Complexity and the History of Economic Though

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The history of thought is a set of patterns that we superimpose on the development of ideas and theories from our current perspective. History is much like a magic eye picture: Change one's perspective and one changes what seems important in history. Thus, our account of the history of economics tells us about ourselves and our current views, as well as about what previously transpired.

Since all patterns do not fit equally well, the pattern view of history does not mean that anything goes; some histories fit the pattern of events better than others. But, inevitably, fitting the pieces of an historical pattern together into a composite whole requires forceful and fast writing on the part of the author, and some gullibility on the part of the reader. What this means is that there will often be three or four lenses that can reasonably be used to look at the history of economics to convey quite different patterns. That is certainly the case for economics.

Most histories of economic thought, mine included (Landreth and Colander, 2002) are written from the perspective of developments in general equilibrium theory being the pinnacle of development. This paper takes a different tack, thus providing an example of this pattern view of history; it considers the history of economic thought from a different perspective than do most contemporary histories of economic thought. Specifically it highlights the contribution of various economists and schools of thought as seen from a complexity view of economics.

I begin by explaining what I mean by a complexity view of economics, and how it differs from what might be called the simplicity view of economics. Then, I discuss the pattern way of looking at history, briefly summarizing the story told in the standard history of thought texts. Having done that I sketch out, in broad outlines, some of the changes that I believe occur in the history of economic thought when one's underlying vision of economics changes from a "structural simplicity" vision to a "complexity" vision.[1] In doing so it briefly considers whether major economists' ratings would rise or fall as our perspective changes. It also briefly discusses two economists who generally do not show up prominently in current history of thought texts, but who would show up prominently in one written from a complexity vision.

Alternative Visions of Economics:

* This paper is adapted from Colander, 2000. For additional discussion of the issues see that book.

[1] Having spent much of my time during the last 20 years writing textbooks, I have learned the importance of simplifications, and have also learned the enormous injustice such simplifications do to the various writers. The ideas of the writers discussed in this paper, and the history of economics it conveys, are much more complex than this paper suggests.

All economists know the economy is complex—very complex. That is one of the reasons why society needs economists—to try to make that complexity somewhat simpler and more understandable. In that endeavor conventional economics has seen itself as a conventional science; it takes complexity and simplifies it by finding a formal structural analytic model—an equation, or set of equations—that fits the data. The model is then tested by comparing the predictions of the model with the empirical data, using formal statistical techniques. These models are generally linear and static, since they are only ones with unique, deterministic solutions. To test the models classical statistical tests are generally used.

To believe that such a model exists before it has been discovered and tested requires a leap of faith; science, at the edge, is necessarily a combination of art and religion. It requires dedicated researchers who are operating on faith until sufficient empirical verification can be achieved so that we will tentatively accept that our understanding embodied in the model has gone beyond faith, and become what we call fact. In many areas, that faith has been borne out; conventional science has numerous successes. In other areas it has been less successful.

Formal models do not develop from a void. The beginnings of science in all areas involve developing informal insights into how some aspect of reality operates. Scientists then begin work on simplifying those informal insights into formal models. All science works on such simplification: The questions in such a simplification process are how to simplify, and whether the simplifications lose important elements of the informal knowledge; they are not about whether to attempt to simplify.

Since formal analytic models compress the data more efficiently than informal models, formal models are preferable as long as they do not lose insights of the informal models which led to them, and which allowed a broader set of explanatory variables and more of a sense of the importance of faith. In most areas where individuals think science has been successful, there has been a general belief that the formal models do not lose insights of the informal model. Where that belief is not generally shared, there is more debate about how successful science has been.

Complexity: Extending the Boundaries of Science

The conventional view of science has been that if one decides that formal structural models lose more insights than they gain, one has decided that science is not relevant to that area. For example, we have no science of love; we rely on our informal understanding. Recently, however, a group of scientists, whom I call complexity scientists, have questioned whether that conventional structural simplification process is the best way of understanding highly complex phenomena. They have suggested that such phenomena might best be approached from an alternative perspective. In doing so they have added a new way in which science might approach complex phenomena.

