THE STOCK MARKET AS A THERMODYNAMIC SYSTEM

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Summary

This article presents a new perception of the operation of the stock market and the situations created by participants in a financial market. This new perception is based on the fact that every financial market is an economic system embedded in the broader system of economic organization, where human behavior is a primary component. The variety of information received by the system from its environment and the messages it emits to it, combined with the unpredictability of the behavior of its elements, are parameters that characterize the capital market as an open system. The complexity of such a complex system creates conditions for the application of the thermodynamics of irreversible processes, governed by the general law of increasing entropy, to such an extent that the stock market can be considered for the first time in Greece, possibly even in the global literature, as a thermodynamic system.

This view was formulated when I was working on my doctoral thesis during the period 1993-1996 entitled «Software Development for Portfolio Selection Using Data Analysis Methods» [Karapistolis D., 1996]. Of course, I could not imagine that at the same time, a stream of thought from scientists aimed to solve the problems of Economics using the principles and laws of Physics, laying the foundations for the creation of a new scientific field, **Econophysics**.

This approach at that time was and perhaps still is today an unprecedented and undeniable fact that places this work, without any doubt, in the field of Econophysics, serving as a pioneer of this new branch of Economics.

2. Introduction

The environment of a stock market is determined by the economic relationships and activities that unfold among the economic factors associated with it. The entirety of these activities is perceived in this study as an open system, namely a Unified Whole composed of interconnected parts, such as listed companies with their issued shares, financial market participants, the investing public, etc., which constitute its components.

This is because:

a) It is defined by its purpose, which is the satisfaction of companies seeking capital and the investment public seeking to deploy their capital, thereby deriving economic benefits.

b) It is animated by the action of its factors.

c) It is characterized by interactions. Supply and demand, spontaneously or not, determine prices, but prices, in turn, determine the level of adjustment of supply and demand, which depends on the socio-economic situation at any given time, which is never the same as any previous one, nor is it likely to be the same as any future one.

The current perception of the stock market consists of the idea that it depends on various socio-economic factors without considering the unpredictability of human behavior as a primary constituent of this economic system. When this parameter is not ignored, as is the case with the present study, it becomes the main reason for considering the market as a living open system.

For this reason, and according to the viewpoint to be substantiated subsequently, the complexity presented by such a system is effectively addressed with the understanding of the thermodynamics of irreversible processes, which are known to be governed by the general law of increasing entropy. [Prigogine I. 1945]

It should not be forgotten that the randomness in the movement of stock prices is a result of the perception that the stock market is governed by deterministic causality, a perception that one must now question after the plethora of research conducted in the world's major stock exchanges. [Peters E.1991 pp. 27-42], the conclusions of which have been found to apply to the Athens Stock Exchange as well. [Syriopoulos K. and Sirlantzis K.,1993]

2. Systemic Approach to an Economic Phenomenon

Speaking about Systemic Approach, we are talking about a fundamental reorientation of scientific thinking. It might be wise to avoid talking about a new science yet, waiting for further developments. However, it wouldn't be particularly risky to discuss a different methodology capable of approaching the complex world around us more effectively.

More accurate, however, is to consider "Systemism" as a different approach to reality that allows a redefinition of the concept and content of the effectiveness of human thought and action, contributing to a more constructive alignment of decisions and consequences. We can consider it as an interdisciplinary approach that complements the gaps in analysis in the space of research and technology by conceiving the empirical world as a formation of interconnected activities.

It is known that Cartesian analytical thinking has greatly contributed to the progress of knowledge. However, it has been interested in the past and still today in the partial causes that it usually perceives isolated from their general framework. The well-known "ceteris paribus" is common and often necessary. The whole is led to its primary elements, the simplest ones, aiming at their individual study and the revelation of the forms and nature of the interactions that exist between them. And then, by intervening in a variable each time, the analyst tries to derive general laws that allow the prediction of the properties of the whole under different conditions.

This principle of segmentation forms the basis of the analytical method, which directs towards the specialization of scientific thought, while at the same time it is useful but often ineffective in regard to the comprehensive view of situations of high complexity (complex and hypercomplex systems, where "noise", either absorbed or constituting a necessary element of their existence). Undoubtedly, the comprehensive view of things, as far as it is feasible, is a necessary prerequisite for understanding evolving phenomena in a continuous and structured manner. The perception introduced by the Systemic Approach is that the whole is something different from the sum of its parts, as it has different properties from those presented by the parts considered separately.

