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# How Economists can use the Laws of Physics On the Example of the Notion of Entropy in its Application to Some Economic Conceptions

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This article deals with the notion of entropy in its applicability to economics. Briefly, it regards some classical cases of such a use as the labour concept of Podolinsky and the bioeconomics of Georgescu-Roegen. This article also attempts to apply the concept of entropy to the analysis of market structures in the example of the perfect competition model. Thus, the article asserts that if we compare different entropy concepts with the main characteristics of a market with perfect competition, we must conclude that the latter is a structure with the maximum level of entropy. But maximum entropy means the system's death. So, as a system or a structure, a perfectly competitive market cannot exist. When analysing such a model, economists recognise its impossibility in real life from an empirical point of view. However, the application of the entropy concept helps us to repeat this approval also as a methodological one. The use of the entropy concept as a methodological instrument helps to question some other economic models, too.

**Keywords**: Entropy, the Second Law of Thermodynamics, Market Structure, Perfect Competition, Uncertainty, Information, Disorder
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## Introduction

The implementation of physical concepts in economics is not a new phenomenon. For example, it is enough to remember Alfred Marshall, who in his researching activity 'migrated' to political economy from mathematics and in his famous *Principles of Economics* used analogies between economic and physical phenomena. As for the notion of entropy, one of the first economists who used it in economic analysis was the Ukrainian scholar Sergei Podolinsky. In his work *Human Labour and Its Relationship with Energy Distribution*, published in 1880 for the first time, he proposed a new definition of human labour on the basis of the Second Law of Thermodynamics. However, the contemporaries of Podolinsky did not understand and did not appreciate his theory.

Nowadays, in contrast to the time of Podolinsky, many economists know and use the principles of the general systems theory, and thus the application of the notion of entropy in economic research is not an exception. The last decades have been characterised by the large-scale penetration of the systems theory and synergetics in economic science and also by the growing popularity of econophysics. Despite this tendency traditional economics textbooks actually do not use a concept of entropy to characterise economic systems (structures) and phenomena. A lot of economic theorists do not have enough knowledge of physics and pure mathematics. On the other hand, econophysics and economic synergetics are too mathematized: often behind complex formulas and models the economic sense of phenomena under consideration is being lost. For example, the modern Russian physicist A. Panchenkov (2007, 154), in his book *Econophysics*, besides conventional definitions proposes the following characteristics of entropy: entropy is the absolute integral invariant of virtual continuum; it is the measure of the virtual continuum's order; it is the measure of the intelligence of the Universe structures; it is the object of the global symmetry of the virtual continuous medium, etc. It is doubtful that a definition, so sophisticated, clarifies the head of an economic theorist and helps him to grasp economic and physical phenomena. Besides, it is necessary to be extremely careful in using the notion of entropy in an economic analysis and, thus, to make certain statements. This is primarily due to the fact that representatives of the natural sciences themselves have no consensus on the definition of entropy: to date, there is a great number of different entropies (entropy of Boltzmann, Gibbs, Clausius, Shannon, Kullback, Hardy, Tsallis, etc.), and there is no single and perfect definition (Panchenkov 2007, 153). It is noteworthy that Nicholas Georgescu-Roegen, whose name we associate primarily with the application of the notion of entropy in modern economics, also emphasised that 'the concept of entropy is so involved that even physicists may go wrong with it' (1986, 3).

Despite contradictory interpretations of entropy, the correct use of this notion in economics can be quite productive, as it methodologically enriches economic analysis. Briefly, this paper regards some classical cases of such a use as the labour concept of Podolinsky and the bioeconomics of Georgescu-

Roegen. Moreover, on the basis of the main and comparatively simple definitions of entropy, I try to demonstrate how the application of the concept of entropy complements the analysis of some other economic phenomena, making them more obvious or, conversely, unenforceable. In particular, this article attempts to apply the concept of entropy to the analysis of market structures in the example of the perfect competition model. So, the article asserts that if we compare different entropy concepts with the main characteristics of a market with perfect competition, we must conclude that the latter is a structure with the maximum level of entropy. But maximum entropy means the system's death. So, as a system or a structure, a perfectly competitive market cannot exist. In addition, the use of the entropy concept as a methodological instrument helps us to question some other economic models, too.

