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Twenty years after putting forward the idea that the economic process is entropic in all its material fibers, it is now time, in this paper, to comment on and clarify some of the issues that have arisen from this idea.

The Entropy Law and its Extension to Matter

In an isolated system, the total amount of energy is constant, but it irrevocably degrades from the available to the unavailable state. Available and unavailable energy are anthropomorphic concepts relating to whether humans can use the energy for their own purposes. Entropy is the ratio of unavailable energy to the absolute temperature of the isolated system. The entropy law says that the amount of unavailable energy will increase in a system over time. Some economists have argued that the entropy law is irrelevant to the workings of the economic system because it is an open system. However, while it is true that net entropy can increase or decrease in an open system, entropic degradation does occur in all systems, so the entropy law is relevant to economic systems.

Matter, like energy, exists in both available and unavailable states, and over time it also degrades from the former to the latter. An important implication of this is that complete recycling would require limitless amounts of energy and time. Materials that are deemed vital will inevitably become scarcer and scarcer over time. The idea of a steady-state economy, put forward by Herman Daly as a solution to the ecological crisis, does not recognize this, and it is therefore logically weak.

The Fallacy of the Energy Theory of Economic Value

A living organism requires low-entropy energy to support its activities. Since low-entropy energy can only be used once, its scarcity increases over time. The entropy law is therefore at the root of economic scarcity. However, it would be wrong to treat the entire economic process simply as a process of degrading low entropy. A number of writers have drawn close parallels between thermodynamics and the economic process, leading to the energetics approach that equates economic value with net energy. David Huettner rejected this method, although he does claim to have established that economic value is proportional to energy content. Huettner's proof, however, is based on a production function that includes only flows, not funds - a formulation clearly not in keeping with economic reality. Robert Costanza attempted an

empirical formulation of the "economic value = energy content" proposition, but his analysis suffers from the same problem as Huettner's: it only includes flows, not funds. Costanza's equation also produces the curious result that the costs of the elements that he does not include equal zero in all sectors. At best, Costanza's analysis reveals that energy is an important stochastic element of cost. The entropic nature of the economic process does not, however, mean that economic value can be determined by energy content.

Lessons for Economics from Thermodynamics

Mainstream economists argue that economic growth is primary and that economic scarcity can be overcome through technological improvements. They view economics as a mechanical process, not a thermodynamic one, and believe that the market will resolve any problems that may arise with respect to the availability of natural resources. While these economists concede that at times markets do not function efficiently, they argue that the imposition of taxes and subsidies can rectify any problems. They point to the continuous improvements in living standards around the world as an argument in favor of a strategy of economic growth.

It must be remembered, however, that the tremendous growth of the past has been fueled by a mineral bonanza that supported technological advances. For these advances to continue, a steady supply of environmental low entropy is needed. In the future, the unavailability of low-entropy energy will be a major constraint on available technologies. For some time now, many have believed that cheap and renewable solar energy will solve the current energy crisis. However, the problem with solar energy is that tapping it requires a disproportionate amount of matter; at this point, using solar energy still depends a great deal on other primary resources. Nuclear energy is another possible future energy source, but here the biggest problem is safety issues. Given these problems with solar and nuclear energy, the only reasonable solutions to the energy crisis are to economize in the use of fossil fuels, or to rely on less energy intensive technologies. Any successful program to economize on energy will require international cooperation.