TRENDS IN ECONOPHYSICS

Ion SPÂNULESCU* and Anca GHEORGHIU*

Abstract. *In this article we attempted a systematization of different directions and branches of econophysics. Thus, all subdomains or branches that use statistical mathematics and statistical physics methods are grouped in the major domain of statistical econophysics, while econophysics subdomains and models that use models inspired by phenomena and laws from other domains of physics or from other sciences are grouped in the major domain of phenomenological econophysics.*

In the paper, some phenomenological econophysics models are also briefly presented.

Keywords: *statistical econophysics, econophysics directions, phenomenological econophysics, economic amplifier, macrostate parameter, economic entropy.*

1. Introduction

To study the economic phenomena and processes, in addition to specific methods and processes of economic science, researchers turned to methods, theories or models borrowed from other sciences, especially from the exact sciences (mathematics, physics) or natural sciences (physics, chemistry, biology) whose laws and phenomena have an exact character, a deterministic one. Such approaches have led to the emergence of directions or even interdisciplinary sciences through which the economic science interacts with the exact sciences, as well as with other types of sciences as social sciences, engineering sciences and others, as we will show in one of the following sections.

The research of economic processes with the help of mathematics or physics started as early as the first decades of the 20th century, through the development of statistics and econometrics by mathematicians (in the third decade of the last century). The economists have taken these techniques and have developed them achieving some interesting results and models,

---

* Hyperion University of Bucharest, 169 Calea Călăraşilor, St., 030615, Bucharest, Romania.

particularly in the domain of econometrics but also in economic statistics through the systematic processing of the economic data series.

The econometrics methods were also approached by physicists or by economists-physicists who afterwards have developed econophysics study methods and models for economic phenomena or processes. It is appropriate to recall here one of the forerunners of this science, Nicholaus Georgescu Roegen, Romanian statistician and economist that showed the role and importance of the concept of entropy from physics in the study of economic processes and has proposed the model of ecological economy [1]. At the border between the twentieth and twenty-first century appeared a special interest for econophysics expressed through the publication of a large number of articles, studies and books in this domain, as well as increasing the number of international conferences and symposiums, at which numerous original papers and communications in the domain of econophysics were presented.

As it was already mentioned, the interest in the study of economics did that for the study of economic phenomena and processes, in addition to mathematics and physics to also appeal to other sciences as will be seen in next section. The methods and techniques used for this purpose have acquired a great diversity, which in turn requires the introduction of a classification to make some order in this area. This is the subject of the present study which will be developed in sections 3-5 of this paper.

2. Study of economic phenomena and processes with the help of other sciences

The evolution and research on the economic processes are influenced by the presence of the human factor in the economy whose influence is, most of the times, hard to quantify. Due to this fact, economic decisions and measures taken at company level, industry level or even at the state level can have a great deal of subjectivity, and sometimes may even be inaccurate or discretionary (to the economies of totalitarian states). This shows the tight character of the interaction between the economy and society. In this case, can we consider that the science of political economy or the economic science fall into the category of social sciences? Possible, but in economics there are also certain laws, most of them being found empirically, which can have a deterministic character especially if for their analysis or modelling are used mathematical methods or those of the exact sciences (as Physics) as is the case of econometrics or econophysics or other borderline sciences in connection with the economy.

There are many sciences or more precisely interdisciplinary scientific directions sometimes called borderline sciences, which are in fact an interface making the connection between two or more scientific domains.

