Entropy and Wealth – Extended summary

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Dedicated to the memory of Themistocles Xanthopoulos whose book series "Requiem with Crescendo?" triggered the paper

Introduction

In our new paper published in journal *Entropy* in October 2021, we provide insights on the concept of entropy and its relevance to societal and economic issues, with emphasis on wealth. We claim that the concept is widely misunderstood and misused, for example, to support ideologies related to ecological economics and negative Malthusian perspectives. The negative connotations are related to the fact that popular imagination has loaded "entropy" with almost every negative quality in the universe, in life and in society, with a dominant meaning of disorder and disorganization. We try to reverse the negative popular perception, by stressing the fact that entropy, as a formal mathematical (stochastic) measure of uncertainty, is related to the plurality of options and eventually to freedom.

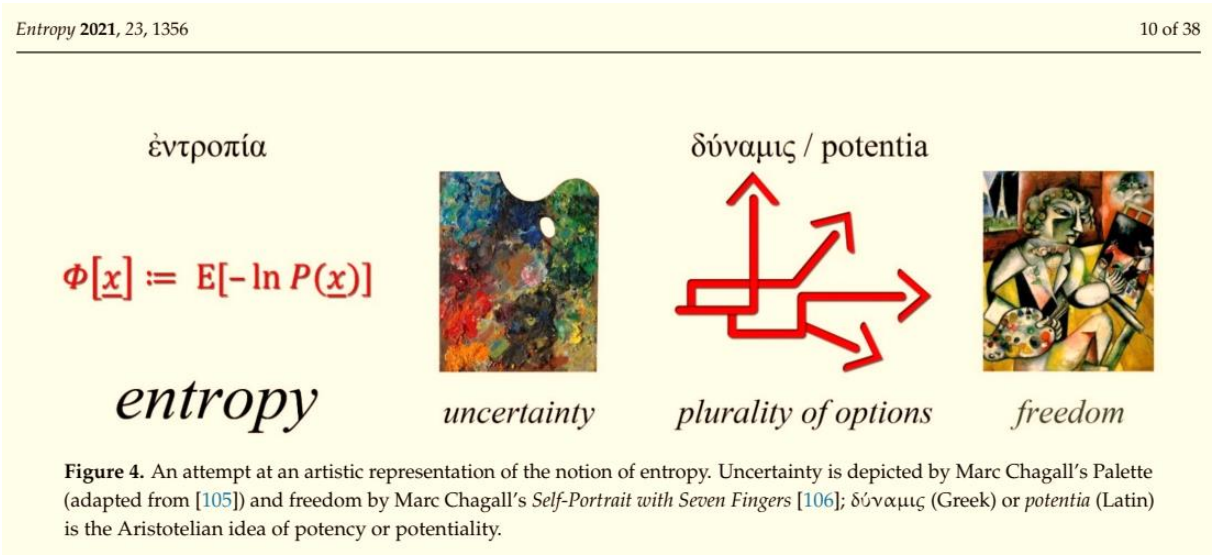

Figure 4. An attempt at an artistic representation of the notion of entropy. Uncertainty is depicted by Marc Chagall's Palette (adapted from [105]) and freedom by Marc Chagall's *Self-Portrait with Seven Fingers* [106]; δύναμις (Greek) or *potentia* (Latin) is the Aristotelian idea of potency or potentiality.

The accompanying principle of maximum entropy, which lies behind the Second Law in physics, gives explanatory and inferential power to the concept, and promotes entropy as the mother of creativity and evolution: While all fundamental physical quantities (mass, energy, momentum, etc.) are conserved, entropy is an exception, a quantity that is not conservative. Nonetheless, the applicability of the entropy concept, with its modern definition as the measure of uncertainty, as well of the principle of maximum entropy, expands far beyond physics and can cover a wide part of the knowledge tree. However, in their majority, applications to fields other than physics, for example in social sciences, have been made in the form of analogies with thermodynamics, using entropy with the metaphoric meaning of the waste produced when work is done. Such applications are often

contaminated by subjectivity and ideological influences. In contrast, we stress that they should exclusively be based on the formal definition of entropy, without metaphors and as objectively as possible.