A number of points should be emphasized about this complexity approach to science. First, those following it are committed to science; they accept structural simplicity whenever it can be achieved. But they argue that there are areas—highly complex phenomena—where structural simplicity cannot be achieved, but where science may nonetheless have something to say.

Second, complexity scientists accept that the purpose of science is simplification. Where they differ from standard scientists is not in the desire for simplification, but in the proposed simplification process. They suggest that for complex systems, a simplification process centered around iterative processes, not structure, may be best. This new approach has come to be called the complexity approach to science. Let me give an example. Say you are trying to understand how ice forms. In conventional science one looks for laws that govern the formation of ice, and, in principle, finds a structural relationship explaining why a molecule changes from a liquid to a solid state. One then expands the analysis from the molecule to the whole. In complexity science, one looks for simple iterative processes that, under certain circumstances, lead to a large-scale transformation of water from a liquid state to a solid state.

A leap of faith that complexity scientists make is that they assume that all complex phenomena are subject to similar forces—that, as complexity increases, transformations take place in which large numbers of interactions all work simultaneously to form a pattern that would otherwise be unpredictable. What should be chaos is actually an ordered pattern. Thus, they study the general development of these patterns, and then apply the results of that general study to specific cases.

The study of complexity is highly mathematical and statistical. Where it differs from what I call conventional science is in the nature of the mathematics and statistics it uses. Instead of trying to find a formal analytical model, with a formal solution for these complex phenomena, complexity theory looks for patterns that develop when non-linear processes are repeated for long periods of time. The mathematics used is non-linear dynamics, and the models generally are open models with no unique deterministic solution. Many solutions are possible; which one is arrived at depends upon initial conditions and the path the model follows. What complexity scientists have shown is that, given certain dynamic relationships, certain patterns can develop, and that sudden changes in these patterns can occur.

The laws of complexity science are statistical probabilistic laws. They refer to large groups of actors and are not reducible to laws of individual actors. Complexity allows that aspects of reality can emerge from chance and the law of large numbers. Even though the individual components of a complex system are chaotic and indeterministic, and the movement of individuals within the body may appear random, the sum of the parts—the whole—can be deterministic. This structural determinism undermines the development of a deductive microfoundation of the aggregate. It means that composites of elements of smaller components are indecomposible, and must be treated as a separate entity and not as the sum of their parts. As complex systems evolve, new patterns can emerge, and these patterns can take on an existence and life of their own.

The complexity approach to science is highly controversial. Some (see especially Horgan 1996) argue that it is ill-defined, and far too grandiose; it is attempting to be a science of everything. These critics object to its attempt to extend the boundaries of science. Others argue that complexity science offers little new, that it is non-empirical, and simply speculative. My view of these criticisms can be understood by classifying all phenomena into three types: (1) those areas for which most people believe that standard science sheds insight, (2) those areas where there is debate about how much insight standard science provides, and (3) those areas where standard science does not tread.

In category (1), where structural simplification has been shown to be useful, such as particle physics or chemistry, for me, there is no debate; these are the realms of standard science. In category (2), within which I classify economics and other social sciences, there is much less scientific agreement about the gains we have achieved from structural simplification; in these fields complexity is challenging the standard approaches to these fields, and the debate is about which simplification process is preferable. Since standard science and scientific methods are being used, complexity science is simply an alternative approach. The critics of complexity science have had little to say about its use in these areas, because, to say anything useful, one would have to compare the success of the complexity approach with the standard approach.

The broad criticism of the complexity approach, such as Horgan's, deal primarily with the third category—the category in which complexity theory is used to analyze areas that conventional science does not touch. Some of the extensive claims that have been made for complexity science—that it will add insight into these areas—have been overdone and too far-reaching; the critics are probably right for these areas. Complexity science is a long way from unlocking the essence of the development of life. But such criticisms are not relevant for the application of complexity to economics since they do not, in any way, undermine the possibility that complexity science can be useful in analyzing the second category, where economics is found.

