II.A.4. IS GREATER COMPLEXITY A LIMIT TO GROWTH?

Summary

Some authors argue that as economies and societies grow they become more complex, that the marginal costs of coordination grow faster than the marginal benefits, and that at the point where the former exceeds the latter economic growth will cease. Others argue that as societies become more complex they generate emergent levels of organization that within themselves are less complex, and thus enable growth to continue and perhaps even accelerate. Still other authors propose that complexity is a subjective experience related to the pace of technological and social change that accompanies economic growth, and to periods of transition during which new technologies are introduced and old ones abandoned. None of the studies reviewed offered definitions of complexity that allowed it to be measured as a unique independent variable. Thus, testable models of the relation between economic growth and complexity were not available. We conclude that the suggestion that complexity may be a limit to growth is still speculative.

II.A.4 IS GREATER COMPLEXITY A LIMIT TO GROWTH?

Many persons have an intuitive sense that as industrial economies and societies grow they tend to become more complex, and that perhaps they can become so complex that they are no longer able to function. If this is true then complexity would be a limit to growth.[1]

The topic of "complexity" has been controversial. Many authors believe it to be profoundly important. Others are skeptical, even dismissive.[2] Different authors have sought to apply the term in different ways, as shown in **IIA-44**.

In these notes I review studies that suggest a relationship between the degree of complexity in a society and the prospects for continued economic growth.

II.A.4.a. Organized Social Complexity

In the mid-1970's Todd La Porte (1975) and others introduced the topic of social complexity as an important and potentially worrisome feature of modern life. In particular, they were concerned that as institutions became more complex the ability of people to make good decisions might be severely impaired.

According to these authors the degree of social complexity is determined by three factors: the number of system components, the relative differentiation or variety of these components, and the degree of interdependence among these components.

La Porte cites several reasons to believe that there are limits to the complexity of an institution or set of institutions. He cites research suggesting that as the number of system components increases, so do the "requirements of coordination." In turn, this generates "pressures on the system to differentiate." This differentiation may be either horizontal, in which case coordination is achieved through a process of exchange, or vertical, in which case

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[1] In economic terms, one would say that the transaction costs necessary to maintain a given level of output might become so great that no output is available for new investment.

[2] For enthusiasts see Lewin (1992) and Prigogine (1989). For skeptics see Horgan (1995).

BOX IIA-44. DEFINITIONS OF COMPLEXITY
[major source: Seth Lloyd, quoted by J. Horgan in Scientific American, June 1995]

1. **ENTROPY.** complexity equals the entropy, or disorder, of a system, as measured by thermodynamics.
2. **INFORMATION**. Complexity equals the capacity of a system to "surprise," or inform, an observer.
3. **FRACTAL DIMENSION**. The "fuzziness" of a system, the degree of detail it displays at smaller and smaller scales.
4. **EFFECTVE COMPLEXITY**. The degree of "regularity" (rather than randomness) displayed by a system.
5. **HIERARCHICAL COMPLEXITY**. The diversity displayed by the different levels of a hierarchically structured system.
6. **GRAMMATICAL COMPLEXITY.** The degree of universality of the language required to describe a system.
7. **THERMODYNAMIC DEPTH**. The amount of thermodynamic resources required to put a system together from scratch.
8. **TIME COMPUTATIONAL COMPLEXITY**. The time required for a computer to describe a system (or solve a problem).
9. **SPATIAL COMPUTATIONAL COMPLEXITY**. The amount of computer memory required to describe a system.
10. **MUTUAL INFORMATION**. The degree to which one part of a system contains information on, or resembles, other parts.
11. **Herbert Simon:** a complex system is one "made up of a large number of parts that interact in a nonsimple way.

coordination is established authoritatively. At the same time, "the relatively inelastic limit of individual information processing capacity prevents nearly complete interdependence." This is due to limited "channel capacity," a "narrow span of immediate memory," and "limitations of absolute judgment" that all persons share to varying degrees. Further, "the development of highly interdependent organized systems is limited by the degree to which members are aware of their interdependence… As the number of potentially inter-dependent actors increase, this awareness relatively declines."

