be negative (that the behavior within the group damages the individual), while B_b would be positive (the behavior of the individual helps the group). From this a sufficient condition for the altruistic gene to increase in frequency is given by

$$B_b/(-B_w) > V_w/V_b. \qquad (1)$$

Within biology there it has been widely argued that this condition rarely holds. However, it has also been recognized that it appears to hold for the social insects, and as Wilson (2012) argues, this implies that even though only a minority of species show this characteristic, they end up constituting a huge portion of the animal biomass on the earth (especially if one includes human beings in that calculation).

Indeed, this formulation can be carried over to humans to resolve the problem of cooperation versus cheating within a Prisoner's Dilemma game theoretic context (Henrich, 2004). The specific problem for humans becomes one of recognizing who is a cooperator and who is not within social groups, with successfully doing so being the condition for cooperation and a higher level coordination to come about. Considering in detail how such cooperation can arise in numerous contexts for dealing with common property resources was the central focus of the work of Ostrom (1990). This can more generally be viewed as a condition for the emergence of higher level institutions out of lower level ones, with these ideas further pursued by Sethi and Somanathan (1996) and Rosser and Rosser (2006).

Somewhat parallel to this is a formulation of emergence in biological evolution due to Eigen and Schuster (1979) known as the *hypercycle*, which involves information preservation and transmission, tying this more to computational forms of complexity. They define a "threshold of information information content" which if exceeded for a system will lead to a degeneration of information due to an "error catastrophe." Let *V*m be the number of symbols, $\sigma_m > 1$ be the degree of selective advantage superiority of the "master copy," and q_m be the quality of symbol copying. The threshold is then given by

$$V_m < \ln \sigma_m/(1-q_m). \qquad (2)$$

This can be seen as linked to *self-organization* as initially formulated by Turing (1952) in the form of *morphogenesis*. When such morphogenesis involves emergence at a higher level this become *hypercyclic morphogenesis* (Rosser, 1991, Chap.6), with Radzicki (1990) applying such arguments to the question of the formation of institutions out of underlying chaotic dynamics. Within evolution the emergence of higher hierarchical levels was also the central focus of Simon (1962).

Another strand of emergent evolutionary processes is associated with the neo-Schumpeterian view strongly associated with Nelson and Winter (1982) and their study of what are the key memes in evolutionary economics. They are known for their advocacy of the idea that routines are the key meme that is the locus of such evolutionary developments. Nelson and Winter themselves were less focused on this matter of emergent higher orders that become the locus of evolution, but some of their followers have pursued such ideas. In particular has been the development of the idea of *mesoeconomics* by Dopfer et al (2004), originally due to Ng (1986). This is a level of economics that is intermediate in level between the microeconomics of the firm where the Nelson and Winter processes presumably mostly operate and the fully aggregated level of macroeconomics. The mesoeconomic level is more at the industry or sector level where a meme may have diffused across firms within a sector or even a set of related sectors. Such developments can lead to this being the most important part of the economy from the standpoint of growth and evolutionary development.

In terms of institutional evolution operating at higher levels of emergent structures, a possibly surprising supporter of this view is Austrian economist, Friedrich Hayek. This would appear to be at least partly associated with his open embrace of complexity (Hayek, 1967) and especially in connection with this the concept of emergence, harking openly back to the British emergentists of the 1920s. His opening to this strand of thought came from his early work in psychology that culminated in his *The Sensory Order* (Hayek, 1952). In this work he specifically saw human consciousness as an emergent property arising from the nervous system and the brain (Lewis, 2012). Crucial in his formulating this was the influence of systems theory as developed by Ludwig von Bertalnffy (1950), who in turn was influenced by the *cybernetics* of Norbert Wiener (1948), thought by many to be another early form of dynamic complexity. Lying more deeply behind cybernetics was the development of the "universal system of organizations" or *tektology* of A.A. Bogdanov (1925-29), arguably a form of evolutionary institutional economics stressing emergence.

