The Need for Emergy Related Measures of Economic Productivity

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ABSTRACT

The purpose of this paper is to generate a wider acceptance of emergy analysis as a decision-making tool in both the public and private sectors. The key to increasing the application of this powerful tool is to link it to productivity. Much of business and public policy decision-making is based on productivity and related efficiency measures. The productivity measures in common use today are narrow and non-systemic and often lead to decisions that are sub-optimal at best and destructive of real productivity at worst.

There are many economic practitioners who have observed and recognized the need for economic measures that are more comprehensive and more systemic. The thesis of this paper is that these insights from economic practitioners are conceptually close to energy systems theory but lack the unifying principles of energy systems theory needed to make them operational. By making the mindset of these selected economic practitioners explicit, we see more clearly how compatible their ideas are with energy systems theory, and empower these practitioners to utilize the power of energy systems theory and associated emergy analysis tool to provide the decision making information needed to improve the practice of business strategy and community economic development.

INTRODUCTION

Most of the literature on Energy Systems Theory (EST) and its environmental accounting tool, emergy analysis is either concerned with developing and extending the theoretical foundation or applying the tool to specific human ecosystems. This paper is intended to fill a different need by establishing conceptual links between a growing set of economic practitioners and energy systems theory. The economic practitioners all recognize the need for more comprehensive measures of economic productivity, but lack a unifying theory that will enable them to present operational alternatives to current theory and practice. We will show in this paper that energy systems theory provides a unifying framework for this new body of literature and that emergy related productivity measures fill the need that is being recognized by these practitioners.

We will highlight those features of EST that are most relevant to economic productivity. In Section I, we show that the systemic perspective of EST clarifies embeddedness relationships among economic and other related systems. In Section II, we show how EST provides valuable insights into money and capital, which lead to better economic indicators. In Section III, we show how optimization principles associated with EST can help to choose among economic development strategies. In Section IV, we discuss the importance of having objective measures of economic value from EST. We will conclude with some examples showing the need for emergy related productivity measures to filter into mainstream economic decision-making.
I. EMBEDDEDNESS OF SYSTEMS

Management professor Peter Senge has recognized the need for modern economics to take a more systemic approach to management decision-making. He has also recognized the power that our subconscious mental models have over the way we perceive and process information, which in turn heavily influences decision-making. A major focus of Senge’s management training process is designed to help managers bring their mental models to the level of consciousness. His observations are that:

The impact on managers’ understanding is profound – most report that they see for the first time in their life that all we ever have are assumptions, never ‘truths’; that we always see the world through our mental models and that mental models are always incomplete, and especially in Western culture, chronically nonsystemic. (Senge, 1990, p. 185)

When Senge describes our mental models as being chronically nonsystemic, he is referring to two primary weaknesses of nonsystemic models: 1) they ignore the influence of the larger systems that contain the system of interest; 2) they ignore the interaction between parts of a system. Energy Systems Theory and Energy Systems Diagrams overcome both of these problems.

The first step in drawing an energy systems diagram is to identify the boundary between the system and its environment, and then to identify the energy sources from the containing system that flow into the system of interest. The energy sources from outside the diagram constrain what can be done within the system. The key observation of Odum that links the economy to the physical environment is that:

Everything which we regard as being of real [economic] value has to be produced and maintained by work processes from the [physical] environment, sometimes helped by people and sometimes not. (Odum, 1996, p. 6)

This observation suggests that an economic system is always embedded in an ecological system because all work involves transformation of energy but only some of this work occurs with the interaction of humans. From this perspective, we can think of the ecological system as nature’s infrastructure for the economical system. The ecological system does not always contribute directly to economic value, but without the ecological support system, there will be no economic value created. Measures of economic value that fail to include the supporting role of ecological systems can be misleading. In this paper, we will also distinguish between work done by humans within a formal exchange economy and work done by humans outside of the formal exchange economy. We will refer to the system associated with human work outside of the formal economy as the social system.