I have no definitive view on whether what is currently known as the complexity approach is going to succeed or not. I am drawn to it nonetheless because of my belief that, in economics, we have been unsuccessful in following a standard structural simplification approach. To achieve our current structural models we are assuming away too many important aspects of our complex economy. Whether the new work in complexity will eventually improve our knowledge of physical phenomena and the economy remains to be seen, but the vision that underlies the complexity approach seems strong. Regardless of whether it is successful or not, complexity provides a general framework within which to think about complex systems that is quite different than the conventional approach and is worth considering.

Complexity Science and Economics

The history of economics has been a history of methodological fights—the famous *methodenstreit* is one well-known example. One of the major reasons for these fights is that it is not clear where economics fits in as a science; usually on one side of the methodological fight have been those who are arguing that the simplifications being used do not do justice to the field, and on the other side is a group who argue that simplification is absolutely necessary, even if bought at the cost of assumptions that do not fit reality. This fight has often been portrayed as a mathematical approach versus a non-mathematical historical/institutional approach, and that division has been a dividing line between mainstream and heterodox approaches. Complexity changes that; it is highly mathematical, and, as I stated above, accepts the need for simplification. But it argues that the mathematics needed to simplify economics often involves non-linear dynamic models that have no deterministic solution.

In earlier time periods, such a statement would be equivalent to saying that there is no feasible mathematical approach to dealing with economics, but recently that has changed. Developments in computers have made it possible to deal with models that are far more complicated than previously could be dealt with. One can simulate, and through rote computer power, gain insight into models with no analytic solution. Thus computers and simulations are the foundation of the complexity approach.

The use of computers and simulations to gain insight into problems involves an enormous technological change in the way economists do economics. Complexity advocates take the position that such a change is a natural shift to new technology. For them those who are not moving toward solving models with computers are demonstrating Luddite tendencies in an attempt to protect their rents. Thus, complexity advocates find themselves on both sides of the fence in the standard methodological debates; they are agreeing with critics that standard science is lacking, but they favor moving to a new, even more complicated mathematics and statistics than standard economics uses, and are arguing that that ultimately it is mathematics that will provide the formal insights into institutions and history that is needed for economics to be a science.

Let me give an example of how complexity economics differs from standard economics. Say one is trying to understand an interaction between investment and changes in income. Standard economics would develop a simple analytically-solvable model—for instance, the Samuelson multiplier/accelerator model—that has a set of deterministic solutions, and then use that to study a variety of cases. In the complexity approach, one would try hundreds of variations of non-linear models, many with no deterministic solution, which capture the dynamic interactions and rely on the computer to show which model best fits the data. One would, of course, study the general properties of non-linear models, but whether the models have analytic solutions would not be a relevant choice criterion as it is now; the choice criteria would be "fit with the data." Elegance and analtyic solvability of models are de-emphasized.

There are, of course, limits to what we can discover through simulations, and there is much methodological work to be done before the complexity approach becomes one that can be generally used. But the complexity vision is that this is the important work, and that, as computing costs continue to fall, analytic solutions in mathematics will be less and less important. Similarly in econometrics; Monte Carlo and bootstrap methods will replace analytic methods of testing in many cases.

Because the complexity approach involves even more focus on mathematics and statistics than does standard economics, the complexity method may seem even less compatible with many of the heterodox approaches and with the study of the history of thought than is mainstream economics. That, however, is only partly true. Low cost of computing lowers the value of theories. The complexity approach demotes theory to a lower level and replaces it with conjectures and patterns that temporarily fit. Determining whether these patterns are meaningful requires a knowledge of history and of the history of economics. Whereas in standard economics the latest theory includes the best of the past, in complexity economics patterns can fluctuate and a variety of theories will be constantly tested. In complexity economics one is not searching out the truth; one is simply searching for a statistical fit that can be temporarily useful in our understanding of the economy. If these fits become good, then we can develop a law, but, because of the way dynamic equations work, the laws can change, and they can change suddenly. One period may be quite different than the period before, and, instead, be much more related to a much earlier period.

Conventional Histories of Economic Thought

Conventional histories of science are stories of how thinking progressed from informal stories and verbal metaphors that capture aspects of reality to more formal structural models. For example, a standard history of physics might go as follows: Kepler discovered informally that planets follow elliptical orbits around the sun, but did not formalize his understanding. Newton compressed Kepler's understanding of the astronomical data into an inverse square law. Newton's compression was supplemented and extended by Einstein's theory and models which reduced the relationship of energy and mass to $E=mc^2$. Each of these laws and models is an example of structural simplicity. It is formal and reducible into a simple equation or set of equations.

