"Summary of article by Tran Huu Dung: Consumption, Production and Technological Progress: A Unified Entropic Approach" in Frontier Issues in Economic Thought, Volume 1: A Survey of Ecological Economics. Island Press: Washington DC, 1995. pp. 183-186

Social Science Library: Frontier Thinking in Sustainable Development and Human Well-being

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The Second Law of Thermodynamics has been recognized and incorporated into economic analysis by only a small number of economists, primarily in the fields of resource and environmental economics. Even here the law has done little more than reinforce the sense that there is a limit to boundless economic growth. Beyond this, the impact upon mainstream economic thinking has been negligible, a testimony to the durability of the neoclassical model and its world of infinite substitutability between relatively scarce and relatively abundant resources.

However, even this limited emphasis on the enveloping implications of the Second Law has ignored other equally important entropic properties of economic processes. The Second Law can be taken beyond dictums regarding the inevitability of the end of the world, and viewed instead as the delineator of contours within which myriad economic activities can yet take place for a considerable time. It is proposed that an entropy-based characterization of three constituent economic phenomena - consumption, production, and technological progress - can provide an additional dimension in which the economist's traditional building blocks can be further distinguished and analyzed. The incorporation of the Second Law into economics is therefore not incompatible with the existing economic paradigm; it is not a replacement of the mainstream approach, but a complement to it.

The basic premises for this approach are as follows:

1) entropy is an objective physical magnitude;
2) many entropies can be ascribed to a system depending on the parameters selected and the level of description, but it is possible to speak of an absolute value of entropy; and
3) the apparent arbitrariness of an entropy can be explained by distinguishing between "randomness" and "disorder."

Consumption and the Second Law of Thermodynamics

In its simplest version, the Second Law of Thermodynamics asserts that, as time passes, closed systems function in a manner that produces a state of increased entropy or randomness. A closed system is one in which there is no gain or loss of energy from the surroundings. The economic ramifications of this are evident in the observation that human biological life depends upon the consumption of low-entropy inputs and the consequent generation of high-entropy outputs, or

waste. Human economic life is the same. Some economists have seized upon this notion to argue that it is economic life itself that creates the tendency to move toward increasingly disordered, high-entropy states, but this is not quite correct. It is actually the consumptive process that purely manifests this property, while the entropic ramifications of both production and technological progress are less clear in this regard.

The relation between the usefulness of materials and their entropy level is an important one. If all things in the universe were to be ranked by their entropy levels, those that are most useful would clearly be grouped at the lower end of the scale. This idea becomes more precise and testable if we recognize that not only will the entropy output from any consumptive process be high relative to the entropy levels of the inputs, but in addition, it will be well above that of the consumed system had it not been consumed at all.

It is also important to recognize that, even without human intervention, the entropy of a system will increase continuously due to the "natural evolution path" of the system. This concept offers a new way to approach the measurement of consumption. To begin with, increasing entropy above its natural state is not a necessary condition for the creation of utility. Utility can be derived from transformations occurring along the natural evolution path (e.g., watching leaves fall from a tree); this is "pure use." Alternatively, utility may be derived from transformations affected by intentional human intervention; this is "active" or "non-pure use." Human intervention will normally cause greater increases in entropy than transformations that occur along the natural evolution path. Consumption can then be associated with active or non-pure use, and is the difference between the entropy level that results after human intervention and that which would have resulted from the natural evolutionary path. If there is no difference, then we have pure use and no consumption, but if there is a difference, then we have consumption, and the magnitude of the difference can be thought of as the degree of consumption.

Production vs. Consumption

In many conceptualizations, production and consumption are viewed as sharing a number of properties; in particular, both involve the utilization of inputs and the generation of outputs. If this is so, then it might be assumed that production shares with consumption the entropic characteristics discussed above. From a physical point of view, however, production differs from consumption in that it is "an *intentional* act which causes a certain physical system to be more orderly, less random *from a certain point of view.*"(204) That is, organizing a productive process requires the rearranging of a set of inputs to conform to a preconceived set of relationships. This notion must be qualified by observing that the Second Law renders it impossible to rearrange a total system so that the new state is completely orderly; thus it is only from "a certain point of view" that orderliness is enhanced. The Second Law dictates that the system must simultaneously become more random from other points of view, producing a net increase in total disorderliness.

Thus, in economic production, the entropy level will necessarily increase above that which would exist due to the natural evolution path, but for given subsystems within the system we can locate areas of decreasing entropy. This suggests a way to measure the eco-thermodynamic efficiency of the process. An activity that minimizes the output of high entropy wastes and

enhances the degree of orderliness, as suggested above, would imply a greater systemic efficiency.

Usability and Technological Progress

Mainstream economists remain optimistic in the face of the Second Law by suggesting that continuing technological progress will indefinitely postpone the limits to growth. The entropic framework can be used to put this argument in a more constructive perspective. Levels of knowledge and technology determine the usability and reusability of a physical state. As knowledge accumulates, an increasing number of systems previously thought to be unusable are found to contain usable orderly patterns; or a state may become more orderly in response to improved knowledge and the resulting technology. However, it must still be stressed that the natural evolution path produces increasing entropy, implying that the Second Law dictates the eventual triumph of the natural evolution path over technological ingenuity.

Conclusion

Both production and consumption can be characterized by their distinctive thermodynamic properties. Consumption generates an increase in disorder, whereas production may result in an increase in orderliness in some parts of the system. The increase or decrease in the local degree of orderliness can be measured in terms of entropy. Following this unified approach, economic processes can produce three outcomes: 1) consumption, if the post-use state is more disorderly than the natural state; 2) pure use, if the post-use state is the same as the natural state; and 3) production, if the post-use state is on the whole more disorderly, but contains subsets that are more orderly. This approach is not only consistent with the Second Law, but it gives the law a more constructive role. Specifically, it provides a common ground for discussion upon which those afflicted with unbridled optimism and those suffering from doomsday gloom can meet, and enhances the possibility that solutions can be found.