On this view the ultimate limits to the growth of social institutions appear to be hierarchical limits. Hierarchy is necessary to coordinate increasingly complex social components, but as it grows the "awareness of interdependence" between the lowest and highest levels declines. Beyond some point, once again, the system will not be able to function effectively.

Winner (1977) extends La Porte's presentation and evaluates different arguments in support of the view that the growth of complexity does *not* pose serious problems for modern society. He concludes that these arguments are not strong (see **IIA-45**).

Taylor (1975) differs with much of La Porte's and Winner's analysis. He says that it is not clear that "technological advance," defined as the simple improvement in some performance measure of a technology, necessarily generates more complexity. A new, more efficient widget might be of greater, lesser or the same complexity as the widget it replaces. Taylor says that "technological change," on the other hand, *does* lead to greater complexity. By "technological change" Taylor means the changes that a new technological advance might have on production, decision-making, coordination and other social processes impacted by the new technology. These processes will become more complex because introduction of the new technology causes "a temporary increase in the level and novelty of contingencies" during the time it takes to replace the old technology. After this transition is complete, the conditions that generated this new complexity will no longer be in play. Thus Taylor conceives of complexity as a largely

BOX IIA-45. WINNER'S CRITIQUE

[source: LaPorte 1975]

Winner notes that many analysts, while willing to grant that modern society is in some sense becoming more complex, reject the view that this is necessarily a serious problem. The reasons given for this view include:

1) *technology and systems analysis:* Improved information technologies and advanced techniques for anticipating and formulating responses to potential problems will allow us to manage complexity.

2) *ecological thinking:* Ecological systems are far more complex than any human system; indeed they include human systems as a subsystem. We can learn from the study of ecological processes how to mange complexity effectively.

3) *redundancy:* The growth of inefficiency, overlap and redundancy in complex social institutions is in fact part of the solution, not the problem. If one component of a system fails others are in place to fill the gap.

4) *incrementalism:* The rational/comprehensive model of decision-making becomes unworkable at levels of complexity even far less than those of most social institutions today. In truth, decisions are made incrementally, which generate only small advances and small damages. But over time we learn from both of these, and thus the general trajectory is one of improvement.

5) *organicism:* living systems are the most complex systems known, and there is no evidence that more complex systems are any less successful than less complex ones. In fact, complexity might support rather than impede further growth. Growth may entail problems to worry about, but "complexity" is not one of them.

Winner responds by noting that while improved information technologies, systems analysis and ecological thinking can all assist us in gathering more information that might bear on social decisions, in the final analysis the decision itself is normatively grounded He notes that while redundancy might help prevent system failure, this hardly addresses the concerns of those whose are most worried about the consequences of the continued *success* of the system. Winner says that incrementalism reduces to the assertion that "complex things cause less of a problem when they are not changing," but that this view ignores precisely the problem at hand, which is that technology is indeed changing, very rapidly, and is having major impacts. Finally, Winner says that organicism is a metaphor, not an analysis, and serves largely as a rationale for quietism.

subjective experience, rather than as a property inherent in a technology. He goes on to note that if technological advance is an ongoing process, the subjective experience will be that “complexity is increasing.” In effect, Taylor identifies the main source of unease as speed: if new technologies are introduced too rapidly, then complexity will be high and could cause problems. But if the same set of technological advances are introduced at some slower pace, adaptation can occur in a way that does not tax individual or social constraints.

II.A.4.b. The Collapse of Complex Societies

In *The Collapse of Complex Societies* (1988) Tainter argues that “complex societies collapse when the marginal costs of complexity exceed their marginal benefits.” He supports this view with detailed analyses of the collapse of about two dozen complex societies. These include the Western Chou Empire, the Egyptian Old Kingdom, the Harappan Civilization, the Hittite Empire, the Eastern Woodlands, the Western Roman Empire, the Olmec, and the lowland Maya.

Tainter does not offer a definition of complexity but says that it

> “…is generally understood to refer to such things as the size of a society, the number and distinctiveness of its parts, the variety of specialized social roles that it incorporates, the number of distinct social personalities present, and the variety of mechanisms for organizing these into a coherent, functioning whole.” (p 23)

He states that complexity arises as a positive response to stresses between groups, and serves to maintain or expand their joint products. He notes that social stratification is a necessary feature of complex societies. He defines collapse as a process whereby a complex society undergoes a significant reduction in differentiation and stratification.