Thus, a system is something more or less than simply the sum of the parts that constitute it. And this is because whether the number of individual elements of the system increases or decreases, new properties appear among its parts or some of those that already existed cease to exist.

The analytical method, as previously mentioned, reveals partial causes which, however, are isolated from the context in which they are situated, with the consequence that they do not adequately reconstruct reality when combined. The Systemic Approach, on the other hand, guides the researcher's thinking through the hierarchy of the levels of organization of the structured whole, until the knowledge and revelation of the structural functions of the system, taking into account the interactions and interdependencies of its individual components, are achieved. It could also be added that because the distinction between cause and effect in the interaction of the individual elements of a complex system is not always explained by the existence of a causal relationship of dependence, the cultivation of a different method of thinking, which is not causative but appears imbued with the teleological element, is interesting.

In other words, the method should be interested in discovering the structural formations of the system, the purpose they serve, and the choices made by the subsystems that constitute it. The focus of interest shifts from the exploration of individual equilibrium conditions or the general equilibrium of the elements that shape the system, to the investigation and evaluation of the interactions and interdependencies that arise among them. Within such a framework, one might say that the best way to approach the financial reality systemically is to study its genesis, structures, and interdependencies, taking into account human reactions and the institutions that govern it. Such a study necessitates interdisciplinary collaboration, as it addresses a subject of significant complexity and diversity and is susceptible to a thermodynamic and evolutionary logic that differs from the dominant mechanistic one.

Complexity, no longer maintaining the character of a post-concept, becomes a real concept and a substantial factor of the system under study. Complexity becomes a function of the system's evolution, and vice versa. Thus, it becomes apparent that with the help of systemic approach and its thermodynamic logical character (system-evolutionary process-tendency towards disorganization-resistance to mutation), extremely complex situations are studied, where variables are numerous and connected not necessarily by linear relationships, as is the case with the financial market.

Approaching reality systemically with the aim of understanding any complex problem, the researcher attempts to design a systemic model without distorting or simplifying the overall picture of the phenomenon. In this endeavor, one must take seriously into account that every human organization system, such as the stock market, does not blindly obey the controls of the "technology" constructed to manipulate its operation. This does not necessarily imply the absence or complete inefficiency of control subsystems in regulating the behavior of every evolved organizational system.

The effort to understand a complex problem cannot rely exclusively on a form of "unique thinking". Absolute faith in the "uniqueness of thought" or the preliminary rejection of alternative forms of logic leads to ideological assumptions that hinder the revelation of scientific truth and often obscure reality. The judgment of the scientist who attempts to approach a phenomenon systemically is a spiritual manifestation of qualitative character that is equally necessary as his ability to handle analytical methods and thoughts.

We must not overlook the fact that every economic model or mathematical description of a phenomenon is necessarily an abstraction because it either ignores or truncates something from the reality it seeks to represent. This is because the construction of a model depends on the abilities of the researcher. The parameters chosen are not necessarily those that will provide the most complete picture of the system, but mainly those that the researcher considers to be the most important.

Furthermore, the researcher relies on an authoritative description of the system's structures depicted by the model, such as the type of competition, the rational investor, or the maximization of consumer utility, undoubtedly ideal situations but far from fully reflecting the complex reality and qualitative nature of economic life. The behavioral equations, the heart of each model and expression of the theories that construct it, cannot encompass all aspects of the problem they describe. As for the duration of the model's behavior, this is the main point where most economic models suffer, precisely due to the imperfections mentioned earlier. The reason is simple: humans learn from their mistakes or remember their misfortunes, resulting in not always acting in the same way but adapting their behavior according to the situation, without any warning. Therefore, if modeling a complex phenomenon is inherently a challenging task, one recourse available is to seek the assistance of systemic approaches that inevitably aim for a more effective handling of complexity and the continuously evolving reality.

2.1 About the system

Consciousness for everyone constitutes that increasingly complex and interdependent technological and non-technological systems affect our daily lives. The study and effort to understand a system pass through the conception of the "intelligence" that governs its operation, enabling the approach of the essence of its creation itself. A general definition states that a system is an arrangement or set of objects, states, or interconnected factors in such a way as to form a whole. Each set is equipped with certain relationships that determine the activities that must be highlighted in its inputs, in order to produce the outputs. Systems are characterized either as open or closed. An open system is in constant communication with its environment. It emits and receives information from the systems that surround it or are related to it. It generates forces that counteract its natural tendency for disorganization and disorder. This is precisely what is called compensatory feedback. The existence of this type of feedback is at the basis of the phenomena of homeostasis, i.e., resistance to change, thanks to which open systems maintain their internal coherence [Passet R., 1996 p.52].