Historical perspective

The name *ἐντροπία* (Greek for *entropy*) appears already in ancient Greek but was introduced in the international scientific vocabulary by Rudolf Clausius only in 1865. Clausius recognized the entropy's relationship with transformation and change, and the contrast between entropy and energy, where the latter is a quantity that is conserved in all changes. However, it was Ludwig Boltzmann in 1887 the one who understood entropy as a probabilistic concept. He linked it to probabilities of statistical mechanical system states, thus explaining the Second Law of thermodynamics as the tendency of the system to run toward more probable states, which have higher entropy. The probabilistic concept of entropy was advanced later in thermodynamics by Josiah Willard Gibbs (1902) and Leo Szilard (1929). In 1948, Claude Shannon generalized the entropy definition and connected it to the information content. This was adopted by Nobert Wiener in his famous book *Cybernetics*, also published in 1948. In 1956, John von Neumann strengthened the connection of the probabilistic definition of entropy with its pre-existing physical content. The last fundamental contribution to the entropy concept was made in 1957 by Edwin Thompson Jaynes, who introduced the *principle of maximum entropy*. This postulates that the entropy of a stochastic system should be at maximum, under some conditions, formulated as constraints, which incorporate the information that is given about this system. Strikingly however, more than 150 years after its introduction and 65 years after its full clarification and completion of its apparatus, the meaning entropy is still debated.

What entropy is not

The very definition of entropy is inconsistent with a deterministic world view. This entails difficulties in understanding entropy because our education is based on the deterministic paradigm. Indeed, it is difficult to incorporate the clearly stochastic concept of entropy in a deterministic mindset. Therefore, many have tried to find analogues that are deterministic-friendly, identifying it with disorganization, disorder, deterioration. All these have a negative connotation in the deterministic mindset. But they are less appropriate and less rigorous as scientific terms and more appropriate in describing mental states and even more so in describing socio-political states (cf. Nazis' "new order", Kissinger's "new world order" and Schwab's "global order"). Another interpretation, predominantly popular in social sciences and economics, wants entropy to be the waste produced when useful work is done.

While in a particular phenomenon one of these interpretations could be relevant, overall they distort the real meaning of entropy, which in fact does not have a negative content.

What entropy is

According to its standard definition, entropy is precisely the expected value of the minus logarithm of probability (see the related equation in Figure 4 of the paper reproduced above). If this sounds too difficult to interpret, an easy and accurate interpretation is that entropy is a measure of uncertainty.

If "disorder" is regarded as a "bad thing", for many the same is the case with uncertainty. The expressions "uncertainty monster" and "monster of uncertainty" appear in many articles. However, if uncertainty is a monster, it is thanks to this monster that life is livable and fascinating. Without

uncertainty, life would be a “universal boredom”, and concepts such as hope, will (particularly, free will), freedom, expectation, optimism, etc., would hardly make sense.

A technocratic system where an elite comprising super-experts who, using super-models, could predict the future without uncertainty, would also assume full control on the society. Fortunately, this will never happen because entropy, i.e. uncertainty, is a structural property of nature and life. Hence, uncertainty is neither disorder nor a “bad thing”. How could the most important law of physics (the Second Law) be a “bad thing”?

In a deterministic world view, there is no uncertainty and there is no meaning in speaking about entropy. If there is no uncertainty, each outcome is accurately predicted and hence there are no options. In contrast, in an indeterministic world, there is a plurality of options. This plurality corresponds to the Aristotelian idea of δύναμις (Latin: potentia—English: potency or potentiality; see again Figure 4 of the paper reproduced above).

On anti-entropic speculations

Given the dominance of the negative connotations assigned to entropy, many thought that it makes it impossible to understand life, when the whole world is ruled by the Second Law of thermodynamics reflecting entropy’s tendency to become maximal. Their perception is that maximum entropy points toward death and annihilation. Therefore, they have sought an anti-entropic (or negentropic) principle governing life, biosphere, economy, etc., because these convert things which have less order, into things with more order. Such attempts assume a non-statistical definition of negentropy and usually resort to metaphysical notions (e.g. noosphere).