## 1. Human labour versus entropy: the law of Podolinsky

Sergei Podolinsky was born in 1850 and died in 1891 in Kiev. He had a medical education and also dealt with political economy, physics, and philosophy. The diversity of his knowledge is reflected in his approach to economic analysis and in general his multidisciplinary character. So, in his economic work *Human Labour and Its Relationship with Energy Distribution*, published for the first time in Russian in the journal *Slovo* (St. Petersburg) in 1880, he proposed the new definition of human labour on the basis of the laws of thermodynamics.

In the book mentioned above, Podolinsky starts his analysis from the examination of energy and the law of energy conservation. He also regards the Sadi (Nicolas Léonard) Carnot's research dealing with the operation of heat engines and, thus, he actually regards the Second Law of Thermodynamics. The second law of thermodynamics asserts that a natural thermodynamic process runs only in one sense, and is not reversible. For example, heat always flows spontaneously from hotter to colder bodies, and never the reverse, unless external work is performed on the system. In terms of entropy the second law of thermodynamics states that the entropy of an isolated system never decreases, because isolated systems always evolve toward thermodynamic equilibrium; that is, toward a state with maximum entropy.

Using the principles of thermodynamics, Podolinsky asserts that the role of the internal energy of the Earth and the energy of the Sun in the energy budget of the Earth with time decreases (Podolyns'ky 2000). The part of the energy which the Earth receives from the Sun dissipates and thus transforms into inferior (unproductive) forms. But part of this energy is being accumulated by animals and plants (transforming into superior forms). Since animals and plants are capable of accumulating the sunny energy, human activities related to crop production and livestock (agriculture) contribute to the accumulation of the productive energy of the Earth. So Podolinsky proposes the new definition of human labour. According to his definition, (human) labour is such a consumption of mechanical and psychical work, accumulated in an organism, which results in the growth of transformed energy on the Earth's surface. (In this definition, we must understand '*work*, accumulated in an organism' as an '*energy*, accumulated in an organism'. '*Transformed energy*' is the energy of superior quality.)

In opinion of Podolinsky, the most productive labour is agricultural. So with this point he is very close to the ideas of physiocrats. But his definition of labour was really innovative. In general, according to Podolinsky, human labour gives possibility to accumulate additional energy on the Earth and to prevent the dissipation of energy (counteracts entropy).

Podolinsky also participated in the socialistic movement of Russian Empire and was an admirer of Karl Marx. He sent Marx the French version of his work (*Le travail humain et la conservation de l'énergie*), asking his opinion on the issue and said that he wrote this work under the influence of *The Capital*. Marx responded favourably to the work of Podolinsky and asked Friedrich Engels to express his opinion. In his letters to Marx, Engels pointed to the value of Podolinsky's discovery but considered its economic conclusions wrong. In the opinion of Engels, Podolinsky's 'real discovery is that human labour is capable of retaining solar energy on the earth's surface and harnessing it for a longer period than would otherwise have been the case'; but Podolinsky wanted to use this argument to prove socialism and, thus, mixed physical phenomena with economic ones ('economics should not be mixed up with physics') (Korniychuk 2000, Burketta and Fosterb 2008).

The main work of Podolinsky was published in Russian, French, German, and Italian. But contemporaries of the Ukrainian scholar did not appreciate it. This fact greatly depressed Podolinsky. The modern estimate of Podolinsky's views is ambiguous. Some scholars write that 'Engels's criticisms of Podolinsky are found to be quite justified from both political-economy and ecological perspectives' (Burketta and Fosterb 2008). However, many modern Ukrainian and Russian economists are deeply interested in the scientific heritage of Podolinsky, and his conclusion about the ability of human labour to prevent the growth of entropy (or to increase land productivity and, thus, accumulation of useful energy on the Earth) they name as the law of Podolinsky (Korniychuk 2000).