Mathematically, an open system can be mapped to an operator T, which acts on the input vector U, to yield the output vector Y. [Diamesis I., 1986 p.108]. In other words,

$$Y = T \cdot U \qquad (1)$$

When a system exchanges information with its broader systemic environment but not matter, i.e., without being disconnected from the outside world and solely using its own reserves for its maintenance, to the extent of the actions and reactions performed within it, then this system is considered closed. [Prigogine I. and Stengers I., 1996 p.184]. Finally, we can argue that a system is a set of elements interacting with a specific purpose, which is not homogeneous and undifferentiated, but appears more as a related and structured set, consisting of organizational levels which are themselves systems. [Chatzikostantinou G., 1985 pp.271-316].

2.2 The concept of information

The term "information" in systemic approach refers to the qualitative coefficient that continuously determines the position or state of a system. Information is distinguished into elementary and composite. The evolution of a phenomenon is a result of the sequence of appearance of various events, some less probable and others more so.

Each event of a set carries a quantity of information, which is connected with the total elements K of the set. It was thus determined that the transferred quantity of information of an event is an increasing function of the form H(x) = log2K, which constitutes the equation of Hartley [Volle M., 1985 p.50].

The function H(x) determines the quantity of information necessary to identify an element among K elements of a set. Based on this definition, the concept of information differs significantly from that used in everyday language. The phrase, or rather the message "guaranteed share," consists of 15 "elements" (including spaces) out of a set of 24 elements, enclosing a quantity of information of 15log224 BIT (information units), equivalent to the message "qwertyui sdfghjk" which has no meaning. From this, it follows that the informational content of a message is exclusively connected to its structure and not its meaning.

In the case where a "text" is relatively difficult to understand, such as a large-dimensional table with double input, studying its structure in depth allows us to grasp the content of the information it contains more easily. This method of study does not replace the "reading" of the table, which is usually a subjective process but necessary for understanding its content.

If we want to calculate the average transferred quantity of information from an elementary message emitted by a complex phenomenon I, consisting of k independent elementary events, we use the following formula by C.E Shannon [Volle M., 1985, p.52]:

Now, let's assume that we have a characteristic I with N gradations, determining in total E equal classes, and that each class Ei (i=1,...N) has ki elements. Then, the relative information with respect to the set E provided by the characteristic I is equal to

$$H(I) = \sum_i p_i \log_2 \frac{1}{p_i} \tag{2}$$

Where $$p_i = \frac{k_i}{k} \text{ and } k = \sum k_i \tag{3}$$

The quantity H(I) is called the entropy of the partition of E, which represents the intensity with which the message I appears. It is observed that the entropy H(I) does not depend on the nature of the characteristic nor on the type of gradations, but solely on the distribution of frequencies p_i. Since it holds true that

$$p_i \leq 1 \text{ and } \log \frac{1}{p_i} \geq 0 \tag{4}$$

Concludes to

$$H(I) \geq 0 \tag{5}$$

From the combination of equations (4) and (5), it follows that in the case where entropy is maximum, the elements of the partition have the minimum predictability. It is therefore evident that the evolutionary path of a system towards a state of maximum entropy leads to disorder, a concept closely associated with unpredictability.

Based on the aforementioned, the following question arises: for an economist studying the stock market, which of the following three approaches should he use to draw his conclusions?

a) Measure the quantity of transferred information from the system.

b) Evaluate the occurrences within it after reading the data.

c) Identify and explain the structural differences that the system undergoes from the inflow and outflow of a large amount of information related to the processes occurring within it.

Before answering this question, it is advisable to clarify certain concepts and relationships.

2.2.1 Information and energy relationship

As is known, energy is a common denominator of all goods, both free and non-free, as every material can be expressed in terms of the energy it contains. Thus, every productive capital is the result of work expressed in energy units and operates thanks to a supply of energy, producing measurable mechanical work. From this perspective, every economic activity utilizes energy, hence the Economy cannot escape entropy.