Just as conventional economics follows standard science, so too conventional histories of economic thought tell the story of how economists have formalized Adam Smith's informal understanding of how competition guides people to serve the common good. Most conventional histories agree that economics is not as far along as is physics, but they see the search for a more formal simple structural model as the right one, and present the history of economics accordingly. Thus, they see the formalization of supply and demand; production functions, general equilibrium theory, national income accounting, and the concepts of capital and labor as structural simplifications that have marked progress in economics.

A two-paragraph conventional history of economic thought written for the layperson would go as follows: It all began with Adam Smith's insight of the invisible hand. Classical economics (Ricardo and Mill are usually highlighted) developed that insight, attempting to derive an acceptable theory of value based on all costs, or on labor alone. It failed in that attempt, but in the process developed the seeds of many ideas that were later expanded by NeoClassical economists. NeoClassical economics differs from Classical economics in that it stopped looking for value only on the cost side, and developed a supply/demand theory of value in which both supply and demand considerations together determined value (Marshall and Walras are usually highlighted). Although this supply/demand approach was developed by a variety of economists, Walras' contribution is seen as providing the beginnings of the most general theory--that of general equilibrium.

In the 1930s Keynes developed an alternative macro theory, but by the 1990s that had fallen by the wayside. Modern economics (Hicks and Samuelson are usually highlighted) has developed general equilibrium theory and in 1954 that development reached its apex in the Arrow/Debreu theory of general equilibrium. Since then, general equilibrium theory has been further simplified, and expanded upon. It has incorporated many variations, but it remains the centerpiece of modern economists' understanding of the world. Along the way to this understanding, there have been many side roads followed, (Malthus, Marx, Robinson, Hayek, Veblen, and Keynes are often mentioned briefly) but these are primarily detours; the centerpiece of economic theory is general equilibrium theory.

How one tells the above story depends on the methodological approach one takes to economics. Relativist historians of economic thought, who see economics as reflecting the problems of the time, see little development of a grand theory; they emphasize the side roads, arguing that there is no overall thread of development in thinking. Absolutist historians, sometimes called Whig historians, see economics as conventional science; they tell the story emphasizing the main lines of development and give much less shrift to the side roads. But, within conventional economics, the trunk is still there. It is a story of the search for simplicity in structure as found in general equilibrium theory.

A Complexity Perspective on the History of Economic Thought

The complexity perspective provides a different pattern to be placed on the history of economic thought. It specifically does not accept that the gains from simplicity of structure have been worth the costs in terms of what we have lost in our informal knowledge. It sees an economics that has found a simple structure, but only at the cost of assumptions that make the theory difficult, if not impossible, to relate to empirical reality. Important elements of economic processes--path dependency, increasing returns, multiple equilibria, and technology are downplayed, and the importance of institutional structure is almost lost. The complexity approach to economics is trying to remedy that. It sees the economy as a complex system that follows the same laws as all complex systems. Complexity theory developed spontaneously, in a search for the laws of complex dynamics. The hope is that insight into large complex systems will come from the study of iterative processes involving non-linear dynamics.

The advantage of seeing economics as the result of such iterative processes is that it allows a more direct inclusion of increasing returns and institutions than does the standard approach. Complexity theory differs from conventional theory in that it holds that the complexity of the economy precludes the far-sighted rationality assumed of individuals in conventional theory. If the economy is truly complex, then individuals cannot rationally deal with every part of it, making any model based on full global rationality inconsistent with the complex structure of the model. People will develop institutions to deal with the world, and these institutions will change their behavior. Thus the data reduction program in economics cannot be held together by a general equilibrium system that assumes far-sighted rationality.

Where the complexity approach challenges conventional economics most is in its explanation of macro phenomena. In a highly complex system, the connection between micro and macro that economics has been searching for cannot be discovered. With this view the complexity approach calls into question the entire line of general equilibrium research that is the centerpiece of standard economics.