## 2. The notion of entropy in modern economics: the ideas of Nicholas Georgescu-Roegen

In modern economics, the use of the notion of entropy is primarily associated with the Romanian-American economist Nicholas Georgescu-Roegen and his work *The Entropy Law and the Economic Process* (1971).

Like Podolinsky, Georgescu-Roegen's analysis of entropy in its relation to human economic activities builds on the basic laws of thermodynamics. In particular, he notes that:

«Received thermodynamic theory is founded on four laws – the first, total energy is constant; the second, in actuality entropy steadily increases; the third, the absolute zero of temperature cannot be reached; and the 'zeroth' (so termed because it was added last but being the most fundamental it had to precede 'the first') which states that thermodynamic equilibrium is transitive condition» (Georgescu-Roegen 1986, 6).

However, Georgescu-Roegen's visual angle for the assessment of human economic activity in relation to entropy is absolutely different from S. Podolinsky's. So, if according to Podolinsky, human labour gives the possibility to accumulate additional energy on the Earth and to prevent the dissipation of energy (counteracts entropy), according to Georgescu-Roegen, humankind with its economic activity is the most significant contributor to entropic degradation by the increasing rates of extraction of natural resources and elimination of wastes into the environment.

To some extent, the mentioned difference can be explained by the fact that Podolinsky, regarding human labour, meant first of all labour in the field of agriculture, whereas Georgescu-Roegen criticised the model of economic activity (growth), typical for the era of industrialism. In contrast to the agrarian society, which mainly has characteristics of a closed and static system, industrial systems are mainly open and dynamic, and the long-term economic growth is regarded as a crucial macroeconomic feature and a goal of industrially developed countries.

Furthermore, during the period preceding the publication of Georgescu-Roegen's works dealing with entropy, economists, influenced by the Great Depression, tried to elaborate the models of long-run growth associated with a smooth and uninterrupted (crisis-free) functioning of an economy. They could be models within the framework of Keynesian economics using an investment multiplier (Harrod–Domar model), or they could be neoclassical models, in which technological progress was regarded as a crucial factor of long-run economic growth (Robert Solow model). Nevertheless, despite the distinction in methodological approaches, the different growth models had something in common, namely the intention to design a special 'golden' formula (function, mechanism, proportion) to ensure the steady growth of an advanced capitalist economy. In some ways, such a formula in economics recalls a hypothetical perpetual motion machine in mechanics. As a perpetual motion machine can do work indefinitely without an energy source, the mentioned 'golden' ratio (as a warranted growth rate in the Harrod–Domar model or the golden rule of capital accumulation in Solow's model, etc.) can help an economy grow smoothly without recessions.

In mechanics, the idea of a perpetual motion machine was disproved by the law of entropy. Similarly, Georgescu-Roegen, using the thermodynamic theory, criticised the numerous growth theories that were popular at that time. In his opinion, although all production processes do not obey the same economic laws, all economic processes, like biological processes, are subject to the Entropy Law. So, in accordance with Gowdy and Mesner, 'invoking the Second Law of Thermodynamics, Georgescu-Roegen incorporates the idea of entropic degradation as a fundamental constraint on all economic activity' (1998, 146).

Indeed, although industrial capitalism must be regarded as a dynamic and growing system, it also depends on limited material resources, whose creation (production) is determined by the Earth as a geological and ecological system. Strictly speaking, the Earth as an ecosystem with its resources is not a closed system, because it constantly receives solar energy; however, from the standpoint of obtainment of mineral and energy resources such as gas, oil, and coal, humankind must regard the Earth as a closed (isolated) system. Even if we imagine that with time such resources can be reproduced naturally, it takes an incredibly long period of time in comparison with a human life as well as the existence of mankind in general. In this way, it is no coincidence that Georgescu-Roegen emphasised the anthropomorphic aspect of thermodynamics laws and pointed to 'the finite human nature' (Georgescu-Roegen 1986, 5).