When Boltzmann expressed the entropy of a thermodynamic system with the following relation:

$$S = -k \cdot \sum p(i) \cdot \log_e(p(i)) \tag{6}$$

He certainly did not have in mind the formula (2) of C.E Shannon, which, as mentioned earlier, calculates the transferred quantity of information of an event [Passet R., p. 60]. Observing equations (6) and (2), we ascertain that they differ only by a constant, known as Boltzmann's constant [Courbage M., 1991, pp. 316-328]. Therefore, information and energy are not unrelated to each other [Passet R., 1987, pp. 254-255].

2.2.2 The concept of class

The concept of order prevailing in the elements of a system, according to R. Passet [Passet R., 1996, pp. 161-164], is related to the predetermined relationships imposed on them. Thus, maximum disorder occurs when each element could freely choose its "position." Conversely, maximum order is that in which each element can occupy only one position. Therefore, order is a way of determining the degree of organization of the system and is certainly linked, due to relation (2), to the entropy of the system.

2.3 Thermodynamics and entropy

As is well known, the dominant concept in thermodynamics is the entropy of the system. This concept, which has a more systemic than analytical character, arose from the need to express the distinction between the useful energy exchanges of the system (bound energy) and the free energy (dispersed energy), the loss of which is irreversible.

In this context, we have classical or statistical thermodynamics, which is certainly characterized by strong determinism. However, the introduction of the concept of dispersed energy and stochastic structures allowed for the development of modern non-equilibrium thermodynamics, which not only softened the determinism of classical views but also highlighted the possibility of shifting the final entropy phase of any open organizational system.

Entropy S, as introduced by Clausius [Prigogine I. and Stengers I., 1986, p. 174], is a function of the system's state. Therefore, if we denote the change in entropy as dS, this change can be expressed based on the equation

$$dS = d_eS + d_iS \tag{7}$$

The term *deS* refers to the energy exchanges between the environment and the system, expressing reversible processes that will have a positive or negative sign depending on the direction of the exchanges.

On the other hand, the term *diS* refers to the irreversible processes inside the system that lead to disorganization and disorder, which are inherent properties of any open system.

Clausius demonstrated that all irreversible processes (e.g., heat conduction) and the production of entropy d_iS are always positive or zero in cases where there are no reversible processes. Therefore, the change d_iS is monotonically increasing over time, meaning that the equation

$$d_iS = \geq 0 \tag{8}$$

The increase of entropy corresponds to the "spontaneous" evolution of the system. Thus, entropy becomes an "indicator of evolution" or a "arrow of time," as aptly named by Eddington, and synonymous with the physical processes within the system. These processes lead the system to thermodynamic equilibrium, meaning a state of maximum entropy, hence maximum disorganization, which in mechanical terms is expressed as complete imbalance.

For a thermodynamic system, all changes in the states it undergoes are not equivalent. This observation arises from the formulation of the equation $dS=d_eS+d_iS$, where the spontaneous change towards equilibrium d_iS differs from the change *deS* that is determined and controlled by modifications in the boundary conditions.

Max Planck emphasized that the difference between the two types of changes, d_eS and d_iS, lies in the fact that d_iS describes the system's approach to a state that "attracts" it and from which it will not depart by its "free will."

On the other hand, the content and form of reversible processes d_eS drive the system towards behaviors that exhibit equal tendency towards both the initial and final states. This is why the transition from one state to another occurs in both directions.

Approaching thermodynamically reality, we must understand that all out-of-equilibrium states are creators of evolution towards the same thermodynamic equilibrium state. When the system reaches thermodynamic equilibrium, i.e., complete stagnation, hence maximum entropy, it exhibits a characteristic property called dispersion. The system "forgets" its initial conditions, in other words, it forgets how it was prepared, resulting in a "drift" towards an unpredictable direction.

The opposite happens during the dynamic evolution of a system adopted by the mechanistic logic of approaching the real world. In this case, the system follows a given trajectory that depends solely on the initial conditions that uniquely determine it.

Thus, perhaps a clearer understanding of the differences between dynamic (mechanistic) and thermodynamic (evolutionary systemic) logic is achieved. Adopting the latter endows shape, reveals character, and shapes the rationale of this work and how it approaches the central question.