Indeed, Hayek (1988) in his final work, *The Fatal Conceit*, applied his view of emergent complexity involving evolution in a higher order way, with such emergent institutional structures competing with each other and evolving as wholes competing with each other and surviving or not through a process of systemic natural selection. Some would argue that this embrace of natural selection operating at the level of higher order societal wholes constituted a contradiction with the methodological individualism of the Austrian School, although in fact in this he harked back to evolutionary ideas of the founder of that school, Carl Menger (1923) that like Hayek he developed late in his career.

Hierarchical Complexity and the Question of Emergence

While we can see Herbert Simon's discovery of bounded rationality as an indirect claim to being a "father of complexity," his most direct claim, recognized by Seth Lloyd in his famous list, is his 1962 paper to the American Philosophical Society on "The Architecture of Complexity." In this transdisciplinary essay he deals with everything from organizational hierarchies through evolutionary ones to those involving "chemico-physical systems." He is much concerned with the problem of the decomposability of higher-order systems into lower level ones, noting that productions ones, such as for watchmaking, as well as organizational ones, function better when such decomposability is present, which depends on the stability and functionality of the lower level systems.

However, he recognizes that many such systems involve *near decomposability*, perhaps a hierarchical complexity equivalent of bounded rationality. In most of them there are interactions between the subsystems, with the broader evolution of the system depending on aggregated phenomena. Simon provides the example of a building with many rooms. Temperature in one room can change that in another, even though their temperatures may fail to converge. But the overall temperatures that are involved in these interactions are determined by the aggregate temperature of the entire building.

Simon also deals with what many consider to be the most fundamental issue involving complexity, namely that of emergence. His most serious discussion of the emergence of higher levels of hierarchical structure out of lower levels involves biological evolution, where these issues have long been most intensively discussed. He argues that how these higher levels emerged has not reflected teleological processes but strictly random processes. He also argues that even in closed systems, there need be no change in entropy in the aggregate when subsystems emerge within that system. But he also recognizes that organisms are energetically open systems, so that "there is no way to deduce the direction, much less the rate, of evolution from classical thermodynamic considerations" (Simon, 1962, p. 8). However, it is the development of stable intermediate forms that is the key for the emergence of yet higher forms.

Simon does not cite this older literature, but this issue was central to the British "emergentist" literature that came out of the 19th century to become the dominant discourse in the 1920s regarding the broader story of biological evolution, all embedded within a broader vision fitting this within the emergence of physical and chemical systems from particles through molecules to such higher levels above biological evolution in terms of human consciousness, social systems, and yet higher systems. Simon dealt with this multiplicity of processes without drawing their interconnection as tightly as did these earlier figures. In the 1930s with the *neo-Darwinian synthesis* (Fisher, 1930; Wright, 1931; Haldane, 1932), the emphasis returned to near-continuous Darwinian process of gradual changes arising the level of probabilistic changes arising from mutations at the gene level, with the gene the ultimate focus of natural selection (Dawkins, 1976).

While Simon avoided dealing with this issue of emergence in biological evolution in 1962, when the reductionist neo-Darwinian synthesis was at the highest level of its influence, soon the emergence view would itself re-emerge, based on multi-level evolutionary process (Crow, 1955; Price, 1970; Hamilton, 1972). This would further develop with the study of nonlinear dynamics and complexity in such systems, with such figures as Stuart Kauffman (1993) and James Crutchfield (1993, 2003), who draw on computational models for their depictions of *self-organization* in biological evolutionary systems.

This view remains questioned by many evolutionists (Gould, 2002). While the tradition going through catastrophe theory from D'Arcy Thompson (1917) has long argued for form arising deep structures in organic evolution, critics have argued that such self-organizing processes are ultimately teleological ones that replicate old pre-evolutionary theological perspectives such as Paley's (1802) in which all things are in their place as they should be due to divine will. Others have criticized that such process lack invariance principles (McCauley, 2005). Others coming from more a more computational from such processes (Moore, 1990). There is no easy resolution of this debate, and even those advocating the importance of emergent self-organization recognize the role of natural selection. Thus, Kauffman (1993, p. 644) has stated, "Evolution is not just 'chance caught on a wing.' It is not just a tinkering of the ad hoc, of bricolage, of contraption. It is emergent order honored and honed by selection."