With his skepticism toward the growth models, including the Solow's, and considering the unlimited progress and the power of technology without limits as a myth (Georgescu-Roegen 1975), in his own model of production Georgescu-Roegen defined a technology as viable if and only if it can maintain the corresponding material structure that supports its resource flows and sustaining functions and that can consequently support the human species indefinitely under current environmental conditions (Gowdy and Mesner 1998, 149–150).

It is symbolic that the principal Georgescu-Roegen work on entropy was published in 1971, that is, at the peak of the relatively long economic prosperity of the sixties and almost on the eve of the global energy crisis of the mid-seventies. So, in some sense, his work played a prophetic role. Besides, bioeconomics, as Georgescu-Roegen called his new theoretical approach, is directly related to ecological economics, whose emergence dates back to the 1980s and which is also associated with Robert Costanza, Howard T. Odum, Herman Daly, and others (Sagoff 2012). Like the bioeconomics of Georgescu-Roegen, modern ecological economics treats the economy as a subsystem of the ecosystem and focuses upon preserving natural capital (Costanza et al. 1997).

As for other fields of modern economics dealing with the Second Law of Thermodynamics, it is necessary to mention such a school of heterodox economics as thermoeconomics. Thermoeconomics deals with the concept of exergy and the efficiency of human-engineered energy systems, such as thermal power plants and chemical plants. The name 'exergy', just as we know it currently, was introduced in the early 1950s by the Slovene mechanical engineer Zoran Rant. He defined it as technical available energy that is externally useful work in opposition to the energy associated with the internal work of a system. So, in modern thermodynamics, the exergy of a system is the maximum useful work possible during a process that brings the system into equilibrium with a heat reservoir.

The word 'thermoeconomics' was coined by the American engineer Myron Tribus in the early 1960s when, together with R. Evans, he studied desalination processes and made exergy analysis, which led him to the idea of exergy costing and its applications to engineering economics (Valero and Cuadra 2009). According to Richard Gaggioli, who is one of the most prominent researchers in the field of thermoeconomics, using exergy content as a basis for cost accounting is important to management for pricing products and for their evaluation of profits; exergy is the only rational basis for evaluating fuels and resources, processes, devices, system efficiencies, dissipations and their costs, and the value and cost of systems outputs (Wall 1986, 12).

Nowadays, thermoeconomics is a school of heterodox economics that applies the laws of thermodynamics to economic theory. Antonio Valero and César Torres Cuadra define it as 'the science of natural resources saving that connects physics and economics by means of the Second Law of Thermodynamics' (2009, 1). Thermoeconomic analysis combines economic and thermodynamic analysis by applying the concept of cost, originally an economic property, to exergy.

## 3. Definition and properties of entropy

Although entropy is associated primarily with the Second Law of Thermodynamics, for today there are different definitions of entropy, not always harmoniously combined with each other (Panchenkov 2007).

We can consider some of the most well-known approaches to the identification and characterisation of the properties of entropy as next ones.

1. ***Entropy as a measure of disorder.*** In particular, in this way entropy is treated in thermodynamics. According to the second law of thermodynamics, the total entropy of any isolated thermodynamic system tends to either remain constant or increase over time, approaching a maximum value. This also means that an isolated system will gradually become more and more disordered.

2. ***Entropy as an energetic process.*** Entropy is associated with the process of the transformation of a high-quality energy (useful energy) into a low-quality energy ('low-grade' energy), or with the process of dissipation of useful energy. Quality of energy, in its turn, is determined by its ability to do (useful) work.

In physics, work and entropy are inversely related. The principal way to decrease entropy is to do work through the expenditure of free energy. If free energy is available and is expended to do work, then the system becomes more orderly and entropy decreases. But if all available energy has been expended, then no more work can be done, and entropy will either remain constant or increase (Bailey 1990).