Figure 1 shows two different mental models for thinking about economic value and productivity. The top part of the diagram shows the mental model behind conventional economic thinking, while the lower part of the diagram shows the mental model behind economic thinking that is compatible with energy systems theory. To clarify the differences between these we will clarify the distinction between money and capital.

II. MONEY AND CAPITAL

The diagram in Figure 1 shows two very different paradigms, or mental models, for thinking about economic value and prosperity. No mental model is complete, but each mental model highlights certain features of reality and hides others. In this section, we consider Senge’s observations that western models, such as the conventional model in Figure 1, are highly non-systemic by showing that the conventional model hides an important distinction between money and capital.
Money is a medium of exchange, necessary for the operation of a formal market economy. Monetary measures convey important, but incomplete, information about the capacity of an economic system to create and maintain economic prosperity. Capital is a complex concept that is related to money, but is more comprehensive as an indicator of the capacity of an economy to generate and maintain wealth. A good working definition of capital is that capital is capacity for work. We will now show how this definition links Odum’s approach to economics to that of other economic practitioners.

Information Infrastructure

Peruvian economist, Hernando de Soto, has done extensive research on issues of poverty and economic development. Through his empirical research, he has discovered a surprising paradox: the poor of the world have a lot of money. In Egypt, for example, the wealth that the poor have accumulated is more than fifty times the amount of foreign direct investment that has been received by Egypt. In Haiti, the total assets of the poor are more than 150 times the foreign investment received since achieving independence from France in 1804 (De Soto, 2000, p. 5).

The obvious question from de Soto’s statement is how people can be so poor if they have so much money. De Soto’s response draws on the distinction between money and capital, which he illustrates by contrasting home ownership in primitive versus advanced economies. In a primitive economy, a home provides shelter; in an advanced economy, the home still provide shelter, but can also be leveraged to obtain more capital and perform more useful work. The home is like a seed that can be eaten directly to provide a small amount of sustenance, but if planted in fertile soil and furnished with sun and rain, it can be leverage to provide a large amount of sustenance.

De Soto’s argument is that a home without access to a formal property rights system is like a seed without access to sun and rain. It is the leveraging ability of the information infrastructure of the legal property rights system that converts dead money into live capital. Economic measures that fail to
account for the leveraging power of the information infrastructure, can lead to bad decisions and can make the process of exporting market economies to developing nations appear much simpler than it is. The false optimism about the ease of exporting market economies is due in part to economic measures that fail to recognize and account for the portion of wealth that is generated by the information infrastructure of advanced nations. He compares the process to exporting the features of a fertile river delta, without recognizing that the source of fertility lies in the upstream river.

From an energy systems theory perspective, it takes energy to create legal and information infrastructure and this infrastructure is an important store of energy that can be used to create future wealth. Odum shows in detail how to use emergy analysis to evaluate information and human services, such as the information infrastructure that de Soto identifies as a critical source of wealth in market economies (Odum, 1996, pp. 220-241).

**Human Capital and Innovation**

Jane Jacobs, a lifelong student of economic development, takes a systemic view of economic well-being consistent with the alternate perspective in Figure 1 and with energy systems theory. Jacobs notes that “If we stop focusing on things …. and shift attention to the processes that generate the things, distinctions between nature and economy blur” (Jacobs, 2000, p. 9). By focusing on processes rather than on things, Jacobs discovered an interesting paradox that “the difference between a rich backward economy and a poor backward economy is not all that great” (Jacobs, 1984, p. 63). The apparent contradiction is explained by making the same distinction that de Soto made between money and capital. The terms “rich” and “poor” refer to money, while the term “backward economy” refers to capital.