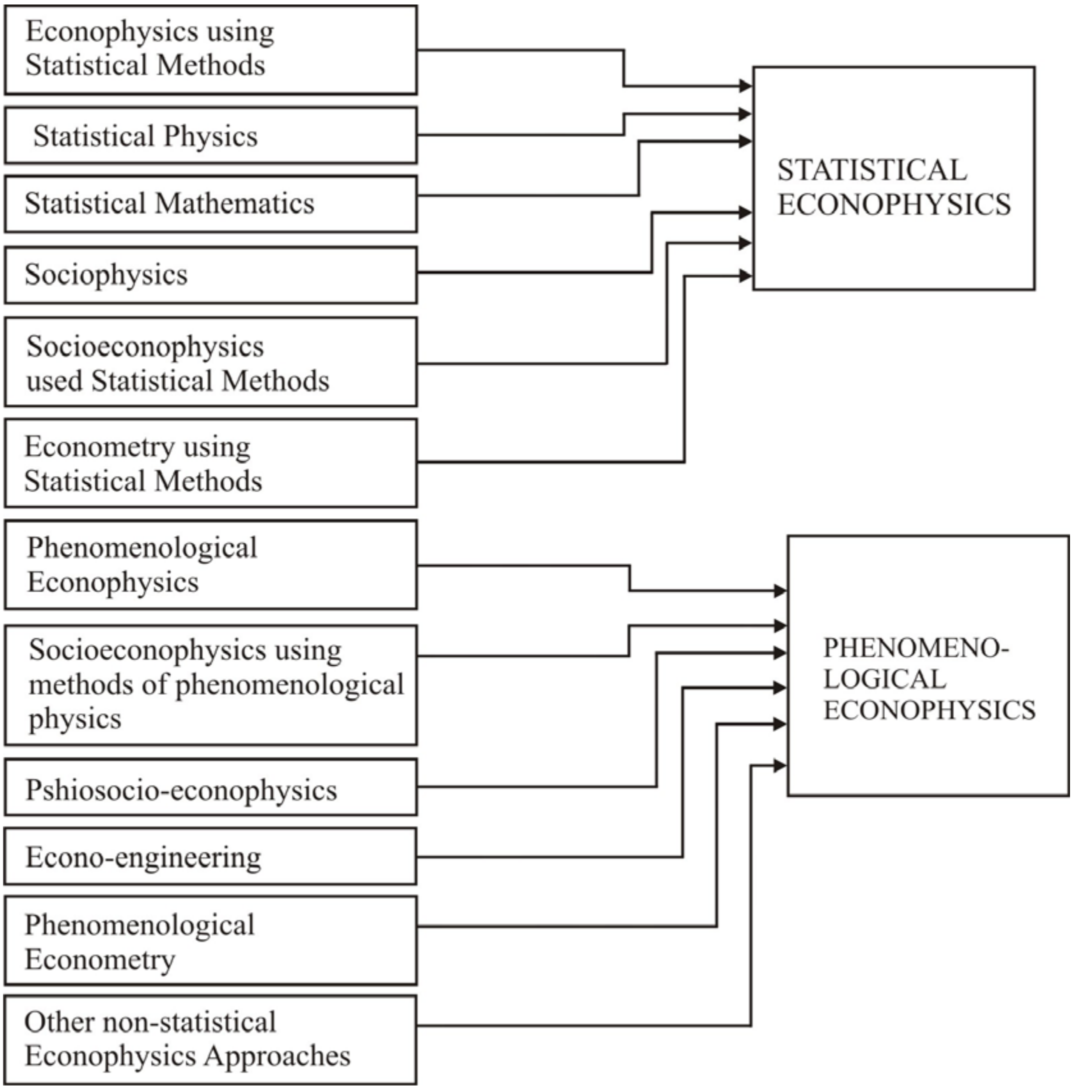


Figure 1. Econophysics directions.

Regarding the economy and physics or mathematics one can speak of econometrics where for economic researches are used mathematical methods, of econophysics, and more recently of sociophysics [2-4] or more exactly socioeconophysics as well as of psychosocio-econophysics, the latter being particularly involved in the issue of stock-market operations, where psychological factors play an important role as is the case of **herd effect** [5] and others similar. Physics is also in conjunction with other sciences resulting physical chemistry, biophysics, medical physics, mathematical physics, astrophysics, geophysics, engineering physics, sociophysics and already mentioned econophysics with its specific branches, socioeconophysics and psychosocio-econophysics etc. (Fig. 1). The list of interdisciplinary connections for the domains mentioned above (economy and physics) remains open, in the future may appear other interdisciplinary or borderline sciences for these domains.