3. ***Probabilistic approach.*** In thermodynamics the calculation of entropy is based on following Boltzmann's formula for an isolated system at thermodynamic equilibrium:

$$S = k \ln W, \qquad (1)$$

where $k$ is the Boltzmann constant ($k = 1{,}38 \cdot 10^{-23}$ J/K) and $W$ is the number of distinct microscopic states consistent with the given macrostate (such as a fixed total energy $E$). The Boltzmann formula shows the relationship between entropy and the number of ways the atoms or molecules of a thermodynamic system can be arranged. With the growth of the number of microscopic states $W$, associated with the macroscopic state of the system, entropy also increases. According to this approach, the maximal entropy characterises the structure that consists of (a multitude of) homogeneous elements (Melnik 2003). Also the maximum of the entropy function is the *logarithm* of the number of possible events, and occurs when all the events are equally likely (Carter 2011, 30).

$W$ in Boltzmann's formula is sometimes called the *thermodynamic probability* since it is an integer greater than one, while mathematical probabilities are always numbers between zero and one.

In fact, Boltzmann's formula characterises entropy as a probabilistic state of a system, that is, entropy is connected with probabilities. Leon Brillouin, in his book *Scientific Uncertainty and Information*, wrote: «Let us examine the evolution of some isolated system. This unstable system left on its own will be destroyed, gradually converting into more probable and stable states. At the same time both probability and entropy are growing» (Brillouin 2006 [1964], 28).

4. ***Entropy as the opposite of information***. Statistical entropy is a probabilistic measure of uncertainty or ignorance; information is the measure of reduction in that uncertainty.

According to Brillouin, additional information about the system we are dealing with is a consequence of the reduction of entropy. Thus, the information is a negative contribution to entropy and is the equivalent of negentropy (negative entropy). He marked that despite entropy usually being described as measuring the amount of disorder in a physical system, a more precise statement is that *entropy* *measures the lack of information* about the actual structure of the system. This lack of information introduces the possibility of a great variety of microscopically distinct structures, which we are, in practice, unable to distinguish from one another. Since any one of these different microstructures can actually be realised at any given time, the lack of information corresponds to actual disorder in the hidden degrees of freedom.

It is important to note that just as in thermodynamics the maximal entropy characterises the structure that consists of (a multitude of) homogeneous elements, according to the concepts of information theory, the same type of a structure is connected with zero (minimum) information. This idea in information theory resembles the law of diminishing marginal utility in economics. The last one states that as more of a good or service is consumed, the marginal benefit (utility) of the next unit decreases. Analogically, if we regard the sequence (a set) of homogeneous events, every next such event (or a message) gives us less (or even zero) information than the previous event.

## 4. The use of the notion of entropy to characterise the stability of a market with perfect competition

Since among other definitions entropy is a measure of disorder, it is natural to consider whether such a notion is applicable to analyse the character of order for market structures. From this point of view, it is interesting to examine the market of perfect competition, because in modern economics this kind of market serves as the starting point in the comparative analysis of key market structures[1].

The development of the model of perfect competition is associated with the names of Antoine Augustin Cournot and neoclassicists, such as William Stanley Jevons, Francis Ysidro Edgeworth, Alfred Marshall, John Bates Clark and Frank Knight (Stigler 1957). In general, in the well-established modern interpretation, a market with perfect competition corresponds to the following basic conditions: a very large number of independently acting sellers; there is perfect knowledge and knowledge is freely available to all participants; a standardised product (perfectly competitive firms produce identical or homogeneous product); a single firm is said to be a price taker because no single firm can influence the market price, taking its price from the whole industry; there are no barriers to entry into or exit out of the market (McConnell and Brue 2008, 400).

Despite the fact that modern economics recognises the unreality of a market with perfect competition, the latter still continues to set a peculiar benchmark. Therefore, it is considered that in comparison with other market structures, a perfectly competitive economy uses the limited amounts of resources

[1] This hypothesis was initially presented by the author of this article at a conference held in Kiev in 2009 (Vozna 2009).

available to society in a way that maximises the satisfaction of consumers; efficient use of limited resources necessitates both productive efficiency and allocative efficiency (McConnell and Brue 2008, 416). However, this traditional thesis can be questioned if in the study of economic structures we apply the definitions of entropy considered above. The fact is that we can primarily characterise perfect competition as the maximum entropy state. I base such an assumption on the following arguments.