Modern thermodynamics also introduces the concept of dissipative structures, which are scattered accumulations of elements. This concept emphasizes both the close connection between structure and order and the link between scattering and energy waste. The interaction of a system with its environment within the framework imposed by boundary conditions serves as a starting point for the formation of new evolutionary states, namely dissipative structures. It could be argued that dissipative structures essentially reflect the overall state of imbalance that produced them. The parameters describing these structures should be macroscopic.

Henry Atlan [Atlan H., 1972] defined the change in entropy per unit time based on the following relationship:

$$dS/dt = d_eS/dt + d_iS/dt \qquad (9)$$

Therefore, a system that exchanges information with the environment can be found in one of the following thermodynamic states:

The state of imbalance when $dS/dt>0$ (10)

The state of equilibrium (stasis) when $dS/dt=0$ (10a)

When referring to a steady state, all quantities describing the system become independent of time. Therefore, in a steady state, the time rate of change is zero, meaning $dS=0$. From equation (9), it follows that in a steady state (thermodynamic equilibrium), the following holds:

$$d_eS/dt = - d_iS/di \qquad (11)$$

As we mentioned earlier, since $diS>0$ always holds, it follows from equation (11) that $deS<0$. The flow of information from the environment to the system determines a negative entropy flow deS, which is counterbalanced by the production of entropy diS due to irreversible processes within the system.

The negative entropy flow d_eS, also called antientropy or negative entropy, defines the transfer of the system's entropy to its environment. In a steady state, the system's activity increases the entropy of the environment. [Chatzikonstantinou G., 1986, pp. 21-26] The negative entropy d_eS functions as the activity that structures the system, while the entropy d_iS acts as the activity that disrupts systemic coherence. J. Tonnelat argues that these processes are responsible for increasing the complexity of the system [Tonnelat J., 1977].

Therefore, in thermodynamics, entropy is the quantity that allows the estimation of a system's energy dissipation while also characterizing its degree of disorder.Thus, the thermodynamics of irreversible processes [Prigogine I., 1969] suggests that open systems are in a constant state of nonequilibrium, sustained by exchanges and responses with their environment, thereby maintaining their structure and function as long as their boundary conditions or external environment remain more or less unchanged.

Generally, a state of thermodynamic equilibrium is described as follows:

For the variable X (e.g., the General Price Index of the stock market), we observe its temporal evolution $dx/dt=f(x)$. In each case, $f(x)$ can be decomposed into two non-negative functions representing, on the one hand, $f+(x)$ "benefits" and, on the other hand, $f-(x)$ "losses" (Diagram 1).

The function $f(x)$ can then be expressed as $f(x)=f+(x)+f-(x)$

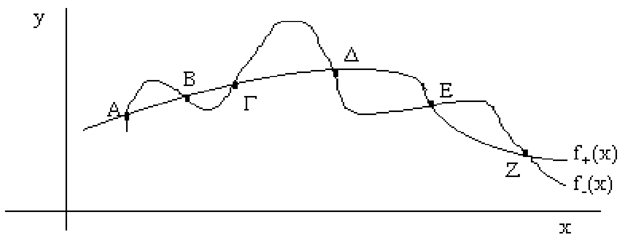


Diagram 1: Analysis of the function $f(x)$ into two non-negative functions

Steady states where $dt/dx=0$ correspond to values where $f+(x)=f-(x)$. These states are attributed to the intersections of the two graphical representations of $f+(x)$ and $f-(x)$. If these two functions are linear, there is only one intersection point, while if they are nonlinear, as in Diagram 1, the number of intersections is greater than one.

Regarding dissipative structures, which are always compatible with a given set of boundary conditions, they increase when the problem is studied in more than one dimension. In the case of, for example, two dimensions, the spatially structured steady state (Diagram 2) can be characterized by the appearance of a **privileged axis**.

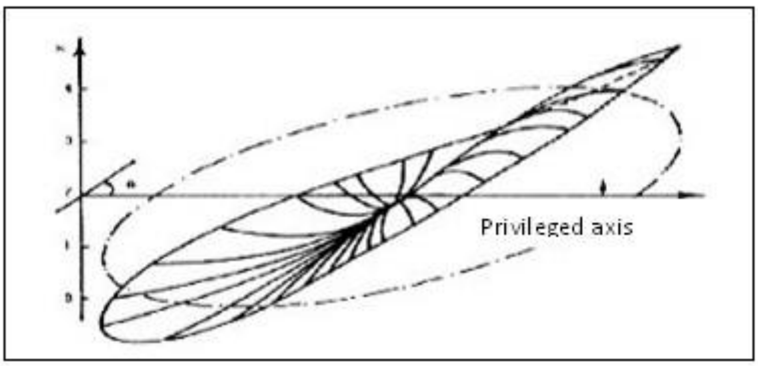


Diagram 2: Steady state in two dimensions. Appearance of a privileged axis.
Source: [Prigogine I. and Stengers I., 1986, p.211]