The economy with all its branches represents a complex system, with a largely unpredictable or even chaotic evolution due to the close interactions with human beings whose decisions or actions are not always the most appropriate or good sense. However despite these human interventions, the practical economy is governed by certain rules that result from practice and obviously can always be improved or optimized. Most economic domains interact with each other, so in the end the economic system emerges as a unitary but very complex system. The study of such a complex system, composed in the form of a conglomerate or cluster of sub-domains that interact with each others, may be subject to complexity sciences [6-9]. Thus, all distinct economic domains may be considered as an ensemble of networks which intermingle and interact in a complex system of neural networks type [6,8]. Mathematicians and physicists have at their disposal different mathematical calculation and analysis approaches of such neural networks.

Political economy, which studies the economic phenomena and processes in close interaction with society, is considered to be part of the social sciences. On the other hand, the empirical or deterministic economic laws, in many cases, present certain regularities similar to those encountered in physics or other exact sciences. For example, excluding subsistence economy supported by rudimentary means, the modern economy is evolutionary type, i.e. it develops ascendant, presenting an amplification effect of initial investments. As it can be seen in the 4.1 section of this paper, such process of the economic development can be described by amplification phenomenon from electronics or applied physics [26]. Similarly, the share prices in the stock markets, that evolve over time, tend to increase in the long term or sometimes even in the medium term. In the latter case, when the ascendant growth trend is broken abruptly we can speak of a stock-market's crashes that usually occurs in situations of economic crisis, i.e. takes place under the abnormal development of the economy when we are dealing with the recession or "negative economic growth" phenomena. Considering such economic laws or regularities similar to those encountered for example in physics, we are now turning to the question if the economic science can be regarded or not as an exact science as physics, mathematics or chemistry? The answer may be **Yes** but only with a certain caution and only for certain branches of economic science, namely for econophysics, econometrics or even for economic statistics, if the latter cannot be considered as a distinct branch of mathematics and if the econophysics cannot be considered like a distinct branch of physics and so to be included in the curricula of physics faculties from universities or colleges.

3. Statistical econophysics and phenomenological econophysics

The researchers in economics are working mostly with economic data series measured or derived from practical work, using them through mathematical methods – in this case the mathematical statistics – in order to elaborate econometric models or equations etc. Thus, the economic statistics is highly developed and together with the econometrics they gave good results in the economic research. This domain's extension using also the methods of statistical physics including quantum statistics has led to the emergence of statistical econophysics. This name comes from the fact that, when we are dealing with a large number of events, states or variable parameters from the economic practice, which can be considered to have a collective-type behaviour, and therefore they can be described and analyzed with the laws of statistical physics or statistical mathematics. To this fact have reached first the physicians who analyzed economic conditions or processes involving a large number of constituents as the shares on the capital markets (stock-markets), analysis of income distribution, money, wealth of individuals, GDP, the number of companies and their distribution by size, wages distribution, number of employees, the distribution of material or human resources etc. (see for example [10-24]). That explains why most studies and works published or communicated to scientific conferences or symposiums refers to such phenomena, events or objects etc., which are explored using statistical physics or statistical mathematics through this giving birth to a new interdisciplinary research that direction we can call **statistical econophysics.**

The studies in the domain of statistical econophysics had a great development, especially in the last two decades (after the years 1995-2000), especially in the domain of stock markets analysis, which made some researchers define econophysics as the borderline science for the study of stock markets. But within the frame of the statistical type econophysics, there have also been and are being studied other economic processes or phenomena such as: global or individual income distributions [12,15], companies distributions by size [14,16], social phenomena (demographics etc.), the distribution of money [13], the distribution of resources (gold, oil etc.) or products etc. In such studies, researchers turned to more types of distributions as: normal Gauss distributions, logarithmic, exponential or power law distribution (PLD) [17], as well as to some distributions of quantum statistics as Boltzman-Gibs, Fermi-Dirac or Bose-Einstein distributions (see for example [13,18,20,21,24]).