The complexity interpretation of the history of economic theory is different from the standard heterodox interpretation of the history of thought for a number of reasons. First, the complexity interpretation fits better in the absolutist approach than in the relativist approach that most heterodox economics takes. By that I mean that the complexity approach sees economics as having a grand theory, and sees the purpose of economic science as finding that theory. It differs from the standard histories in that it sees multiple potential patterns of simplification, but it is, in many ways, an absolutist history with a twist. It sees conventional economics as having followed a reasonable, but ultimately wrong, path in its search for simplicity of structure as the central trunk of the story. Instead, it suggests that there is another trunk, which finds simplification in dynamics, not in static structure.

Second, the complexity approach also takes a much more sympathetic view of the earlier development of standard economics than do most heterodox approaches to the history of economics. The reason is that, until recently, the high-powered computers and mathematics to explore the alternative complexity simplification path did not exist, so the complexity approach was not viable. What makes it viable now is the development of computer technology that has so increased our ability to get numerical solutions to complicated non-linear equations, and to see the implications of iterative processes involving non-linear equations, that it changes the way it is reasonable to look for patterns in data. The point is often made with the “12-cent Ferrari” example. Had the same degree of increases in technology occurred in the automobile industry as has occurred in the computer industry, automobiles would be essentially free and a Ferrari would cost 12 cents. That would change our transportation pattern; shouldn’t the change in computer technology also change our research pattern?

Before advances in computers made dealing with more complex systems possible, it was only reasonable to explore the alternative structural simplicity path. Thus, from a complexity perspective many economists may have had a complexity perspective, but they did not follow up on it in their formal work because they did not have the tools to do so. Numerous examples can be given. Consider Joseph Schumpeter’s discussion of multiple equilibria. He writes:

> Multiple equilibria are not necessarily useless, but from the standpoint of any exact science the existence of a uniquely determined equilibrium is, of course, of the utmost importance, even if proof has to be purchased at the price of very restrictive assumptions; without any possibility of proving the existence of (a) uniquely determined equilibrium—or at all events, of a small number of possible equilibria—at however high a level of abstraction, a field of phenomena is really a chaos that is not under analytical control. (1954)

John Hicks had a similar understanding of the problem. He writes that serious consideration of increasing returns could lead to the “wreckage of the greater part of general equilibrium theory.” (1946, p. 84) My point is that many earlier economists understood the implications of complexity, of which increasing returns and multiple equilibria are important elements, but they also recognized that they did not have the tools to deal with it formally, and therefore did not work on such issues. The role of

Kenneth Arrow, one of the economists who made a major contribution to general equilibrium theory, but who also was central in establishing the Santa Fe Institute that has explored complexity within economics, is another example.

Any history of thought told from a complexity perspective must also recognize that while conventional economics used general equilibrium theory as its core organizing feature, much of the development of applied economics was not dependent on general equilibrium theory. Other avenues developed, including much work that considered increasing returns, and much of the complexity work will build on that work. It is not the standard practice of economics, but the formal general equilibrium centerpiece of economics, that complexity challenges.

Conventional Wisdom and Our Intellectual Predecessors

Now that I have given a general discussion of how switching to a complexity perspective changes the way we view economics, let me consider how previous writers fare in the changed perspective. I consider the issue in three separate sections. First, I consider general schools of economics; next I consider some economists who would move up or down in my rankings. Finally, I briefly discuss two individuals who, from our current standpoint, are relegated to footnotes, but who would enter into the panoply from a complexity perspective. I should make it clear that the discussion is a "reporter's treatment" of the field, not a specialist's treatment.

Assessment of Schools of Thought

In the standard history of economics text, the mainstream, or NeoClassical, school is given primary focus, but students are introduced to various other schools including the German historical school, the Austrian school, American Institutionalists, and the radical-Marxian school. The general views of each of these schools is presented, and contrasted with the mainstream development from Classical to NeoClassical to modern.

In a history of thought told from a complexity perspective, the story told about these heterodox schools would be much the same as is currently told, but told a bit more sympathetically. Many of the heterodox objections to standard economics would be presented as precursors of the modern complexity school’s objections: The German historical school opposed the equilibrium method, believing instead that history mattered, and that different periods could be unique; the Institutionalists opposed NeoClassical theory as too simple; Austrians saw the market mechanism as an example of spontaneous order, again providing a precursor to the complexity focus on emergent order; radicals saw that there was more than a single way of looking at the economy.