The emergence of the privileged axis leads us to abandon the idea of the uniform influence of factors affecting the system. Consequently, some peculiarities arise. The system acquires a physical quantity that is a function of the parameters describing it, different from the quantity imposed by its boundary conditions.

The system thus determines its own size, defining an area that is topologically structured, where order becomes apparent.

Therefore, under conditions far from equilibrium, various self-organizing processes occur that lead the system on the one hand to the emergence of dissipative structures and on the other hand, nonlinear processes result in acting recursively on the cause aimed at the system's mutation. [Prigogine I. and Stengers I., 1986, p.212]

Thermodynamics thus identifies the evolution of the system with entropy production, while equilibrium is identified with a state of maximum disorder, beyond which any further entropy production is impossible. It is therefore easily observed that the entropy of a system has a direct relationship with its organization (or structure) and the energy it encapsulates.

Having named the free energy of a system as the available energy that can be transformed into work, we observe that in a state of maximum entropy this energy is zero and can only take a positive value if the system acquires a specific structure. This observation stems from the second law of thermodynamics, which informs us that work is produced only when the system undergoes a change in its state. [Passet R., 1997, pp. 163-164]

Thus, as a system moves away from the state of maximum entropy, its structure acquires particular significance, as the free energy it contains increases, resulting in the provided mechanical work being greater.

However, the increase in free energy is directly linked to the increase in the amount of information extracted from the system. Given that every medium that generates information consumes negative entropy, which it converts into information [Zacharopoulos Z., 1990 p. 8], we can argue that a thermodynamic system, like any system, becomes productive through the information it contains.

3.The stock market as a thermodynamic system

The stock market, therefore, as a complex system, is distinguished by the variety of inputs it receives from its environment in the form of streams of information. The components that make up the stock market constitute an organized whole, which presents intricate interconnections, so that whatever happens in one of these parts affects to varying degrees the others, without the final result being a mere sum of individual reactions.

The outflows of the system are also complex and intertwined among themselves. They mainly refer to the financial messages emitted by the stock market in all directions, as well as to the financial results that arise after each session.

The interdependencies and interactions of the factors acting in the stock market constantly generate states of imbalance reflected in the stochastic structures created by the different cohesion of the system's elements that constitute the various levels of organization and which are always compatible with a given set of boundary conditions, that is, the operating rules of the system.

Under such assumptions, the stock market becomes the subject of study, interpretation, and a broader understanding of its operation as a thermodynamic system, whose evolutionary course is characterized by chaotic behavior and not just as a system of mechanical operation.

Therefore, two conditions become apparent:

That to understand the functioning of a stock market, it is not enough to create a set of specifications.

That the system tends mainly to balance forces coming from within itself.

During the historical evolution of the stock market, reversible and irreversible processes occur, as we mentioned earlier, through changes in deS and diS. If we consider the legal framework within which the constituent elements of the system operate together with the macroscopic parameters used to describe its evolutionary path as a set of boundary conditions, then the changes in deS are determined and controlled by this set.

Reversible processes within the stock market, corresponding to changes in deS, can be characterized by the following conditions: the temporary suspension of trading in a company's shares, the introduction of a new company to the market, and interventions by the Securities and Exchange Commission in setting upper and lower price limits for stocks. Of course, the most reversible process should be considered the mechanism of supply and demand for stocks to determine their fair value.

As for the irreversible processes diS, the most significant of those occurring within the system are due to the participants' expectation to derive financial benefits from the daily sessions of the stock exchange, as no one invests knowing in advance that they will incur losses.

In combination with the factor of awareness, namely skillfulness, the ability to assimilate and process information that distinguishes participants in the stock market, these are the main processes that create the entropy of this system.

However, among the processes taking place in the system, especially the irreversible ones, have enormous structural value because the system does not exist without them. Indeed, the stock market is fueled by the expectations of those participating in it, while the ability of participants to be aware is the main lever of their reactions, so the entropy generated from these, diS, is consistently monotonous, meaning it has the direction of the future and never the past.