On the other hand, as we pointed out in a previous paper [25], econophysics also implies the inclusion in its area of research of other domains of physics (not only statistical physics), especially from phenomenological or fundamental physics, as chapters of electricity, solid state physics, thermodynamics, nuclear or optical physics etc. Indeed many researchers included in their papers some econophysics models based on analogies between the economic phenomena or processes and laws or processes from different domains of physics other than statistical physics (see for example [25-28]). In this way we can talk about a new face of econophysics named **phenomenological econophysics** [25]. In Figure 1 we show a classification of the different econophysics branches or directions, which according to the research methods (statistical or from phenomenological physics) can be included either in statistical econophysics or in phenomenological econophysics. As we already stated, both the econophysics types and directions are equally useful for modelling of the economic processes or phenomena, resorting to the laws of general (phenomenological) physics or especially to the statistical physics in the frame of the statistical econophysics [25]. In the next section we give some example of econophysics models belonging to the phenomenological econophysics which we have been early proposed and analyzed in our previously published papers [26-28].

4. Approaches and models of phenomenological econophysics

In this section will be mentioned in brief a few models in the framework of phenomenological econophysics proposed by us in some of our previously papers or communications at international conferences.

4.1. Economic Amplifier [26]

As mentioned in the section 2 the modern economy has an uptrend, i.e. shows an amplification effect of initial investments. So, the amplification phenomena from physics are more suitable to describe the outgrowth of economic processes because the economic development means the amplification of value of utilized and processed resources. Based on this analogy, in our studies was proposed an econophysics model structured on amplification phenomenon concept from applied physics (electronic physics and semiconductor physics etc.) named **economic amplifier** [26].

One of the most important parameter of an electronic amplifier from physics (or electronics) is the amplification factor, sometime noted with β, which is defined by equation [29,31]:

$$\beta = I_{out} / I_{inp} = Output / Input \tag{1}$$

where I_{inp} and I_{out} represent the input and respectively output current from active electronic device in electronic amplifier structure.

For economic amplifier, we have proposed a similar amplification factor [26]:

$$\beta_{economic} = Income / Investments, \tag{2}$$

or for financial organizations (banks, mutual funds, leasing corporations, insurance corporations etc.) as:

$$\beta_{bank} = Financial\ income / Initial\ capital. \tag{3}$$

It must be observed that the economic amplification defined by the ratio between total income and investments (see rel. (2)):

$$\beta_{ec} = \frac{Income}{Investments} = \frac{V}{I}, \tag{1'}$$

coincides with the investment multiplication factor k from the famous model developed by Keynes [30]:

$$k = \frac{\Delta V}{\Delta I} \tag{4}$$

where ΔV represents the increase of income and ΔI the increase of investments.

The economic amplifier model can be very well applied for modelling the economic development based on the initial investments both at the micro and the macroeconomic levels. So, for the electronic amplifier with the bipolar transistor in common emitter configuration or with the integrated circuits (Fig. 2), the amplification factor β is defined as (see eq. (1) and [31]):

$$\beta = \frac{I_{out}}{I_{inp}} = \frac{I_C}{I_B} \tag{5}$$

where I_C represents the collector current of the output (final) transistor and I_B represents the input current through the base of the first transistor from the first stage of electronic amplifier [31].

Figure 2. Simplified representation of an electronic amplifier with transistors or integrated circuits.

The dependence of the output or collector current I_C (mA) = I_{out} as a function of input current, I_B (μA) = I_{inp} of an electronic amplifier, therefore, β, given by Eq.(5), have a linear shape resulting a constant value for β (Fig. 3,a).

