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Methods

Quantifying economic sustainability: Implications for free-enterprise theory, policy and practice

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ABSTRACT

In a previous paper (Ulanowicz, Goerner, Lietaer, and Gomez, 2009), we combined thermodynamic, network, and information theoretic measures with research on real-life ecosystems to create a generalized, quantitative measure of sustainability for any complex, matter/energy flow system. The current paper explores how this metric and its related concepts can be used to provide a new narrative for long-term economic health and sustainability. Based on a system's ability to maintain a crucial balance between two equally essential, but complementary factors, resilience and efficiency, this generic explanation of the network structure needed to maintain long-term robustness provides the missing theoretical explanation for what constitutes healthy development and the mathematical means to differentiate it quantitatively from mere growth. Matching long-standing observations of sustainable vitality in natural ecosystems and living organisms, the result is a much clearer, more accurate understanding of the conditions needed for free-enterprise networks to produce the kind of sustainable vitality everyone desires, one which enhances and reliably maintains the health and well-being of all levels of global civilization as well as the planet.

1. Creating a sustainable economy: a new empirical narrative

The trickledown narrative of economic health appears to be collapsing. In his October 23rd testimony to Congress, even Alan Greenspan admitted that the banking crisis which broke in September, 2008 had demolished his confidence in the reigning neoliberal orthodoxy and opened a vacuum in economic policy direction worldwide. The lead story of the October 11, 2008 issue of *The Economist* summed up the impact: “With a flawed diagnosis of the causes of the crisis, it is hardly surprising that many policymakers have failed to understand its progression.”[1]

It is our hope that the new ability to define and measure healthy development in complex flow systems, hereafter called Quantitative Economic Development (QED), can help provide a solid empirical/mathematical basis for the more accurate diagnosis of how to build and maintain economic vitality being advanced by a wide array of activists, from micro-credit banker Mohammed Yunus to *Natural Capitalism* economist Paul Hawkins. The result is both greater validation for the Triple Bottom Line (Elkington, 1998) approach to building social, economic and environmental health in tandem, and a rediscovery of Adam Smith's original vision of free-enterprise networks backed by a new clarity on the critical conditions needed to keep them strong.

QED's support for Triple Bottom Line thinking and Smith's original vision comes from an assessment of long-term economic vitality that rests entirely on the health of the multi-scale business networks and human capital that make up the real economy. This structural approach to economic sustainability adds mathematical precision to Daly's (1997) contention that one of today's key problems is that current theory fails to differentiate healthy development from mere growth in GDP monetary exchange volume. It also helps explain where neoliberalism went wrong.

2. QED's approach to quantifying sustainable economic development

The basic idea behind QED is that the same laws of growth and development apply both to natural flow systems and economic ones. This notion rests on a thermodynamic hypothesis with long historical roots in ecological economics,[2] namely, that similar energy concepts and network analysis methods can be applied to all matter–energy–information flow systems because, as Systems Science has long observed and Prigogine's

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[1] *The Economist*, October 11, 2008, pg. 13.

[2] Odum (1971), Hannon (1973), and Costanza (1981), for example, have all used energy theory as the basis for understanding economic operation. Georgescu-Roegen (1971) used it to create a thermodynamic theory of economics while Daly (1973) used it to urge a steady-state view and a focus on the socio-economic infrastructure needed to undergird structurally stable growth (Daly, 1997). In fact, according to Kenneth Boulding (1981), many early economists held energy views, until those who favored Newtonian mechanics channeled economics towards today's familiar mechanics of rational actors and the reliable self-restraint of General Equilibrium Theory, which now dominate the academic literature as well as the boardrooms and political venues of the world.

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(1967) work in Self-organizing Systems confirms, such systems exhibit strong parallels in behavioral patterns and developmental dynamics.

QED's assessment of sustainable development grows out of energy flow's natural connection to network structure. Ecologists, for example, have long known that an ecosystem's ability to maintain its own vitality over long periods—that is, its "sustainability"—depends largely on the layout and magnitudes of the trophic pathways by which energy, information and resources are circulated. As early as 1951, Leontief showed that economic structure can be effectively modeled as a similar flow-map (input–output map) of goods, services, money or value circulating across a network of businesses (Leontief, 1951). QED's measures, therefore, are based on the layout and magnitudes of flows (T) from any node i to node j (T_{ij}), where flows can represent biomass going from prey i to predator j (see Fig. 2), or money or materials going from business sector i to sector j or from country i to country j. This approach adds a structural specificity lacking in earlier thermodynamic measures such as emergy (Odum, 1996) and exergy (Dincer and Cengel, 2001) which look at the level of free energy embodied in the organization, not how the organization's structure must be laid out for optimal longevity and work.[3]

The long-term maintenance of vitality appears to rest heavily on two structure-related attributes: 1) *efficiency*: the network's capacity to perform in a sufficiently organized and efficient manner as to maintain its integrity over time (May, 1972); and, 2) *resilience*: its reserve of flexible fall-back positions and diversity of actions that can be used to meet the exigencies of novel disturbances and the novelty needed for on-going development and evolution (Holling, 1973, 1986; Walker et al., 2006).