The context for Jacobs’s statement was the economy of Uruguay in the middle of the 20th century, when Uruguay was viewed by many as being the economic miracle of South America. The country had a population skilled in farming and animal husbandry. A high demand for meat, leather, and wool enabled the country to generate significant amounts of export income. However, the high degree of specialization in these products sowed the seeds of their downfall. The temporary success of this specialized economy reduced incentives to create innovative products and to learn how to replace imported goods with local production. The specialized economy appeared to be productive, but its vulnerabilities were exposed by a series of events that caused a sharp decrease in demand for Uruguayan exports. These events included substitution of products developed in Europe and the United States, revived competitive European markets, and expanding markets in New Zealand and Australia. The end result was a severe decline in the Uruguayan economy.

This example highlights the difference between money and capital. During the height of Uruguay’s animal husbandry industry, they were able to generate significant amount of export income and were rich in this sense. However, they lacked the ability to create innovative products or to replace existing products with their own productive capacity. In this sense, they were a backward country on the road to poverty, which is why Jacobs concludes that there is really very little difference between a rich and a poor backward economy. Measures of economic value that focus on money alone will fail to signal the weakness in a rich backward economy, such as that of Uruguay in the 1950s Measures of economic value that focus on capital can recognize and signal shortages in the human capital needed to support an economy.

From an energy systems perspective, the deficiency in the Uruguayan economy was a culture that no longer supported innovation, learning and adaptation. However, a culture that supports these attributes requires energy to build and maintain it. This energy in the form of human capital is an important source of economic value and productivity. Measures of economic well-being that focused exclusively on money failed to signal the weakness of the Uruguayan economy, but emergy measures that include the value of information and human services could have identified the weakness of Uruguay’s economy.
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Natural Capital and Ecosystem Services

Amory Lovins is a business strategy consultant who recognizes the untapped value of natural capital in most business organizations and industries. Lovins’ interest in natural capital led him and his co-authors to identify four important types of capital:

- Human Capital, in the form of labor and intelligence, culture and organization
- Financial capital, consisting of cash, investments, and monetary instruments
- Manufactured capital, including infrastructure, machines, tools, and factories
- Natural capital, made up of resources, living systems, and ecosystem services. (Hawken et al., 1999, p. 4)

Lovins' four-way classification is consistent with the three-way distinction in Figure 1, if we lump together financial and manufactured capital. This combination is justified by recognizing that the types of infrastructure that Lovins includes in manufactured capital are made with money and define a store of financial capital from past work that represents capacity for future work.

Lovins et al. go to great lengths to distinguish natural capital from natural resources. The distinction is one of money versus capital and can be illustrated with a forest:

- Resources and ecosystem services both come from the earth – even from the same biological systems – but they are two different things. Forests, for instance, not only produce the resource of wood fiber but also provide such ecosystem services as water storage, habitat, and regulation of the atmosphere and climate. (Lovins et al., 1999)

- Natural resources are tangible, have obvious market value, and are included in conventional financial accounting systems. However, silent and invisible ecosystem services must also be preserved and maintained if we are to maintain prosperity for ourselves and future generations. Lovins proposes a new form of capitalism that he calls Natural Capitalism, which is motivated by the observation that there are severe accounting fallacies in our current system. The fallacies derive from what Lovins et al. describe as a system where “…with dangerously narrow focus, our industries look only at the exploitable resources of the earth’s ecosystems – its oceans, forests, and plains – and not at the larger services that those systems provide for free” (Lovins et al., 1999).

Lovins recognizes the need for more comprehensive accounting systems that include all forms of capital, but he fails to provide an example of such alternate accounting system. What Lovins is calling for is energy systems theory, which allows one to account for all forms of capital on a common scale, in other words, emergy analysis.