The above argument deals with the presentation. But the assessment of these heterodox schools of thought would not significantly change. Although one can find many areas where the schools were precursors of complexity work, complexity economics did not develop from these schools. Complexity economics developed out of standard economics, and is best seen as a natural evolution—the economics field responding to the changing technology. The complexity approach shares with standard economics a focus on formal mathematics and maintaining a formal scientific approach.

Most modern institutionalists argue against the use of formal mathematics, radicals replaced a NeoClassical ideological bias with an alternative bias, claiming that bias was inherent in science; Austrians relied on deduction to the almost total exclusion of induction; and the German historical school was anti-formalist in almost all the forms.[2] Thus, in my view, none of these schools would have led to complexity economics. They would have likely led standard economics elsewhere. Thus, from a complexity perspective, these heterodox schools are seen in roughly the same light that they are seen now by sympathetic interpreters--as schools that had some of the important insights, but which were ahead of their time.

Assessment of Individual Economists

While the assessment of schools may not change much, the assessment of individual economists will. The following table provides my fast and dirty overview of selected economists' change in rankings when they are considered within a complexity framework. The discussion below the table gives a brief justification for that assessment.

Economist	**Change in Ranking**
Smith	up
Malthus	neutral
Ricardo	down
Mill	up
Marx	up
Walras	down
Marshall	up
Hayek	up
Keynes	neutral

Adam Smith

Smith goes up in the rankings because of his recognition of the problems of complexity, his emphasis on increasing returns, and his vent for surplus argument, all of which can be seen as leading to ideas that are consistent with the complexity perspective. In the conventional texts Smith is presented as "the father of economics"--the person who codified economic thinking—but he is also presented as a fuzzy thinker whose informal reasoning allowed many inconsistencies. He had a variety of theories of value, a confused presentation of the price level, and unclear policy prescriptions. Later Classical economists had to clarify these. From the complexity perspective, Smith is still inconsistent, but there is good reason for that inconsistency since the mathematical techniques had not yet developed to handle the issues that he recognized were important. His emphasis on vent for surplus, increasing returns, and the need for a broader setting for economics fits well with the complexity vision, as does his unclear policy

[2]The schools did not necessarily start that way, and it can be argued convincingly that early heterodox economists were simply waiting for the right mathematics to come along. But there seems to be a path dependency argument. Arguing against current mathematical approaches attracts followers who oppose math, and thus these heterodox schools did not attract the individuals who developed complexity theory.

prescriptions--the complexity approach to economics does not lead to definitive policy prescriptions.

Thomas Malthus

Malthus stays neutral in the ranking, but it is a neutrality that results from his rising in one dimension and falling in another. He rises because of his work on population; Malthus saw that the interesting issue in understanding economics was in iterative processes. His ideas on population were central in the development of Darwin's ideas, which has a close tie-in with the complexity perspective. He falls in the rankings because the dynamic process that he emphasized was one that focused on diminishing returns. He did not allow for the development of ongoing endogenous growth. He further falls in the ranking because his macro argument that general gluts were possible fails to use any of the insights of complexity, and thus helped reinforce the view that if one approaches the macro economy logically, there can be no unemployment.

David Ricardo

Ricardo is seen in many ways as the hero in the structural simplicity vision; he took Smith's ambiguous ideas and formalized them into economic laws. The standard history of thought emphasizes how his theory of comparative advantage is one of the greatest developments in economics. It is also generally acknowledged that he developed the labor theory of value as far as it could be developed (the 93 percent labor theory) and clarified the argument for trade. With his theory of rent, he was a precursor of the NeoClassical marginal productivity theory.

In part Ricardo falls because, with his current high ranking, there is nowhere to go but down. While his formalization helped make Smith's ideas specific, that same formalization led economists to the focus on structural simplicity, and took away the emphasis found in Smith on increasing returns. Ricardo's search for value within a unique equilibrium system made the theory simpler than it otherwise would have been and directed economic researchers away from taking seriously the complexity of the economy.