Both resilience and efficiency are related to the levels of diversity and connectivity found in the network, but in opposite directions. A well-woven multiplicity of connections and diversity plays a positive role in resilience, for example, because additional options help the system rebound from the loss or disruption of one or more pathways or nodes. Yet, flow systems also require efficient end-to-end circulation of products in order to properly catalyze crucial processes at all levels of the whole. Redundant pathways and excess diversity hinder such throughput efficiency, leading to stagnation that erodes vitality by dissipating weak throughput via various inefficient sectors. In short, resilience and efficiency are essentially complementary because the streamlining that increases efficiency automatically reduces resilience. In general, greater efficiency means less resilience, and, conversely, greater resilience means less efficiency.

This inherent push–pull tradeoff explains why, after a certain point, increasing a system's efficiency makes it more brittle even as it grows bigger and more directed. Conversely, while increasing diversity and connectivity makes the system technically more resilient, beyond a certain point the loss of efficiency also makes it more stagnant. The upshot is that systems become *un*sustainable whenever they have either too much or too little diversity/connectivity (or too much or too little efficiency).

Since resilience and efficiency are both necessary, but pull in opposite directions, nature tends to favor those systems that achieve an optimal mix of the two. Furthermore, a system's balance of efficiency and resilience can be calculated via its configuration of diversity and connectivity. This allows the system's sustainability to be captured in a single metric that establishes its place in the continuum from brittle (insufficiently diverse) to stagnant (insufficiently efficient).

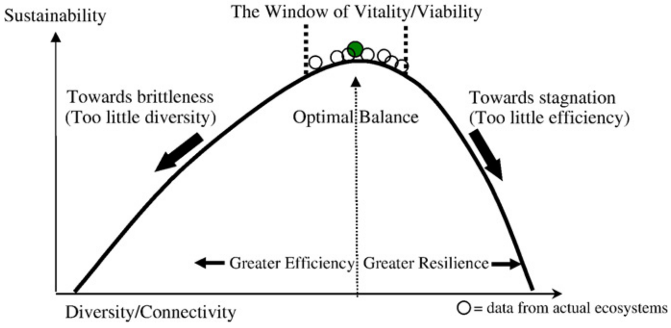

Fig. 1. Sustainability as a function of efficiency and resilience.

Consequently, in our previous paper (Ulanowicz et al., 2009), we argued that flow-network sustainability can reasonably be defined as *the optimal balance of efficiency and resilience* as determined by nature[4] and measured by system structure. The underlying mathematics are sufficiently well-behaved that there exists only a single maximum for any given network system, as shown in Fig. 1. Interestingly enough, since optimal sustainability is situated slightly toward the resilience side, the resulting asymmetry suggests that resilience plays a greater role in optimal sustainability than does efficiency.

Data from natural ecosystems appear to confirm the mathematics of this Sustainability measure in that they match Zorach and Ulanowicz's (2003) Window of Vitality, a narrow range of health situated around peak Sustainability that delimits long-term viability in natural systems. These data, however, are not sufficient to determine the exact optimum of Sustainability (Ulanowicz, 1997).

Readers desiring a full technical and mathematical derivation this single metric of Sustainability are referred to our earlier paper. The next section explores some of its practical implications for economic health.

3. Tradeoffs among resilience, efficiency, size and long-term health

Much as Daly (1997) argued in economics, theoretical ecologist Ulanowicz (1980) has observed that a flow system's long-term sustainability depends on a judicious balance of size and internal structure (development). In ecosystems as in economies, size is generally measured as the total volume of system throughput: Total System Throughput (TST) in ecosystems and Gross Domestic Product (GDP) in economies. Both GDP and TST are poor measures of sustainability, however, because they measure volume, while ignoring the network structure needed to process resources and circulate energy to all parts of the whole. This leaves them unable to distinguish between growth and development or between a bubble economy and a resilient one.

Since sustainable development requires a balance of efficiency and resilience, Ulanowicz (1980) used configurations of flow pathways and magnitudes in natural ecosystems to develop a measure of network efficiency called the Systemic Efficiency (SE or E), which gauges overall system performance as well as its ability to pull more and more energy into its sway, while reducing extraneous diversity/connectivity.[5] Ulanowicz and Norden (1990) also used network characteristics to create a measure of resilience, called Resilience Capacity (RC or R), that takes into account the system's average

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[3] It has been suggested (Christensen, 1994) that exergy or emergy could serve as alternative mediums to quantify each flow, such that one retains the flow structure in the consequent measure. Those who suggest this (Brown, 2005) feel that it would improve upon Ascendency calculated using conventional energy or carbon. This proposition, while intriguing, remains to be seen since it has not been correlated with actual organizational longevity as QED's measure of Sustainability has in ecosystems.

[4] Presumably, the balance found in nature also reflects underlying physical laws of structural stability and optimal flow, such as those seen in power laws and fractal development.

[5] Systemic Efficiency, called Ascendency in earlier literature, is defined mathematically as:

$$SE = T_{..} \cdot X = \sum_{i,j} T_{ij} \log\left(\frac{T_{ij}T_{..}}{T_{i.}T_{.j}}\right)$$

The log is the natural logarithm of base e, and, as in the normal convention, a dot as subscript means that the index it replaces has been summed over all components.