Generalized Input-Output Analysis

Ecological economist Herman Daly has clearly recognized the need to include the physical environment in measures of economic value. He proposed generalizing economic input-output analysis by including the physical environment as one of the sectors (Daly, 1993). In the simplest version of Daly’s generalized input-output analysis, all conventional economic sectors are aggregated into a single sector while the physical environment is treated as the second sector. Three additional types of interactions are included in this framework:

- Environment to Economy
- Economy to Environment
- Environment to Environment
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The flows in Daly’s framework are energy flows rather than cash flows since the environmental sector deals with energy, a form of capital, rather than money. Daly’s work builds on the work of economist Nicholas Georgescu-Roegen, who was one of the first to recognize that economic processes are really energy transformations and that energy must be incorporated into measures of real wealth (Georgescu-Roegen, 1975).

Representation of Capital

Odum’s contributions to economic thinking are that he was able to see things others did not see, to create a unifying theory to explain his insights, and to create a representational system to help others see what he saw. Hernando de Soto fully recognizes the importance of representational systems in the context of property rights when he observes that in the West “every parcel of land, every building, every piece of equipment, or store of inventories is represented in a property document that is the visible sign of a vast hidden process that connects all these assets to the rest of the economy. Thanks to this representational process, assets can lead an invisible, parallel life alongside their material existence” (de Soto, 2000, p. 6).

This idea of representational systems provides the link between de Soto’s view of economics and Odum’s views of economics. De Soto states, “One of the greatest challenges to the human mind is to comprehend and to gain access to those things we know exist but cannot see. Not everything that is real and useful is tangible and visible.” (de Soto, 2000, p.7). He observes that cultures have flourished through history by inventing representation systems that allow people “to grasp with the mind what human hands could never touch” (de Soto, 2000, p. 8). Energy systems theory augmented with energy systems diagrams is such a system, allowing decision makers to grasp energy flows with their minds that cannot be touched with their hands.

The point of this discussion is that productivity measures which are based only on the physical and tangible aspects of a good or service cannot capture the potential energy available for work that the good or service represents. The real value of a good or service includes its potential for future work as well as its present capabilities.

III. OPTIMIZING PRINCIPLES

Systems that account for capital rather than money require principles of organization and design that will lead to the most effective use of all available resources. In this section, we show that Odum’s generalized maximum power principle is a natural extension of commonly accepted optimization principles in business and economic development.

Nobel prize winning economist, Milton Freidman, has argued vigorously for the principle of profit maximization as a guiding principle of economics and business strategy. For Friedman, the impact of the principle of profit maximization goes far beyond a specific firm. Friedman argues that profit maximization is crucial in sending clear signals through the economic system, in the form of prices, that will lead to an optimal allocation of resources and ultimately to the greatest benefit to the greatest number of people. In his argument, a manager who fails to maximize profits for his or her firm is guilty of distorting the market signals needed for the market to identify the best allocation of resources (Friedman, 1962). Friedman’s maximum profit principle can be stated as:

Maximum Profit Principle: Those firms that survive will be those that are able to attract and use available financial resources most effectively.

We will argue that Friedman is articulating an important principle, but that the practices growing out of his principles may not lead to the desired result because his principles are focused too narrowly on
the formal exchange economy and ignore the constraints that the supporting natural and human systems place on human economic preferences and choices.

One argument supporting the general theme of Friedman’s Maximum Profit Principle is that an analogous principle has been discovered in the pure working of nature’s economy. Russian biologist Alfred Lotka formulated the Maximum Power Principle in 1922, which can be stated as:

Maximum Power Principle: Natural systems that survive are those that are most successful at capturing available energy and using it effectively, within the carrying capacity of their environments (Lotka, 1922).

Energy systems theory argues that the height of a tree, or the shape of a leaf, or the strength of the jaw bone of a beaver have all achieved their current state by operating according to the maximum power principle. Those species or individuals that fail to operate by and adapt to the maximum power principle will not survive.