John Stuart Mill

Mill is generally presented as the mature Classical economist who had little to add to formal Classical thought. He made a few contributions: He pulled Classical economics towards a humanist mode; he led Classical economics away from the wages fund theory; and he drew a distinction between the social laws of distribution and the technical laws of production. With these insights he moved away from the labor theory of value, but he did not abandon it. In the standard view, he receives high ranking, but not at Ricardo's level. From the complexity perspective, Mill's ranking increases. His focus on social laws of distribution was an important development in recognizing the complexity of the economy. He recognized that social and economic phenomena couldn't be divided. He saw the importance of path dependency in a way that Ricardo did not. His nervous breakdown can be seen as a natural reaction of an individual's trying to fit the complex world into too simple a structure.

Karl Marx

Marx is generally presented as a Classical economist who did not share the mainstream ideological views. He turned the labor theory of value into a theory of exploitation, and, in doing so, showed some deeper problems with it. He focused on increasing returns, the tendency of economies to grow, and how distribution was tied into that growth process.

Marx's ranking improves from a complexity perspective not only because of his formal analysis, but also because of his informal analysis of class, and his emphasis that individuals' rationality is shaped by the social situation around them. His failure to see social relations evolving to maintain stability in the economy still limits his being considered a precursor of complexity economics.

Léon Walras

The standard view of Walras is that he led economics into general equilibrium theory as well as that he developed marginalism. He receives high marks for both. In the complexity perspective, since general equilibrium and marginalism fall in the ranking, it is not surprising that Walras also falls. Walras directed economics into a particular mathematical structure that did not fit.

Alfred Marshall

In the standard history Marshall receives a positive, but subdued, treatment. He played a key role in introducing supply and demand concepts, but he simultaneously failed to formalize theory. Thus he is often accused of following the "zigzag windings of the flowery path of literature," and his work is characterized by Paul Samuelson as having "paralyzed the best brains in the Anglo-Saxon branch of our profession for three decades."[3] In his *Principles of Economics* Marshall struggled with how to include both the Classical focus on dynamics and growth--which called for explicit treatment of increasing returns--and the NeoClassical focus on diminishing marginal returns in the production of goods.

As Marshall typically did when faced with conflicts, he used what might be called "the Marshallian Straddle" to circumvent them. He discussed each but never integrated them. Still, his stature rises somewhat relative to Walras because the reason he refused to formalize was precisely that his perception of the economy was that it was complex, and that the tools were not up to formalizing the insights; he recognized the limitations that Walras did not. He rejected any simple specification of general equilibrium and in Note 21 in *Principles* argued that the true foundation of aggregate economics was to be found in thermodynamics, an idea that clearly places him in the complexity perspective.

Frederick Hayek

[3] See F.Y. Edgeworth (1925), II, p. 282 and Paul A. Samuelson, (1967), p. 109.

Hayek usually receives only a short mention in the standard history of thought, in part because he lived until the 1980s and his work was continually evolving, and, in part, because he did not fit the standard mold. Starting in the 1940s with his publication of *Abuse of Reason* (1940) Hayek's work was evolving outside of the Austrian tradition of Ludwig von Mises. As it did, it better fits a complexity tradition. In his vision, Hayek came very close to the modern definition of complexity; however, he did not conduct any deeper empirical or analytic research into the field of complexity.

Hayek understood the nature of complex phenomena and correctly associated them with the economy. His emphasis on spontaneous organization has complexity written all over it, as does his focus on prices as storing systemic information that individuals did not have and could not compute. In his Nobel address in 1974 he developed the arguments in his earlier work and argues that the reductionist approach of economics, which is mimicking that of the pure sciences, is inapplicable to economics since economics studies phenomena of "essential complexity, i.e. with structures whose characteristic properties can be exhibited only by models made up of relatively large numbers of variables." (Hayek, 1989, p. 4) In the same address Hayek also recognizes that "organized complexity" is dependent on the "manner in which the individual elements are connected with each other" at least as much as the individual properties of the agents in the system. Thus, Hayek, especially, in his later writings, will significantly move up in the rankings.