Tainter proposes that “investment in sociopolitical complexity as a problem-solving response often reaches a point of declining marginal returns.” He offers detailed historical accounts of particular societies showing how the costs of various activities necessary to maintain a high level of social organization increased in the periods prior to their collapse. In the case of the Mayan civilization that prospered between the 4th and 8th centuries AD, Tainter records an increase in “vast hydraulic and agricultural engineering…massive public works, and military competition" just prior to the beginning of its sharp collapse in 790 AD. Similarly, he notes that in the late Western Roman Empire

> "…the combined factors of increased costliness of conquest, and increased difficulty of administration with distance from the capital, effectively required that at some point a policy of expansion must end…By the time of the Principate the marginal return on investment in empire had declined considerably…When the stresses impinging on the Empire grew, it would decline further still. " (p 150)

Tainter considers the prospects for modern societies. He offers a detailed account of resource depletion in the industrialized countries, and states but does not examine further his belief that the returns to technological innovation are declining. He suggests that the marginal costs of information processing and sociopolitical control are increasing. He offers as evidence the facts that that the number of bureaucrats in the British Admiralty has increased while the number of sailors declined, that crime in America is increasing even though public spending on crime prevention is growing, and similar anecdotal items.

Despite these indications that complexity in the industrial world is approaching the level at which its net marginal benefits are zero, Tainter states that collapse is unlikely, perhaps impossible. The reason given is that there is no alternative condition into which an industrial economy can easily "fall." In pre-industrial times complex societies were surrounded by more simple societies. When they collapsed their lower-level social components could continue as part of a looser network of adjacent simple societies. If a modern society were in danger of collapsing, its component parts—cities, communities, occupational groups, families—would integrate into nearby complex societies, by choice or by force. Tainter concludes that the world faces a paradoxical future: the increasing costs of complexity mean that economic growth will slow to a crawl, but the inability of the system to collapse means that we just might be able to hold out long enough until some unexpected technological breakthrough once more allows a positive rate of economic growth.

II.A.4.c. Structural Complexity and the U.S. Economy

Pryor (1996) contends that social and economic life in the United States has become more complex in recent decades and that complexity serves to impede economic growth. He focuses on *structural* complexity, which he defines as the complexity of a *system* at a point in time.[3] He says that an increase in structural complexity can be understood in terms of three main characteristics: an increase in the direct information required for that system to function; more elaborate interactions or internal configurations; and greater differentiation or heterogeneity of units. Pryor suggests that such aspects of complexity can be measured by use of the Theil coefficient (H), defined as

$$H = \Sigma p_i \ln (1/p_i)$$

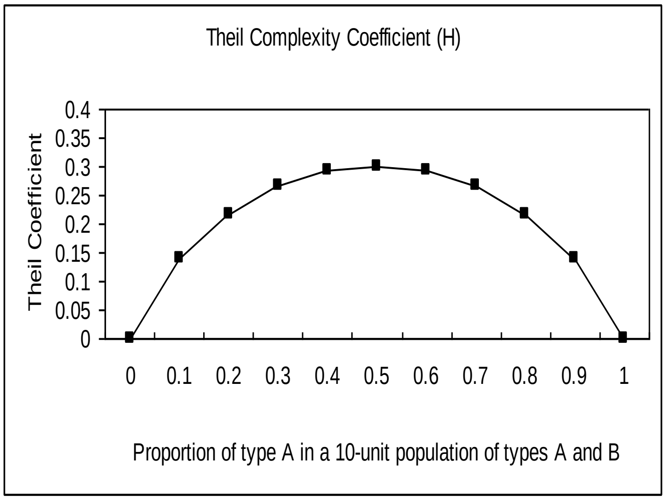
where p_i is the proportion represented by type i of a total population N, i (1... N). The complexity of a system as measured by the Theil coefficient peaks at a point between the extremes of total uniformity ($p_i = 0$) and total randomness ($p_i = 1/N$), both of which have zero complexity. The Theil Coefficient is explained in more detail in **IIA-46.**

Pryor computes Theil coefficients for a large number of social and economic time series, including age, race, religion, family structure, education, wealth and income distribution, occupational categories, and others (see **IIA-47**). He concludes that "structural complexity—the information required for the economic system to function—is generally increasing."

