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Methods

The evolutionary approach to entropy: Reconciling Georgescu-Roegen's natural philosophy with the maximum entropy framework

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ABSTRACT

The paper explores the relevance of recent developments in the Maximum Entropy hypothesis for reinstating Georgescu-Roegen's natural philosophy, with special emphasis on the concepts of evolution and time. The key point is the naturalization of the notion of 'subjectivity' in both the Georgescu-Roegen framework and Jaynes's subjectivistic interpretation of thermodynamics and statistical mechanics. I introduce the concept of 'observer relativity' with reference to the evolution of 'physical inference devices'. Then, the MaxEnt formalism can be understood as a principle underlying natural selection. Further, given natural selection, maximum entropy production (MEP) results from the confluence of maximum power (Lotka) and the maximization of information capacity, driven by energy dispersal. In these processes, hierarchical structures of gradients of energy dissipation reflect alternative positions of system boundaries, and hence different perspectives of observer-relativity. Thus, I can distinguish between observer relative Entropy_{OR} and observer independent Entropy_{OI}. This allows to reconstruct conceptually the two notions of time proposed by Georgescu-Roegen, with subjectivistic time seen as time relative to the evolutionary process involving incommensurable qualitative change. I claim that this philosophical view offers a powerful conceptual framework for recent empirical research into the energetics of economic growth.

1. Revisiting the 'Entropy Law' from the Perspective of Maximum Entropy

Since Nicholas Georgescu-Roegen introduced the notion of entropy into economics, the discussion has revealed a number of misconceptions and even mistakes in his seminal approach, which, however, did not result into a wholesale rejection of the thermodynamics agenda in economics. The constructive side of the response is mainly reflected in the search for empirical regularities in long-run trends in energy consumption, based on the notion of exergy (see e.g. Ayres and Warr, 2003, 2005; Warr et al., 2008), which in turn can build on standard approaches to thermodynamics in engineering, since the intermediating factor is evolving technology. Exergy is a concept that is embedded into thermodynamics, but which differs from the more fundamental concepts of the general laws of thermodynamics in being contextualized, i.e. empirically determined with relation to specific physical environments, and thus being more directly amenable to economic analysis. Compared with this approach, the notion of entropy appears to be overly abstract and irrelevant for economic analysis, leaving by far too many degrees of freedom in interpretation (for a comprehensive survey, see Buenstorf, 2004). In contrast, the negative response to Georgescu-Roegen mainly concentrates on some flaws in his arguments, which have also been pointed out by physicists (e.g. Jaynes, 1982). These are, in particular, his strong opinions against the statistical mechanics foundation of entropy and his attempt at amending thermodynamics by a new 'law' referring to material flows. Those critics reinforce the argument about the irrelevance of entropy for economics in emphasizing its insufficiency in dealing with the evolution of resource constraints in the economy, thus questioning the direct connection between thermodynamics and ecological and environmental economics which Georgescu-Roegen had established (e.g. Khalil, 1990; Gillett, 2006).

In this paper, I explore this contested ground again, armed with a number of new conceptual approaches to entropy that have emerged recently in the context of the Maximum Entropy school in physics and the geosciences, in particular. This approach differs from most conceptualizations of entropy in the economics literature as the Maximum Entropy production hypothesis is applied on steady states of open non-equilibrium systems, so it is more general than the standard equilibrium thermodynamics and the dissipative structures approach in non-equilibrium thermodynamics. As many problems with the original Georgescu-Roegen approach result from the mismatch between the equilibrium concepts of standard thermodynamics and the fact that the human economy is an open equilibrium system, the Maximum Entropy approach might offer a fresh perspective. I emphasize right from the beginning that I am not

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concerned with the Georgescu-Roegen argument about thermodynamics and resource constraints which I consider to be flawed for the case of an open Earth system anyway, and given the growth of technological knowledge with qualitative novelty. My concern is the question whether thermodynamics generates certain most universal propositions about the direction of change in the economy and its underlying mechanisms, which thermodynamics would relate with the general phenomenon of the dissipation of energy in evolving physical structures and the corresponding production of entropy (thus concurring with strands of thought such as Lozada, 2006).

Georgescu-Roegen's way of thinking was driven by some fundamental philosophical propositions, which become highly relevant here. Therefore, I also adopt an analytical–philosophical stance, which translates into the attempt at drawing a new conceptual map for placing entropy in the context of economics. Here, two notions loom large. One is the notion of evolution. Georgescu-Roegen's attack against the statistical mechanics approach to entropy is based on his fundamental distinction between 'arithmomorphic' and 'dialectical' theories, hence emphasizing the principled role of qualitative novelty in evolution. His other notion is the distinction between two conceptualizations of time, the time of mechanical physical clocks and time as a flow through human consciousness. He argues (Georgescu-Roegen, 1971: 130 ff.) that the time's arrow cannot be established by the former, but only by the latter, which implies that its direction cannot be deduced from the laws of thermodynamics directly. Thus, evolution, entropy and a subjectivistic epistemology conflue in shaping Georgescu-Roegen's idiosyncratic view on the role of the 'entropy law' in economics.

