

## **Econophysics: Entropy and its discontents?**

For over fifty years, neoclassical and biophysical economists have been divided in their views regarding the extent to which the second law of thermodynamics- the “entropy law”- is applicable to the field of economics and sustainable growth. According to econophysicists such as Nicholas Georgescu-Roegen, the entropy law is the “the most economic in nature of all natural laws” and “the taproot of economic scarcity” (Georgescu-Roegen, 1979). On the other hand, traditional economists, most notably Jeffrey T Young (1991), argue that the rationing function of the market mechanism will naturally solve the problem of scarcity, thus the application of entropy to economics is unnecessary. Before evaluating the credibility of this claim, this essay will focus on accurately defining entropy, a term that has perplexed scholars mainly due to its loose definition in terms of “order” and “disorder”. As will become clear, such ambiguity in terminology has led the arguments of economists such as Young to be rigged with flaws. The main thrust of this essay will highlight the overwhelming evidence pointing to the fact that the entropy law is intrinsically linked to the production process, thus its application to economics is essential. However, as the final part of the essay examines, the claim that the entropy law can be utilized as a modelling tool for long-term sustainable is more questionable.

For the purpose of clarity, it should be noted that in this essay the *thermodynamic* entity of entropy will be applied to mainstream economic theory (as opposed to information entropy, for example). Furthermore, in order to avoid confusion, entropy will be defined as “the degree to which finite-time processes are irreversible” (McMahon & Mrozek, 1997). Entropy is one of the four laws of thermodynamics, which essentially describe energy transformations from one form to another (Glucina & Mayumi, 2010). Whilst the zeroth law and third law seem to be included to “ensure logical coherence”, the first law- that the energy of an isolated system is constant- and the second “entropy law” as defined above consistently occur in nature (Glucina & Mayumi, 2010). Entropy describes the quality of energy in a system, the quality referring to the “potential to transfer energy across the system boundary as work” (Glucina & Mayumi, 2010). Therefore, the higher the entropy, the lower the quality of energy, whereas the lower the entropy in a system refers to higher quality energy being used (Glucina & Mayumi, 2010). When Rudolph Clausius established this idea over 150 years ago, he stated that it is impossible for entropy to decrease in the whole universe, and once such a state of internal equilibrium is reached, its entropy is maximized.

It is important to note an ambiguity that has misled several scholars. Even by analogy, thermodynamic entropy and “disorder” are very different. This confusion arises from the statistical interpretation of entropy, where “disorder” refers to when there are lots of possible distributions whereas “order” refers to only a few possible distributions (Glucina & Mayumi, 2010; Corning & Kline, 1998). Another misconception that arises from referring high (thermodynamic) entropy as “disorder” and low entropy as “order” is when using gaseous systems as an analogy of this. For example, even though, by analogy, the spatial position of particles in a solid seem more “ordered” and thus to have low entropy, a heat-flow can change the entropy even within a solid body, because the energy in its constituent atoms vary despite having limited movement due to the solid nature of the body (Glucina & Mayumi, 2010).

Many scholars advance the notion that the entropy law is fundamental to the study of economics. Foremost among them is Nicholas Georgescu-Roegen. Georgescu-Roegen argues that because the process of transforming inputs into outputs requires energy, economic theory must take into account the irreversible nature of the production process: one unit of energy can only be used once. Thus, energy cannot be recycled. Even though the first law of thermodynamics is implicitly taken into account in most modern economic models, it fails to recognize the irreversibility of the production process. Indeed, Georgescu-Roegen critiqued the circular flow of income, one of the most fundamentally important neo-classical economic models, for failing to portray the real impact that human activity has on resources. (Georgescu-Roegen, 1976, 1971). As Herman E Daly, Georgescu-Roegen’s student, stated, the argument that entropy drives the economy logically concludes that infinite economic growth in a planet where resources are scarce is impossible (Daly, 1991, 1993, 1997; Daly & Farley, 2004; Daly & Cobb, 1994). This is because it is not possible for the total energy used per unit of time to surpass the total energy flow per unit of time (Glucina & Mayumi, 2010). Daly (1992) notes that as sources deplete, sinks become polluted. Consequently, the importance of the entropy becomes apparent because it states that “sinks cannot serve as sources”. Daly (1992) also acknowledges that if the entropy law were not to exist, then “we could turn sinks into sources, recycle everything, and burn the same gallon of gas over and over.” According to Daly, the fact that economic theory is yet to incorporate such an important fundamental feature is a “glittering anomaly” (Daly, 1992).

The argument that the entropy law should be incorporated into economic theory is a plausible one. In his book “The Origin of Wealth”, Beinhocker (2007) notes that the only way we

maintain the low entropy of goods that are given high value (such as an iPod) is by maintaining a disorder in the ecosystem that exceeds the low entropy of the iPod. This concept poses serious uncertainties for sustainable development and environmental economists, as it suggests that any effort to ecologically improve our production process, the negative effect on the environment (in terms of pollution or waste, for example) will always outweigh the more efficient method of production. No matter how much our technology may improve, no technology can reach thermodynamic maximum, thus 100% efficiency is impossible. Indeed, Georgescu-Roegen (1979) claims that no matter how efficient our technology can be, all of our resources will be depleted by 2100.

However, there is much controversy surrounding these claims, and many have denied entropy's relevance to economic theory and environmental sustainability. The most notable critic of Georgescu-Roegen and Daly's argument is Jeffrey T Young (1991). Young warns that by trying to apply the concept of thermodynamic entropy to economics, we are committing "scientism": the view that "the characteristic inductive methods of the natural sciences are the only source of genuine factual knowledge and, in particular, that they alone can yield true knowledge about man and society" (Bullock & Trombley, 1999). Young proposes several reasons for this claim.