1. ***Probabilistic approach.*** A market with perfect competition is absolutely deconcentrated. It is presented by a very large number of sellers (and buyers) who offer completely identical goods and cannot affect a price of their products. An equilibrium price in such a market is established under the influence of supply and demand at the level of an average cost. Thus, the price differences here (between sellers) are minimal; theoretically they are absent. That is why, in such a situation, if we consider a single firm that sells a certain product at a price $p_0$, there is a great probability that all such products in the market are being proposed for a given price $p_0$. Or, from another point of view, there is a great probability that every firm sells goods at a given price $p_e$ and gets a given rate of profit.

As indicated above, the maximal entropy occurs when all of the possible states of a system are equally probable. In the case of a market with perfect competition, we also deal with events, which are equally likely. Since all sellers in the market offer identical (homogeneous) goods at the same price, the buyer is indifferent regarding which sellers to deal with. This means that a firm in such a market cannot have its constant costumers. The probability that a consumer $B_1$ will buy a certain product from a seller $S_1$ equals the probability that he will buy the same product from another seller $S_2$ or from another seller $S_2$, and so on.

Which is a general number of combinations of consumer distributions between sellers (firms)? If a number of sellers equals $\boldsymbol{n}$ and a number of buyers equals $\boldsymbol{m}$, the general number of these combinations $\boldsymbol{N}$ is equal to $\boldsymbol{n^m}$. For example, if we have the situation of a pure monopoly, the number $\boldsymbol{N}$, despite the number of buyers, always equals 1. But the number $\boldsymbol{N}$ is maximal for a market with perfect competition where both $\boldsymbol{n}$ and $\boldsymbol{m}$ are very large.

This numerical expression does not mean that a pure monopoly market is a structure with the minimal level of entropy, but, as for a market with perfect competition, it seems to be in accordance with Boltzmann's probabilistic formula of entropy, considered above, because the maximum of the entropy function is the logarithm of the number of possible events, and occurs when all the events are equally likely.

2. ***A homogeneous structure.*** The market with perfect competition is a type of homogeneous system (structure). But according to the thermodynamics approach, the maximal entropy characterises the structure that consists of (a multitude of) homogeneous elements.

3. ***From the information point of view.*** As a homogeneous structure a market with perfect competition must be characterised by zero information. As it was mentioned above, according to information theory, the equilibrium set of homogeneous elements in a state of chaos (absolute equilibrium) cannot have the information (Melnik 2003, 206). Indeed, a market with perfect competition is also a market with perfect information inasmuch as information here is absent (has no value). Its absence is due to the fact that since the sellers offer completely identical products, they have nothing to hide from each other. The absolute absence of barriers to entry in this market also means a lack of information barriers. But minimum (zero) information corresponds to maximum entropy.

In modern economics such a market, marked as perfect competition, is a rather theoretical construction and practically does not exist. In addition, it is also called 'the competition without competition' (Yudanov 1997), because we cannot find here any price competition (since no one seller is able to influence a price, as well as modify it without adverse consequences for themselves) as well as non-price one (as goods here are standardised and homogeneous)[2]. However, considering a market with perfect competition as the maximum entropy structure, we come to the same conclusion about the impossibility of its practical implementation. Moreover, if we accept the assumption that a market with perfect competition is characterised by maximum entropy, we can make following conclusions.

1. Since entropy is a measure of disorder, a market with perfect competition is totally unorganised (unstructured). It is a chaotic, unsystematic market. That is why it is a short-lived (with a minimum density of time) formation.

2. As unorganised, such a market exists outside of any economic institutions, including the market ones. Thus, a perfectly competitive market cannot realise itself as a market institution (that is, on the principles of the market economy).

3. Being completely chaotic and unstructured, such a market cannot be considered as a system. This means that in achieving the maximum level of entropy, a system dies (ceases to exist). Thus, a perfectly competitive market characterised by the maximum level entropy cannot exist, basically.