Pryor prepares a detailed spread sheet model of the economy of the United States for the period through 2050. The model shows that economic growth is expected to decline from a rate of 1.5%/yr in the 1990's to 1.29% for the period 2030-2050. Pryor interprets this slower growth as the impact of greater complexity. However, a closer review shows that complexity itself (i.e., the Theil Coefficient) is not a variable of the model. Rather, the trajectory of growth is generated

[3] Pryor distinguishes structural complexity from *behavioral* or *dynamic* complexity, which refer to the self-organizing properties of some systems, and *subjective* complexity, which refers to the experience of a participant in a system.

BOX IIA-46. The Theil Complexity Coefficient



Discussion:

The Theil Coefficient (H) is a commonly used measure of complexity. The standard form is:

$$H = \sum_{i=1}^{N} p_i \ln\left[\frac{1}{p_i}\right]$$

Where p_i is the proportion of component I in the population of N units. A simple example of the behavior of the Theil Coefficient is shown in the diagram above. A population of 10 units has 2 components, A and B. If all 10 units are B, the system is not complex at all (H = 0), but as the proportion of A components increases, so does complexity. Maximum complexity is reached when $p_A = p_B$ (H = 2.7). But as the proportion of A continues to increases, complexity decreases, to the point where when all 10 units are A, H = 0 once more. A greater diversity of components (say, A, B and C), with varying proportions, will show different levels of complexity. Complexity also increases as N increases, even when the diversity and proportions of components remains constant.

BOX IIA-47. Relative Theil Coefficients of US Social & Economic Variables over Time [source: Pryor, 1996]

year	age	religion	education	household type	total wage/salary inequality	male wage/salary inequality	employment structure
1950	0.939	0.54	0.926				
1958							0.113
1960	0.940	0.55	0.912	0.764			
1967					0.337	0.248	0.114
1970	0.945	0.53	0.870	0.787	0.358	0.286	
1977					0.360	0.282	0.113
1980	0.950	0.55	0.823	0.855	0.347	0.276	
1987					0.372	0.325	0.118
1988				0.880			
1990	0.955	0.52	0.795				
2010	0.963						
2030	0.973						
2050	0.981						

Discussion:

The Relative Theil Coefficient is the ratio between the absolute Theil Coefficient of a distribution (see Box IIA-46) and the maximum Theil Coefficient possible for that population, given its size and number of components. The closer a Relative Theil Coefficient is to one, the closer it is to a completely uniform distribution of values among the components of that population. A population of 10 persons, each 30 years old, would have a Relative Theil Coefficient of one.

Example: The distributions used by Pryor to calculate the Relative Theil Coefficient for household type in 1960 and 1988 was as follows:

	Proportions of all households: 1960	1988
married couples w/ children < 18:	.442	.270
married couples w/o children < 18:	.303	.299
other family types children:	.044	.080
other family types without children:	.064	.066
living alone:	.130	.241
other non-family households:	.017	.044

When these values are plugged into the formula for the Theil Coefficient they produce the values of 1.369 for 1960 and 1.577 for 1988. The value of the Theil Coefficient for a completely uniform distribution of 6 components (ie., where the proportion of each component is .1667) is 1.792. Thus the Relative Theil Coefficients are .764 and .880, as shown in the table.

Pryor's calculations show that complexity has increased for all the variables shown except religion and education. However, the extent of increase varies considerably, and the interpretation and significance is unclear.

by such factors as an increase in the proportion of aged persons, increasing inequality of income and wealth, a bottleneck in the supply of technological skills, the shift of labor into the service sector, and higher taxes. It is not clear that the concept of "complexity" makes any independent substantive contribution to the analysis.

II.A.4.d. The Santa Fe Institute

Kauffman (1995) and his colleagues at the Santa Fe Institute (Cowen et al 1994) have sought to establish the study of complexity as an important scientific and intellectual discipline. Their many explorations of this topic are too diverse to try to summarize here, but several themes appear repeatedly in their work. These include:

* Many important phenomena in the world can be understood as *complex adaptive systems*. Examples include pre-biotic chemical reactions, living organisms, nervous systems, ecosystems, the biosphere, languages, economies, societies and perhaps galaxies. These systems, despite their obvious differences, have common features that explain their growth and development over time.