The analogy between the maximum profit and maximum power principles can be seen more clearly from the following example, given independently by two avid fishermen familiar with energy systems theory (Blackham, 2001; Hall, 2001, personal communications). If trout feed in slow moving waters, the advantage is that little effort is required to obtain food, but the disadvantage is that there is little food to be found. On the other hand, if trout feed in rapidly moving water, the advantage is that there is more food to be found, but the disadvantage is that more energy is required to obtain this food. In order to thrive, trout have been able to identify a moderate strategy where they swim in moderately moving water, and spend a moderate amount of energy to obtain a moderate amount of food. This strategy is consistent with the maximum power principle.

Figure 2 shows the trout principle more clearly. The horizontal axis represents water speed and the vertical axis represents energy. The lower line shows the energy expended to obtain food and the upper line shows the energy obtained from the food. The optimal strategy that trout have discovered is the one that maximizes the differences between the energy spent and the energy obtained. In other words, trout are energy profit maximizers, just like the human money profit maximizers for which Friedman argues.

To summarize, Friedman proposes a normative principle, but one that is limited to the formal human economy. Lotka proposes a parallel optimizing principle that is descriptive, rather than normative, and applies it only to the portion of nature’s economy that operates without human interaction.

The limitation of Lotka’s maximum power principle is that it does not include human choice and actions. Odum, however, has generalized Lotka’s Maximum Power Principle to include the human economy:

Generalized Maximum Power Principle: Those human-nature partnerships that capture and use all sources of energy as effectively as possible will be the ones that will be economically viable, in the long run.

Like Friedman’s principle, Odum’s statement is normative, providing humans with direction about what they should do to make effective use of available resources. Unlike Friedman’s principle, Odum’s optimizing principle is not limited to the human economy, but applies to the whole greater economy, including nature’s economy as well as the human economy.

Many economic practitioners, including development expert Jane Jacobs, have articulated the need for emergy related productivity measures, such as the generalized maximum power principle, even though they are unfamiliar with energy systems theory. Jacobs has enough ecological understanding to recognize the analogy between nature’s pure economies and economies involving humans. Jacobs observes that an ecosystem can be described as an energy conduit with energy infusions entering the system and energy discharges leaving the system.

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Jacobs illustrates the connection between economies and ecosystems by contrasting a barren desert with a lush rain forest. The difference that Jacobs observes is that the barren desert has little capacity to capture energy that enters the system; therefore, most energy is dissipated in the form of lost heat with very little evidence that significant amounts of energy have entered the system. In the rain forest, the energy is not only captured, but is passed around from species to species and reused and recycled. She describes the energy flow paths in the rain forest as being “dilatory and digressive”. This means that the energy entering the system gets cycled and recycled, used and reused. The result is that energy flows through more parts of the system and therefore supports more life (Jacobs, 2000).

Jacobs concludes from this contrast that what happens inside the conduit is what is important for measuring the productivity of the system. You cannot understand what is happening merely by measuring the output; it is what the system does to transform the energy into high quality energy that is important for measuring productivity.

Jacobs likens an economic system to an ecosystem by associating imports with energy infusions and exports with energy discharges. She observes that the economic development of any region always begins with a “gift from nature”. In Venice, the gift was salt from the sea. In Copenhagen the initial gift was herring. In other places such as Paris, Chicago, and San Francisco, the gift was in the form of a suitable trading location. Jacobs conceptualizes these gifts of nature as “imports over time” rather than more traditional imports over space, since they have always been in the same place, but were created at an earlier time.

Jacobs correctly identifies these gifts from nature as natural capital and also recognizes that human capital and natural capital must interact to produce a form suitable for human use. The Venetians, for example, became very clever at guiding salt water into a series of evaporation ponds to extract the salt in a usable form. Financial capital entered the picture when the Venetians became proficient enough at salt extraction to produce a surplus, which could then be used as exchange currency to import goods and services that they could not effectively supply for themselves.