Therefore, looking to the past to reveal future expectations and the awareness ability of market participants is risky, as the overall behavior of those participating in the stock market, considered chaotic, is not only unpredictable but also sensitive to initial conditions.

As a result of this perception, the use of econometric models should be avoided in describing the stock market. Instead, the analyst should focus on discovering the hierarchical levels of organization of listed companies and the structural conditions arising from the generated entropy, as entropy in this context is conceived as the degree of system homogenization, i.e., the tendency to maximize profits from participants in stock market activities.

The stock market can therefore be considered a thermodynamic system because contradictions are constantly created within it that shape developments either towards increasing entropy or in the opposite direction, a characteristic property of complex systems.

Regarding the evolutionary path of the system, it should be noted that after each opening of the stock market, disturbance is always caused in the system, which is reflected in the General Price Index (GPI) of the stock exchange, offering benefits and losses to participants ($f+(x)$ and $f-(x)$ respectively).

Therefore, with the closing of the session, the system is in a thermodynamic state of imbalance, as for every change in time of the GPI, $dX/dt > 0$ holds. However, there are also states of stagnation (or thermodynamic equilibrium where $dX/dt = 0$), the number of which is certainly greater than one. This has the consequence that, on the one hand, the evolutionary path of the stock market is considered nonlinear, and on the other hand, the system is considered stable, as after a finite number of disturbances, it returns to an equilibrium position, albeit different from the one it previously held.

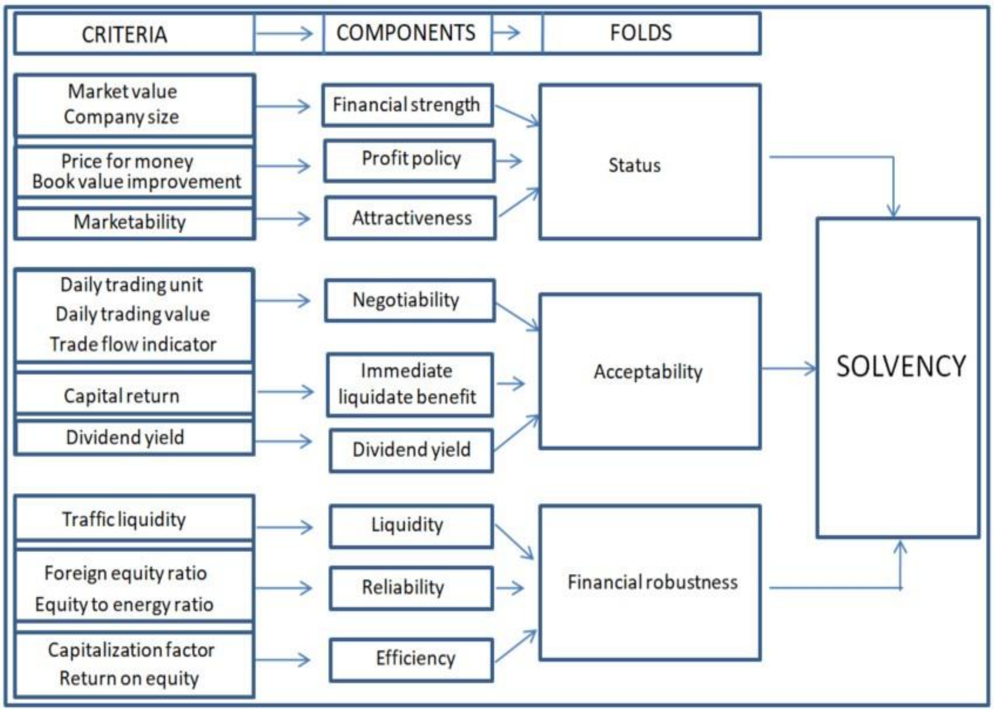
Regarding the stochastic structures of the stock market, these exclusively concern the emerging groupings of companies, which are due to the non-linear dependencies and interactions of variables created by boundary conditions expressed through different criteria such as market value, liquidity, P/E ratio, turnover, etc. These variables determine the various levels of organization of the system according to the performances presented by the companies in relation to these criteria.

The dependencies of these variables create new variables called factors. These factors create the privileged axes, which are structured stationary states, called factorial axes.