However, if we see entropy as uncertainty, we also understand that life is fully consistent with entropy maximization. The human-invented steam engines (and other similar machines) increase entropy all the time, being fully compatible with the Second Law, yet they produce useful work. Likewise, the biosphere increases entropy, yet it produces interesting patterns, much more admirable than steam engines. Life generates new options and increases uncertainty. Compare Earth with a lifeless planet: Where is uncertainty greater? In which of the two planets a newspaper would have more events to report every day?

Entropy and Marxism

When a system has several degrees of freedom, corresponding to several possible states, while at the same time there is no force dictating or giving preference to a particular state, then entropy maximization will distribute the probabilities of occurrence among all possible states. If no constraint is imposed on the system, all states will be equally probable. The equality in probability is completely different from the deterministic equality, in which all members of a population are in precisely the same state. For the distribution of wealth among the human population, the deterministic equality would result in what is known in the Marxist literature as a classless society. In this case, practically there is only one option, and entropy is the minimum possible. Perhaps this corresponds to a so-called hunter–gatherer society, which historically appeared before the notion of wealth was formed (i.e., when the only option was zero wealth).

The hunter–gatherer society has been admired in Marxist literature as a form of ancient communal ownership and also aspired to in a modern form. The notion of a classless society remains popular

even today and, strikingly, it has been regarded as a basis for real personal freedom, despite corresponding to the minimum value of entropy. Apparently, Marx and Engels were faithful to the deterministic scientific paradigm of their era, which they attempted to transplant into history and sociology. They could not have been aware of the modern concept of entropy. The popularity of their ideas even today reflects the fact that the deterministic paradigm remains quite strong. In it, entropy has no place, let alone in its connection with freedom.

Entropy in economy

In modern societies, the technology has increased the upper limit of possible wealth of individuals by so much that practically does not put any restriction in entropy maximization. As a result, entropy maximization of the income distribution of individuals, with the only restriction being the total income of the society (or equivalently, the average income per individual), results in exponential distribution. This appears to be the natural distribution that is connected to a stable economy.

There seem to exist two main forces acting in opposite directions to modify this natural distribution. On the one hand, an organized society redistributes income and wealth through their transferal from the richer individuals to the poorer by means of several mechanisms (e.g. taxation). As a result of redistribution: (a) poverty below a low level is eliminated; (b) the middle class, becomes more populated and amplified; (c) the rich lose income.

On the other hand, the actions of economic elites, pursuing a greater share of the community's wealth, tend to modify mostly the income distribution tail, converting it from exponential to power-law (also known as Pareto, after the famous Italian civil engineer and economist of the late 19th and early 20th century Vilfredo Pareto). The effects of this force on the income distribution are to: (a) increase the number of poor; (b) diminish the middle class; and (c) benefit the richest.

At the same time, the elites advance both the technological limit and the average wealth. Naturally, the advancement of technology and average wealth are the positive side of elites' action, but this is hardly understandable by people. For this reason (and possibly other reasons too), elites use different means to make their actions more efficient and acceptable within the society. These include overstating existing or non-existing threats, and then presenting themselves as philanthropists (e.g., by funding nongovernmental organizations dealing with these threats) and world saviours. The means by which the elites increase their profits certainly include political power, and more recently, an attitude of world control. Apparently, if they succeed in controlling the world, this will decrease entropy and hence delimit freedom. In turn, it will lead to decadence, the signs of which are already visible in the Western world.

Empirical investigation using modern data

In order to empirically study the tail of income distribution, and in particular to check whether its tail is exponential or Pareto, we used data for the net worth of richest people of the world and the evolution thereof. Specifically, we used data from the Forbes and Bloomberg lists of billionaires for the years 1996 to present. Based on these data and with focus on the distribution tail, we concluded that the exponential tail is not uncommon, while the Pareto tail appears particularly in anomalous periods. Impressively, the latest period of pandemic resulted in unprecedent profits of the richest, with a clear Pareto tail (see Figure 9 of the paper, which is also reproduced here).