First, Young (1991) argues that entropy is a physical concept that should be only limited to thermodynamics because it is only relevant to closed and isolated systems. Therefore, due to the fact that the Earth *in energy terms* is an open system (where matter, heat and work can move across a system boundary) as it receives "negentropy" (limitless solar energy), the entropy model is inapplicable to economics. Therefore, Young claims that long-term entropic decay only occurs for matter and not energy. Ostensibly, Young's assumption is a formidable one: the Earth is indeed an open system in terms of energy. However, the following assertion that this equates to entropy being irrelevant in economics appears misleading. To the contrary, as Daly (1992) comments, the economy is an open system by nature *because* it resists entropic decay by "sucking low entropy from its environment" (Schroedinger, 1945). Therefore, the notion that the economy's resistance to entropic decay equates to its irrelevance is the main weakness of Young's critique of entropy's relevance to economics. Perhaps the economy's ability to resist entropic decay is why it is so fundamental to the study of economics.

Second, Young notices a problem of aggregation. As there is no neutral aggregation system between energy and matter (Young, 1991), the concept of “order” is only quantifiable if a single material resource and a single unchanging technology are being taken into account. Perhaps, Young argues, due to new knowledge and innovation, entropy can decline on a general scale less than the increase in entropy in general elsewhere. Even though Young accurately notes the difficulties in quantifying how much “order” and “disorder” there is in a system, the reason for such a difficulty rests on his flawed assumption that thermodynamic entropy equates exactly to “order”, which, as discussed above, can be scientifically incorrect. Daly (1992) points out that an increase in knowledge, for example, about the hole in the ozone layer, can actually reduce our resource base. Therefore, Young’s definition of entropy as an increase in “disorder” has led to the fundamental disagreement between himself and Daly. However, Daly’s arguments are more credible, most probably due to the fact that his definition of entropy is less ambiguous as Young’s.

Third, Young recognizes that even though the entropy law and the law of diminishing returns are different concepts, the latter implicitly takes the entropy law into account (Young, 1991). This is because according to the rationing function of the market mechanism, markets perpetuate themselves by reflecting scarcity accurately into prices. After a certain point, economists argue that when prices become too high, firms are forced by the market to shift to more renewable methods of production. For example, the increase in global price of rare earths due to China’s quota recently forced Japan amongst other countries to innovate and consequently create new, renewable and more cost-effective ways of manufacturing rare earths. However, Young again fails to recognize the underlying principle of entropy: that all real processes are irreversible. Therefore, even though the market mechanism will go some way to reduce the net entropy in the environment, it by no means takes into account that our resource base, ultimately, is finite. Consequently, the notion (often derived from inconsistent definitions) that entropy is irrelevant to economics appears to lack validity.

Despite all of this confusion, what remains clear is that the extent to which the entropy law is relevant to mainstream economic theory depends on many factors. First and foremost, will technology efficiently replace non-renewable methods of production? And second, to what extent does the entropy law shed light on the long-term limits of economic growth (Glucina & Mayumi, 2010)? What many econophysicists fail to consider is that many economies (such as the UK) have become mainly tertiary sector economies, thus specializing in services such as

teaching, finance and law. Consequently, the economic output that they produce can be measured in monetary terms but not in terms of energy consumption. Entropy seems to have little applicability to the sustainable growth of these economies, because the “carrying capacity” of an economy is only measured in terms of the production of goods, as output from the service sector generally has little or no environmentally degrading effect.

Furthermore, Daly and Georgescu-Roegen do not take into account that it is unlikely for entropy to be the main limit on long-run growth. According to Glucina and Mayumi (2010), growth is more likely to be constrained by the “Earth’s finite assimilation capacity (notably for CO<sub>2</sub>) than her finite resources”, an important factor that thermodynamics does not predict. Therefore, even though entropy is intrinsically linked to the production process thus highlighting its relevance to economic theory, perhaps a possible global transition to the tertiary sector could reduce its applicability to economics. Despite this, it cannot be denied that no matter how service sector our economies become, humans will always demand material goods, which can only be produced industrially. Therefore, even though Daly and Georgescu-Roegen’s assumptions seem to overstress entropy’s relevance to the limits of economic growth, it is irrefutable that denying entropy’s relevance to economics is indeed a “glittering anomaly” (Daly, 1992).

A consensus is yet to be reached with regards to the relevance of the second law of thermodynamics to economic theory. However, it has become clear that to neglect entropy’s relevance to resource economics is an alarming assertion based on misconceptions; entropy is clearly linked to the production process. It must be noted, however, that entropy’s relevance to economics depends on the nature of the type of economic theory in question. Despite entropy undoubtedly being a useful part of the economic conceptual framework in order to identify scarcity and resource-based problems, it does not answer the “normative questions imposed by sustainability” (Baumgartner, 2004; Sollner, 1997) due to its innately quantitative nature. Thus, although it is essential to incorporate the entropy law to the basic economics toolkit, the Entropy Law must be accompanied with other theories in order to effectively entail the other more innately unquantifiable entities of sustainability, such as social development. Perhaps one aspect that could strengthen the relevance of entropy to mainstream economics is kinetic theory, a concept arguably just as important as entropy (Glucina & Mayumi, 2010; Lambert, 1998), because it gives an insight into the time-scale of each thermodynamic transformation. By applying kinetic theory- that has been significantly overlooked in thermoeconomic

literature- to economics, then and only then will the principle of the second law of thermodynamics be taken seriously by all mainstream economists.

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