Looking at economic development from this perspective, Jacobs realized that the way to measure and track productivity was to create an “Import Stretching Ratio”, defined as the value of the exports from a region compared to the value of the imports. Imports include imports over time as well as imports into one place from another. She sketches out how an import-stretching ratio might be computed, but not being familiar with emergy, she failed to realize that the ratio she was describing...
was the ratio of the emergy output to emergy input for a region or that the strategies that would maximize the import stretching ratio are those strategies that are most consistent with the maximum power principle.

**IV. PERCEPTION AND REALITY**

Another weakness of non-systemic measures of economic well-being is that they rely solely on human perception of value, while ignoring the limitations of the larger energy systems that contain the economic system. Even well meaning efforts of ecological economists to include environmental values in the economic arena suffer from this shortcoming.

Energy systems theorist Charles Hall describes the fundamental difference between ecological economics and emergy analysis by looking at the questions asked in both approaches. According to Hall, the question asked by ecological economists is “How can we measure the contributions of nature to the human economy in terms relevant to human beings?” (Hall, 1995, p. 205). Hall contrasts this with the fundamental question asked by emergy analysts: “How can we fit the activities of humans into the grand energy schemes of the world around us, which sooner or later will determine what we do anyway?” Hall is saying that humans are free to choose what we do and what we value, but we are not free to choose the consequences of our actions. Our actions will only bring prosperity if they are consistent with the larger patterns of nature.

It is difficult for many to see the danger of measuring economic value and productivity by perceived monetary value, since money has been around for a long time and will probably continue as the measurable medium of exchanges. However, the Internet boom and bust of the late 1990’s provides a compressed time scale in which to observe the ultimate futility of currencies based solely on perceived value.

Marshall Blackham, a venture capitalist of the late 1990s, observes that in the early days of the Internet boom, companies had no profits and little revenues early on so they used Internet traffic, or “number of hits” as a measure of success. As Internet stocks climbed higher and higher, the traditional measures of value didn’t work. Instead stock prices became highly correlated to “hits” on the website. Once people saw the connection between hits and value in the market, “hits” acquired a perceived value and became a legitimate form of currency, as long as venture capitalists and buyers of stock had a perception of a direct link between hits and real money.

While reflecting on the implications of energy systems theory, Blackham drew the following insights from his experience as a venture capitalist. When hits were a legitimate form of currency, startup companies began to develop their business strategies around maximizing hits, assuming this was a good surrogate for maximizing money (profits). As the perceived link between hits and money was broken, hit currency became seriously devalued and the companies who had a large portion of their capital in the form of hit currency found themselves in big trouble.

The analogy here is that hits are to money as money is to energy. Hits served as a surrogate for money when new Internet startups did not know how to measure the value of their companies. But when the strategies for maximizing hits diverged from strategies for making money, hit strategies failed. The convergence of hit strategies and money strategies seems to be correlated with money supply. The more money available, the stronger the link between maximizing hits and maximizing dollars: the less money available, the weaker the link between hits and money. In other words, when money was available to fund Internet companies and money was available to buy their stock, everybody believed that the number of hits translated into value. Once money became scarce, those companies that were not generating money found themselves in trouble because hits didn’t pay the rent, hits didn’t pay their employees, and hits didn’t even buy lunch. They needed money not hits.

The analogy is that energy is the real currency for measuring wealth. When energy is abundant, money is a good surrogate for energy. However, as energy becomes more scarce, the link between maximizing money and maximizing power (in the energy use context) weakens. In times of abundant energy, strategies for maximizing profits may coincide with strategies for effective energy
use. In times of limited energy sources, strategies for maximizing profits may involve increasingly externalizing the costs and result in ineffective uses of energy. This is the time when a biophysical perspective on economics becomes necessary so that energy effectiveness is measured directly by energy flows rather than indirectly by money flows.

Just as the Internet companies crashed by assuming that a hit maximizing strategy was consistent with a dollar maximizing strategy, we as a society run the same risk (if the analogy is valid) of crashing by pursuing dollar maximizing strategies under the assumption that they will automatically result in effective energy use.