4. If the increase of entropy means the reduction of the system's ability to do work, a market with the maximum level of entropy should be characterised by minimum productivity and functionality. In particular this means that any other economic structure characterised by a higher level of market

[2] In particular, in his critique of the theory of perfect competition, Friedrich August Hayek wrote: «what the theory of perfect competition discusses has little claim to be called 'competition' at all»; «advertising, undercutting, and improving ('differentiating') the goods or services produced are all excluded by definition – 'perfect' competition means indeed the absence of all competitive activities» (Hayek 2009 [1948]).

(production) concentration can create (provide) a larger volume of utility (benefits) than the structure with perfect competition.

5. As a structure with a maximum level of entropy, a perfectly competitive market should be characterised by a lack of energy, that is, movement capacity. In our case it is not a mechanical motion, but processes of modification and/or development of a system. Thus, the market with perfect competition is incompatible with the processes of innovative changes.

These conclusions are not statements, but only assumptions; they are, rather, questions designed to encourage further research and discussion involving economic theorists as well as physicists. For example, I think Brillouin's thesis that the maximum entropy state is also the most stable (see above) requires further consideration. Firstly, if we deal with a system, when a last one reaches the maximum level of entropy, it stops being characterised as a system, since in this state maximum entropy it is already destroyed.

Secondly, if we regard the particular case of a market with perfect competition, in historical context, we can see its non-viability and, on the contrary, the trend of its displacement by such market structures with a higher level of complexity and market concentration such as monopolistic competition, oligopoly, monopoly markets, and so on. From this point of view the appeal to the concept of entropy in general gives us additional arguments to assert that internally homogeneous systems, structures, and formations are unsustainable. At the same time the market structures sample demonstrates how systems tend to complexity and higher information capacity. In other words, we do not observe here the movement system's elements to the maximum entropy state as the most probable one, but, opposite, the 'escape' from the state with maximum level of entropy to the structure with less entropy level.

It makes sense to note that Part III of the Frank H. Knight's famous work *Risk, Uncertainty, and Profit* has the title *Imperfect Competition through Risk and Uncertainty* (1921). His approach is very in tune with the proposed view of the perfectly competitive market as the maximum entropy formation, because uncertainty is connected with entropy (entropy as a measure of uncertainty). So the thesis about the 'escape' of markets from perfect to imperfect competition forms in order to reduce uncertainty and risk also suggests the assumptions made above.

Besides, if we conclude that a market with perfect competition is totally unorganised and chaotic, we must consider which type of disorder we are dealing with in this case. One of the founders of synergetics, I. Prigogine, in his book *Exploring Complexity*, together with G. Nicolis, indicated at least two types of disordering. The authors wrote that order looks like a kind of compromise between two antagonistic factors. The first factor is a non-linear process like a chemical one, which continuously and uncoordinatedly sends innovation signals in the form of fluctuations. Another factor is the process of transportation type that catches, passes, and stabilises these signals. The violation of the delicate balance between these two factors leads to qualitative changes of a state. One of them is a chaotic state in which every element of a system acts independently. In another situation, we have a homeostatic, frozen state, which is characterised by complete homogeneity and in which all fluctuations are suppressed. So, the complexity from both sides is constricted by two types of disorder (Nicolis and Prigogine 2003 [1989]). In this sense, a market with perfect competition must be regarded from the standpoint of a dynamic and evolutionary process in economy, and thus this type of market can correspond to a specific phase of such a process.

As an example, we can consider a process of the diffusion of innovations or the life cycle of a product. Suppose that a certain company offers a completely new product on the market. As the sole distributor of this product, it has monopoly advantages and can receive a supernormal profit, but only until the moment when other firms also begin to supply the same (new) product. Increasing competition leads to a drop in prices, and the economic profit, derived by an innovator, just disappears. Eventually, if the diffusion of a certain innovation proceeds too (infinitely) rapidly and when other firms enter the market of an innovative product extremely easily — that is, without special information or technological, institutional, or other obstacles (barriers) — it undermines the very motivation of the individual firm to the innovation activity.