John Maynard Keynes

Keynes stays neutral in the rankings in large part because he currently gets such high ratings. His questioning of econometrics, his emphasis on the nonergodicity of the economy, and his work on probability all can be seen as a positive from a complexity perspective. But, in policy, he never shied away from the simple static models that were developed to capture his views, and never made clear that his analysis rested on a complexity perspective, even though he had opportunities to do so. Thus, the foundations of his *General Theory* were ambiguous, and, despite many possibilities in which he could have laid its foundations in complexity, he did not do so. His primary interest in policy took him away from theoretical issues, and his willingness to accept standard theory, if it arrived at the policy result he wanted, leave him unchanged in my rankings.

Two Economists who Move from Footnotes to the Main Text

In this final section I consider two economists, Charles Babbage and John von Neumann, who seldom show up prominently in standard histories of economic thought, but who have a significant place in a history told from a complexity perspective. As Nathan Rosenberg (2000) nicely points out, Babbage applied complexity reasoning to the economy as he expanded Smith's ideas to the industrial age. He emphasized nonlinear costs and thought of the economy within a complexity perspective. Had economics focused on his work rather than Ricardo's its history likely would have been quite different.

Unlike Babbage, who is hardly ever mentioned at all in histories of economic thought, John von Neumann frequently gets a short section in history of economics texts for his work on game theory. That work, however, is not what earns the main focus from a complexity perspective. Instead, it is his work on self-replicating systems. That work, which is a precursor to work in artificial intelligence, and is related to the development of the computer, is central in the development of the complexity perspective, and places von Neumann as a pivotal figure in any history of economic thought told from a complexity perspective.

The importance of John von Neumann to economics should come as no surprise. He is already considered by many to be one of the most brilliant minds of the twentieth century. He contributed significantly to numerous branches of science, including mathematics, quantum mechanics, and computer science. In standard economics he is known for his development of game theory, which pushes the analytic approach to economics as far as it can be pushed. But it is not game theory that would be emphasized in a complexity history of thought; it is his work on self-replicating systems, where he developed the logic of what was necessary. Specifically he specified the minimum requirements needed for self-replicating systems in his theory of automata. That theory is an important cornerstone in complexity theory, and is particularly useful in trying to understand and simulate artificial life, which is central for understanding and simulating iterative processes.

An automaton is a general-purpose universal machine which can execute the instructions of any algorithm. There are natural automata, such as the nervous system, and artificial ones, such as computers. Von Neumann argued that, similarly to natural living systems, artificial systems should also be able to reproduce themselves. He imagined a machine floating on the surface of a lake, where a lot of machine parts float as well. Following instructions, the machine—a universal constructor—assembles another machine. It can reproduce itself if it has a blueprint of itself within itself. Reproducing automata are description copiers—they include a blueprint of each machine they construct within it. The "genetic" information of the machine is thus both interpreted as an algorithm to be followed, and as genetic material copied uninterpreted, as a piece of the machine being copied.[4] That work is far from standard economics but it lies at the heart of complexity theory.

Conclusion

This quick and dirty overview of the history of thought is delivered from a complexity perspective. In many ways the most interesting part of the story is its relation to heterodox economics, many of whose practitioners have had something close to a complexity vision. But the complexity approach did not develop from heterodox economics. The line of descent is through standard economics. The complexity approach developed from the standard approach to economics for two reasons. The first is the limitations and problems with the standard approach; it simply did not provide a meaningful model of the aggregate economy. But that failure was not enough to cause the mainstream of economics to abandon the approach, and those who did became known as heterodox economists. What was necessary for the mainstream of economics to consider

[4] It is interesting to note that only later it was discovered that DNA within all natural living organisms has the same dual function, and that natural systems reproduce according to von Neumann's abstract method.

the complexity vision was the second reason, a change in research technology, primarily the computer, which allowed economists to study dynamic systems that previously were beyond analytic study.

The methodology of complexity economics is quite consistent with the methodology of standard economics and, as such, does not fit well with many heterodox traditions. Still, many heterodox economists have had a complexity vision, and thus complexity economics can be seen as a melding of heterodox vision with standard scientific methods, which is only now coming of age.

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