* Among these features is the fact that upon reaching threshold levels of complexity, systems will spontaneously generate new levels of order. This typically means new levels of organization (hierarchy) that can mediate and coordinate exchange between sub-units. This new level of organization is once more "simple." But if more units, more interrelationships, or greater differentiation occurs, additional levels of organization will arise.

* The "region" of complexity in which this new order is generated is in fact the region of *maximum* complexity. As we saw with the Theil Coefficient, this happens at some point between the poles of complete randomness, on the one hand, and the pole of complete order, on the other.

* There may be many possible configurations for any given level of organization. It may be impossible to predict which of these will be realized at the moment that a new level is generated. Thus, the characteristics of each level are emergent and novel, rather than determined.

* Since the region of maximum complexity is most likely to give rise to new and novel configurations that help it (the system) remain intact, it will be more likely to "survive" under stressful, or competitive, situations. Thus a process of evolution may "drive" systems to situate near their points of maximum complexity.

The story told by the Santa Fe theorists concerning economic growth differs dramatically from that told by La Porte, Winner, Trainer and Pryor. According to Kauffman complexity encourages rather than impairs economic growth. This happens because technological innovation, in both the process and product domains, creates new "niches" that contain opportunities for even more innovation.[4] Kauffman constructs models of innovation in which the diversity of innovation resources, and the number of different ways in which they can combine, define an innovation space containing a "sub-critical" and a "supra-critical" region separated by a "phase transition." Above this phase transition technological innovation, and thus economic growth, becomes self-sustaining. In general, the Santa Fe theorists tend to be enthusiastic about the prospects for free-markets, entrepreneurial initiatives, and capitalist institutions.

II.A.4.e Assessment

The efforts by Tainter and Pryor to identify "complexity" as an independent variable whose increase over time can explain, respectively, the collapse of pre-industrial societies and the post-1970 slowdown of economic growth in the industrial countries, are not convincing. The quantitative analysis that supports this effort is either non-existent (Tainter) or weak (Pryor). It is not clear that the concept of "complexity" helps us understand social and economic behavior in ways that previously resisted analysis.[5]

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[4] This model is described in Section II.A.3.b and illustrated in Box IIA-30.

[5] See Yoffee et al. (1988) for an in-depth analysis of civilization collapse using more the conventional approaches of history and the social sciences.

From the 1970's to the present La Porte has done important work concerning decision-making in large, complex institutions, but his earlier, more ambitious suggestion that complexity might prove to be a useful category of far more general application has not been pursued.

Much of the work of the Santa Fe scholars is too technical for me to assess. Many critics, including friendly ones, believe their treatment of complexity offers useful metaphors but poor models.[6] Much of their discussion of social and political phenomena strikes me as naïve.

Is it obvious that technological innovation and economic growth necessarily generate greater complexity? The contrary story can also be told. In the course of economic growth regional cultures and dialects tend to diminish. In the United States agricultural produce is more uniform today--in size, color, and quality--than it was decades ago. The diversity of diseases has been reduced. It might be argued that the most profound thrust of technological innovation and economic growth is precisely to *reduce* the complexity of the world and make it more uniform, stable and predictable. Indeed, one of the themes of certain environmentalist critiques of industrial civilization is that it destroys the natural complexity, interdependence and richness of the biosphere and imposes thereon a numbing uniformity.

In retrospect it appears that some of Taylor's cautions may have been well considered. What we call "complexity" may be largely a subjective experience that occurs when unfamiliar circumstances impose themselves. In response we take steps to either adapt to or change these circumstances. To a large extend we've found that complexity can be embodied in our technologies and facilitate, rather than obstruct, effective human use of them.

The intuition that *something* is happening that might be described as an increase in complexity is widespread, and the topic deserves continued attention. But to date the attempts to characterize complexity, and to demonstrate that it is a constraint on economic growth, are unsatisfying.

[6] See the extended discussion on this point in Cowan et al. (1994)