Therefore, we can conclude that such a market structure in which barriers to entry and exit do not actually exist, resources are infinitely mobile and the prices are too flexible, corresponds to the homeostatic type of disorder. According to Nicolis and Prigogine, this type of disorder means the frozen state of a system, which is characterised by complete homogeneity and in which all fluctuations (innovation signals) are suppressed.

## Concluding remarks: entropy as a methodological principle

Of course, we can doubt the transfer of a thermodynamics principle into an economic analysis and the analogy of economic actors with gas molecules randomly moving in space. But, similarly with a thermodynamic system (a state) with maximum level of entropy, in the case of a market with perfect competition we observe the same invariance of a macrostate in the relation of changes in location of microelements. For example, if we regard a thermodynamic homogeneous system (with maximal entropy), the mutual swapping of the particles 'A' and 'B' does not change the macrostate (parameters) of a system. Similarly, in a market with perfect competition a buyer does not matter in which vendor to buy, and also the geographical location of a firm is not important.

The similar invariance we also observe in the case of a homogeneous social system. As an example we can regard the behaviour of a crowd. Besides, such invariance characterised the socialistic (communistic) system in the imagination of Vladimir Lenin, who asserted that 'every cook must learn to rule the State'. In other words, it is the type of a social system where each member of society is easily replaced by another one. So, Newton turns into a cook and a cook easily becomes an 'outstanding' physicist. Naturally, the conversion of 'cooks' into 'Newtons' destroys the science itself. But precisely this mutual conversion between 'Newtons' and 'cooks' acquired massive character in the former USSR during the 'heroic' time of building communism and the period of mass repressions of Stalinism. Thousands of brilliant scientists and cultural figures carried out unbearable primitive physical work in Stalin's camps, while the key positions in the economy, science, and arts were often occupied by ignorant and incompetent persons. And just as the increase of entropy in a thermodynamic system is accompanied by its (system) loss of the ability to do work, such monstrous substitutability of people-cogs in the Stalinist system inevitably led to the low productivity of social labour.

We can use the entropy invariance principle (the principle of equal probability) as a kind of methodological device (method) and compare it with Karl Popper's principle of falsifiability. For this analogy (existential thinking about the method), I was inspired by the contemplation of a picture depicting something very abstract. Looking at it, I began to realise that it was a truly brilliant picture because it could represent absolutely everything! It could be called 'War', 'First Love', 'Echoes of Spring', or even 'The French Revolution'. Try to prove that this is not true! It also could be named 'Perfect Order' and such a title also would be true. That is why I associate this kind of art with the state with maximum level of entropy.

The presented indifference to a name resembles the impossibility of falsification of pseudo-scientific theories in the concept of Karl Popper (2005 [1959]). Popper claimed that, if a theory is falsifiable, then it is scientific. So, Geoffrey M. Hodgson (2012, 98) regards the utility maximisation principle (function) as an example of such an unfalsifiable theory. In particular he wrote:

«The utility-maximization assumption is unfalsifiable, but it is not a tautology in the logical sense because it is conceivably false. Logical tautologies – such as a triangle has three sides – are true by definition. By contrast, it might be the case that individuals are not maximizing anything. But we can never establish this on the basis of empirical evidence. This does not necessarily mean that the utility maximization framework is useless or wrong. We do not have to uphold falsifiability as the mark of science – a criterion attributed to Karl Popper, who in fact adopted a more nuanced position. Neither tautological nor non-falsifiable statements are necessarily meaningless or unscientific. A key problem with utility maximization is that it is so general that it can explain anything; consequently its explanatory power in specific instances is dramatically diminished. Its explanatory success is an illusion. Close inspection of its proclaimed achievements reveal that the results always depend on additional assumptions».

If we assert that an unfalsifiable theory is characterised by maximum level of entropy, it can create confusion. However, the 'illusory explanatory success' of an unfalsifiable theory resembles the situation where the increase of entropy means the reduction of the system's ability to do (useful) work. Besides, at the point where Hodgson (2012, 98) asserts that such models as axioms of utility maximisation must depend on auxiliary assumptions to generate specific results, I emphasise the similarity between an unfalsifiability of the mentioned models and entropy as the opposite of information.

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