When specified, these factorial axes primarily provide information about the natural size of the stock market, which is different from what the boundary conditions impose, through the variables used to describe the system. Secondly, they remind us of the non-uniform influence of the factors on the formation of the organization levels of the companies participating in the capital market.

Furthermore, the factorial axes determine the root cause of the structural differentiation of the stock market, which is nothing other than the reliability that these companies exhibit within and outside the stock market activities. At the same time, they specify, as we will see below (Table 1), the macroscopic parameters that describe the formed structures through the aspects and components of solvency that compose them. [Karapistolis D., 1999]

Table 1: Criteria, components and aspects of solvency



Therefore, in response to the question "what should an economist do to study the capital market," the answer is as follows: the analyst, usually lacking in evaluating the quantity of information flowing through the system, should first focus on determining the free energy contained within the capital market (i.e., the usable quantity of information) in order to choose the most effective course of action.

To the extent that they are unable to determine the free energy of the system, it is suggested that during its evolution, they evaluate the consequences resulting from the generation of entropy by two main factors: expectation and awareness of the participants in the stock market.

These consequences manifest through specific structural changes aimed at moving the system away from the state of maximum entropy, and are reflected in various levels of organization, which are distinguished by the escalating reliability that characterizes the elements composing them [Karapistolis D., 1996].

4. Concdlusions

Viewing the stock market as a thermodynamic system provides the analyst with a deeper and more comprehensive understanding of how to approach it, based on the following:

Knowing that the system is in a continuous state of static non-equilibrium, sustained by the exchanges and responses of various pieces of information it interacts with its environment.

Being able to identify the entropic state of the system, as it is the source of generating all kinds of information.

Understanding the energy state of the system, allowing the determination of relationships between its elements. This enables the study of the evolving structures of the stock market. Consequently, it can describe the logic behind the actions of the involved factors, define the levels of organization of the system, and simultaneously explain the emerging structures.

Having the capability to study the "noise" (disturbances) present at each level of the system. These noises differ across levels due to the different coherence of the elements comprising them.

Finally, identifying macroscopic parameters describing the evolving dynamic structures of the stock market, which reflect the non-equilibrium conditions that produced them.

The different coherence at each level suggests the existence of various functions among the elements of the level, hence different structures. Studying the entropy of the system should be done through data analysis methods, leading to secure conclusions mainly due to the documentation of the causes leading the system to specific reactions.

Thus, the structural approach undertaken by the analyst allows understanding the existence of those forces among the elements of the system linked by complex relationships, which usually induce slow changes in the existing structures. The rates are slow due to the presence of compensatory feedbacks opposing the mechanisms reinforcing the system's initial imbalances.

Therefore, the existence of different structures in the stock market is mainly due to the nonlinear interactions and dependencies among the elements of the system, which ultimately shape various levels of organization within the system.

These factors, which the analyst must identify, combined with each other, constitute the generative cause of the structural differentiation of the system, namely the stability emerging from the listed companies in the capital market. Meanwhile, the evolutionary path of this thermodynamic system is attributed to the combined energy of participants' expectations for financial gains and the awareness capacity of its constituent elements.

This developed perception finds application in the new method of evaluation and management of stock portfolios, which we propose, called the Synthetic Approach of stock prices, based on which the analyst determines the Stable Portfolio [Karapistolis D. 1996], namely the set of companies at the highest level of system organization. This set provides the investor with a long-term reasonable gain with minimal interventions in its composition, due to the slow mutation of system structures. This significantly reduces the cost of portfolio diversification, making the resulting benefit highly appealing to any rational investor, as it greatly increases the portfolio's actual return.

The proposed approach to the stock market, a thermodynamic-inspired, systemic one rather than mechanistic as already mentioned, offers in our view a significant field of exploration and reflection. The potential for generating discussion among experts presupposes an understanding of the respective perceptions and an appreciation of the different meanings of the concepts of "dynamic evolution" and "thermodynamic evolution" of a system.

The development of national stock markets and the ensuing Globalization of Finance, by dramatically increasing the complexity of situations and often creating conditions of insurmountable difficulties concerning even the comprehension of the magnitude of emerging information, necessitates overcoming the entrapment in established "unique" analytical frameworks.

Today, more than ever, it is crucial not only to avoid simplifications that obscure the truth but also to strive for more effective management of the complexity inherent in every economic system and undoubtedly in the stock market.

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