We see from this analogy that money is a secondary form of wealth, while energy is a primary form of wealth. By this, we mean that money cannot satisfy any real economic need directly; it only satisfies an economic need when it is exchanged for energy in some form or another (food, water, clothing, shelter, education, etc.). Money is only capable of satisfying economic needs indirectly when the economic exchange system is embedded in a social system that supports the exchange economy. The requisite social system includes not only a legal framework, but also a perception of economic value in the minds of the participants in the economic exchange system. Without such a support system, money is absolutely worthless. Consider the extreme case of being stranded alone on a desert island with a pocket full of money, but without access to any form of energy that can satisfy the need for food, water and shelter. The money is of no value in this situation.

V. EXAMPLES

Two examples suffice to illustrate the need to shift our thinking about economic prosperity towards emergy related measures. Traditional measures of economic growth were improving in the United States in early 2004, but high unemployment levels persisted. Economists began to see the connection between unemployment and productivity measured as economic output per hour of labor. The incentives to increase labor productivity favor replacing human labor with machines; therefore, as we increase labor productivity, we also increase unemployment. "Productivity gains are going to prevent the kind of job growth creation [seen] in the 1990s," says John Challenger, CEO of the Chicago-based outplacement firm Challenger, Gray & Christmas, which tracks labor issues. (Christian Science Monitor, March 8, 2004)

What is missing from the key measure of labor productivity is that the process of human work creates economic value by increasing the workers capacity for further work. This is especially true in an information economy. Odum observes that information, especially in the form of human services has a high transformity, and is, therefore, capable of generating high economic value (Odum, 1996, p. 220). He suggests that human services can be quantified by multiplying the energy expended by a human being by the transformity of the individual’s education and experience. By measuring productivity in this manner, the process of human labor is a benefit in terms of increasing transformity, as well as a cost. Redefining productivity in this way would move us away from a system with incentives not to invest in the development of the human capital in a society.

As a second example, we consider the case of the North Atlantic cod fishing industry. The cod fishing industry had been the mainstay of the local economy along the North Atlantic coast of the United States and Canada for centuries. However, in the 1960’s, both the number and the size of cod began to decrease. Fisheries scientists and ecologists recognized that the only way to preserve the industry was to allow the ecosystem to heal so that fish sizes and quantities could return to former levels; however, this information never filtered into market signals, which were badly distorted by government subsidies to keep the industry in business.

The exchange economy was embedded in a legal and social framework that supported economic exchange, and fish customers were certainly willing to pay the artificially low prices of the fish. However, the whole industry collapsed in the early 1990s because the natural system supporting the social system was no longer capable of supplying the energy in the form of healthy cod to meet the demand that customers were willing to pay for.
What people wanted in this case was to continue to eat cheap cod; on the other hand the biophysical realities limited the amount of fish caught to the amount of fish in the bays. Even though ecologists and fisheries scientists foretold the decline in both the number and size of fish, the economic signals demanded more fish than could be caught. It was biophysical reality not human preference that dictated the outcome in this case.

This example illustrates a divergence between traditional economic measures and emergy related measures. By traditional measures the economy of the North Atlantic region appeared strong until the sudden collapse. In contrast, if emergy measures had been in place, different decisions might have been made while there was still time to avert the social, ecologic and economic disaster that occurred.

CONCLUSION

Many thoughtful observers and practitioners of economic life have recognized shortcomings in the way we define and measure economic productivity. The critiques highlighted in this paper can be strengthened and unified by placing them in an energy systems theory context. The conceptual framework that links the formal exchange economy to emergy analysis is a triple-economy model, with the formal exchange economy nested within the larger human services economy which is also nested within nature’s service economy. The common currency of all three economies is energy rather than money, which points to the need for comprehensive energy accounting tools to manage the triple economy. Emergy analysis provides a broader framework for thinking about economic productivity. This reduces the likelihood of unanticipated negative side effects and leads to better decision making and management of the triple economy.

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