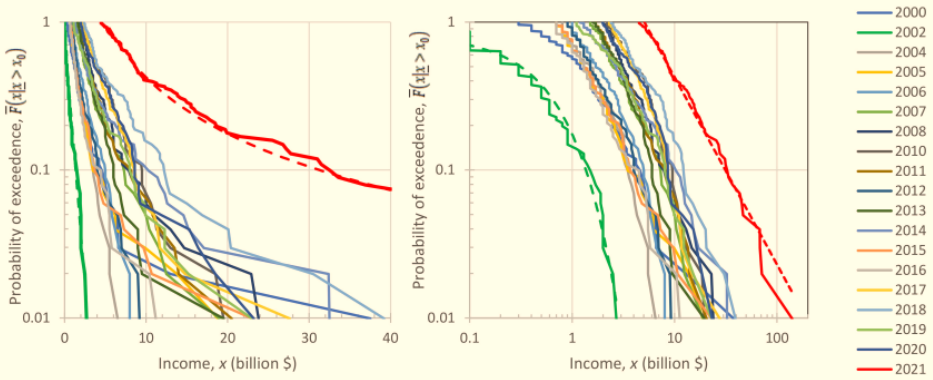

Figure 9. Conditional probability of exceedance of the annual income of the richest persons in the world for the indicated years. The income per person was found by subtracting the total net worth of a year from that of the previous year. For the years 2002 (lowest average income) and 2021 (highest average income) exponential and power–law trends, respectively, are also plotted with dashed lines of the same color (where in the left panel the green dashed line for 2002 is indistinguishable from the continuous line). In both panels, the probability of exceedance is plotted on logarithmic axis, while the income x is plotted on linear axis in the left panel and logarithmic axis in the right panel.

Furthermore, we used detailed official data of income distribution for USA and Sweden. We showed that income distribution is consistent with the principle of maximum entropy, and in particular with the exponential distribution (see Figure 15 of the paper, which is also reproduced here). Yet the effect of the elites is visible, as the distribution tails exceed those of the exponential. On the other hand, the data do not support the well-known "80/20 rule", which is consistent with the Pareto distribution (with a specific value of the tail index). Specifically, 80% of the income is not generated by 20% of the population, but by more than 40% thereof, which is fully consistent with the exponential distribution. Interestingly, the "80/20 rule" is often called the "Pareto rule", but the historical investigation we conducted reveals that Pareto did not suggest that, but later authors loaded him with things that he never said.

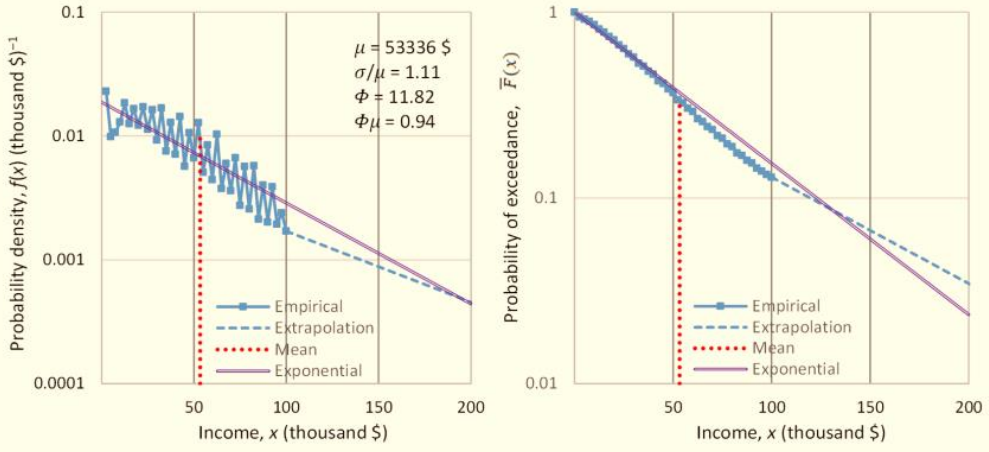

Figure 15. Illustration of the entropic framework using income data from the USA for year 2019; (**left**) probability density; (**right**) tail function (probability of exceedance).

Overall, in the paper we have tried to dispel the "bad name" of entropy in social sciences and have emphasized its connection with the plurality of options. We showed that increasing entropy is associated with increases in wealth. In addition, we showed that a standardized form of entropy can be used to quantify inequality.