I will present a fresh perspective on this fundamental philosophical stance by introducing an equally philosophically grounded interpretation of the Maximum Entropy school in physics, which is so far neglected in the economics debate, to my best knowledge (compare its omission in Ruth, 2005; Ayres, 1994: 36 has only a cursory reference to this, though affirmatively; similarly, e.g. Kåberger and Månsson, 2001). This is significant both for purely theoretical reasons and for empirical research. The former stays at the center of my attention, so suffice to emphasize the second now: One important field of applying the Maximum Entropy approach is the geosciences or Earth system studies, and obviously the human economy is a part of these larger systems. So, empirical support in favour of the Maximum Entropy approach with regard to the Earth system directly raises the question how far the economic subsystem follows similar principles (Kleidon, 2010b; for a critical view on entropic approaches to the Earth system-economy interaction see e.g. Smil, 2008: 341 ff.).

The Maximum Entropy school goes back to the seminal work by Jaynes (1957a,b) on proposing a radical shift in interpreting the concept of entropy. In this view, entropy turns out to be the central conceptual category in drawing inferences about physical systems about which only limited information is available. This approach, labelled 'MaxEnt', is no longer focusing on physical phenomena in the strict sense, but on the methodology of how to draw inferences about them. This shift is rooted in the Gibbs approach to entropy and thus establishes a different path to tackling the Georgescu-Roegen issues, who almost exclusively focused on the Boltzmann line of thinking in his critical endeavours and the classical phenomenological thermodynamics in his own approach. Subsequently, I show that the treatment of the Second Law of Thermodynamics as a 'rule of inference' (Jaynes, 1998) allows for a reconsideration of Georgescu-Roegen's views, which, though refuting his criticism of the statistical mechanics approach again (though with a different emphasis), reinstates some of his central arguments on evolution and the economy.

My argument is not without precedence in ecological economics. One central question is how the thermodynamic and the information theoretic meaning of 'entropy' can be reconciled, which sit awkwardly in between the disciplines, because a formally homologous concept has two very different material interpretations. In the Maximum Entropy school, this tension can be easily resolved because a more general mathematical formalism is offered in which the information theoretic standard use (i.e. the Shannon approach) is just a special case in the context of the analysis of communication systems (Jaynes, 2003: Chapter 22; for the generic mathematics, see Niven, 2007). Instead, the Maximum Entropy formalism appears to be a much more general information theoretic framework in dealing with inference processes of any kind, including inferences about standard ensembles of thermodynamics and statistical mechanics as the classical case (but also, for example, inferences about complex social networks, see Newman, 2010: 565 ff.). As such, this approach is familiar to econometricians (Golan, 2002). However, the core insight by Jaynes went far beyond a simple application of entropy as a principle of inference in the narrow sense, because for the physicist, the fact remains essential that the inferential notion of entropy corresponds to experimental facts about entropy. This has also been the starting point for relating the MaxEnt principle of inference with the Maximum Entropy Production (MEP) principle in the geosciences (Paltridge, 2009, looking back on his seminal work in the past three decades): How far does the successful application of MaxEnt approaches in predicting complex Earth system dynamics imply that those systems also maximize the production of entropy as a physical magnitude in the sense of classical, hence phenomenological thermodynamics? The significance of this question results from the fact that the MEP principle refers to open non-equilibrium systems (and not only to equilibrium systems, as classical thermodynamics), and would therefore assert the most general hypothesis about their trajectories, namely that they approach a steady state in which the production and export of entropy to their environment is maximal (for a short and concise statement, see Kleidon, Mahli and Cox 2010). So, a complete statement of the Maximum Entropy approach includes both MaxEnt as an inference method and MEP as a physical hypothesis.

The conceptual conjunction between thermodynamic and information theoretic uses of entropy has been presaged in ecological economics by Robert Ayres (1994) in his attempt at reconciling the two. Ayres had already developed two important insights, starting out from an observation that directly matches with Georgescu-Roegen's original qualms with statistical mechanics: This is that information is an *intensive* (hence, qualitative, or dialectic variable, in Georgescu-Roegen's parlance), whereas entropy in thermodynamics is an *extensive* variable (Ayres, 1994: 36). One of Ayres' important insights is that there is a direct physical relation between Shannon information H and thermodynamic magnitudes, because the former can be interpreted as a general measure of distinguishability of a system from its environment (Ayres, 1994: 44, $H = B/T_0$, with H the Shannon information, B the available useful work, and T_0 the temperature of the environment). The other is to differentiate between this thermodynamic concept of information (D-information in his terminology) and the evolutionary one, which is survival relevant information (SR-information). The latter refers to a selective context in which a certain information proves to be functional with reference to differential reproduction.

Based on Ayres's contribution, I propose a new philosophical approach to entropy (further developed in Herrmann-Pillath, 2010; Herrmann-Pillath and Salthe, in press). The central idea directly follows from recent advances in applying the MaxEnt approach on the theory of evolution (for an overview, see Whitfield, 2005, 2007). This triggers a surprising twist in dealing with the Georgescu-Roegen issue: Whereas Georgescu-Roegen confronted statistical mechanics and evolution, the shift towards the Jaynes approach in interpreting the former implies that evolution can be seen as a process maximizing entropy. My extension of this view builds on evolutionary epistemology and endogenizes the position of the observer in the inferential approach to entropy: I argue that, if the MaxEnt formalism is the correct and most parsimonious way to form expectations about the behavior of complex systems, this also applies for the evolution of endogenous observers under natural selection. In this view, every living system is conceived as a 'physical inference device' (Wolpert, 2008), and natural selection results into the