While the mechanisms are not the same, the problems of emergent self-organization apply as well to socio-economic systems. Simon's focus tended to be on organizations and their hierarchies. While he may well have sided with the more traditional neo-Darwinian synthesizers when it came to emergence of higher order structures in biological evolution, the role of human consciousness within human socio-economic systems means that the rules are different there, and the formation of higher order structures can become a matter of conscious will and planning, not mere randomness.

Epistemic Issues and institutional Hierarchic Emergence

So far the form of complexity that has been the main focus of our discussion of institutional evolution has been that of dynamic complexity. However, especially as one considers the issue of the emergence of hierarchies in institutions and organizations out of dynamic evolutionary processes, other forms of complexity become relevant. One is clearly that of hierarchical complexity as discussed by Simon (1962), but Simon was also concerned with problems of computational complexity arising from his study of bounded rationality, which led him to become an important figure in the development of artificial intelligence in computer science (Rosser and Rosser, 2015). Part of the problem in this hierarchical structure of institutions is that there is also a hierarchy of information, but with the possibility of asymmetries of information arising between the different levels of the hierarchy.

The issue of hierarchy also appears within computational complexity in the appearance of different levels of computational complexity, with the apparent gap between those that can be solved in polynomial time versus those in non-polynomial time such as exponential time being a central gap. Highest of all are those that cannot be solved due to a halting problem, which may arise from paradoxical self-referencing (Koppl and Rosser, 2002; Rosser, 2004). Such issues may imply some sort of mechanism to move to a higher level beyond where the problem is posed in order for some sort of solution to be achieved. Whereas most of this kind of discussion is done in terms of the functioning of Turing machines, when this is placed in the world of institutions, problems of the inability of memes to solve problems may well instigate the emergence of a higher level institution to resolve or manage the question at hand.

Indeed in the world of market institutions we have seen the development and emergence of higher order systems initially appearing to resolve problems arising at lower levels. Spot markets led to futures markets, which in turn led to options markets and on to ever higher order derivatives markets, with the higher orders dominating the lower orders. This sort of process has been argued for by Mirowski (2007) in his theory of *markomata*. In this view markets are fundamentally information systems and institutions are ways to manage these systems. They develop these hierarchical structures, but these structures in turn compete with each other in a manner that involves natural selection between them. They change by random mutations, and those that survive pass on their structures to future systems. This theory of markomata becomes a theory of higher order institutional evolution fundamentally based on information systems and their computationally complex hierarchies. In this concept the ideas of dynamic and computational complexity come together as a foundation for a more advanced theory of behavioral institutional evolution.

Conclusions

Central to understanding the complex behavioral institutional evolution is understanding the ideas of the founder of evolutionary institutional economics, Thorstein Veblen and the founder of behavioral economics and hierarchical complexity, Herbert Simon. For Veblen important was his formulation of the concept of cumulative causation, later taken up more prominently by such figures as Young, Myrdal, and Kaldor. This links to modern dynamic complexity theory through increasing returns, which leads to muiltiple equilibria and complex disequilibrium dynamics. Veblen's vision was thoroughly Darwinian in that he did not propose any directed teleological evolution in the way that favored more by fellow institutional economist, John R. Commons.

Arising from Veblen's ideas of institutional evolution is also the possibility of complex emergence of higher orders of institutions based on cooperation, linking to ideas of Herbert Simon, as well as drawing on the theory of multi-level evolution developed by biologists such as Crow, Hamilton, and Price. The existence and competition between hierarchical economic institutions also implies problems of computational complexity, again with no definite direction or outcome a likely result. Evolution itself is a profoundly complex process, and so it is when it happens to economic institutions.

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