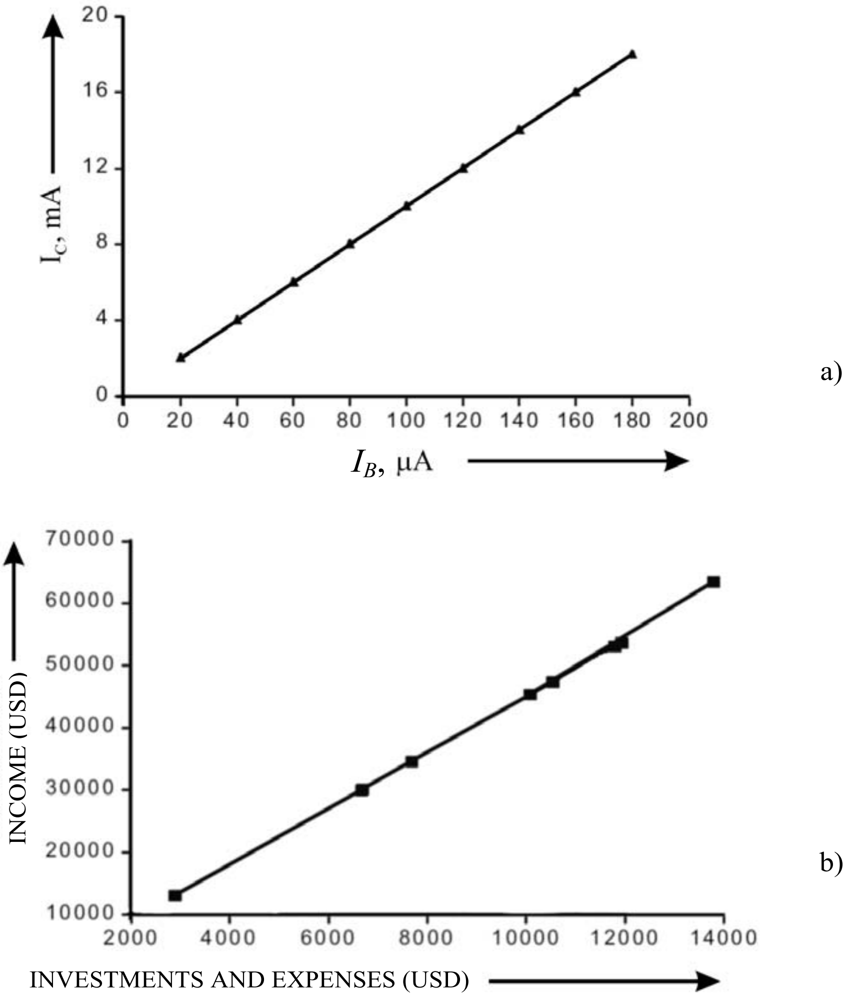


Figure 3. a) $I_C = f(I_B)$ dependence represents a straight line; b) Income representation depending of investments and expenses for a small manufacture.

Indeed, the Eq.(5) can be written as:

$$I_C = \beta I_B \tag{6}$$

representing a straight line (when $\beta = \text{const}$) intersecting the origin of the coordinate axes (Fig. 3,a).

Under normal economic conditions and economic policies, by applying the economic amplifier model for the investments analysis, one may see that the output's income as a function of input total expenses (investments, materials etc.) has also a linear or near linear dependence (Figs. 3,b and 4) justifying the econophysics model we have proposed.

Indeed, for β_{ec} = constant, the equation (1') can be written in the form (equation (6)):

$$V = \beta_{ec} I \tag{5'}$$

which is verified in practice both at the microeconomic (Fig. 3,b), as for the macroeconomic level (Fig. 4).

An example of applying of the economic amplifier model at manufacture level (microeconomic level) is given in figure 3,b, where the total income as a function of initial and annual investments and expenses are represented. As if can be seen from figure 3,b, the ratio between the output total income and the input total expenses (including investments), meaning, economic β, has a monotonous rising dependence, near a straight line.

The economic amplifier model can be also very well applied on the macroeconomic level. A good example is given in figure 4 where the dependence of the Gross Domestic Product (G.D.P.) of Romania as a function of the capital accumulation between 1990-2004 years is represented. As it can be seen from figure 3, the resulting function has a near linear dependence. The medium value of 5.19 for the economic β at national level for Romania for above mentioned period was calculated.

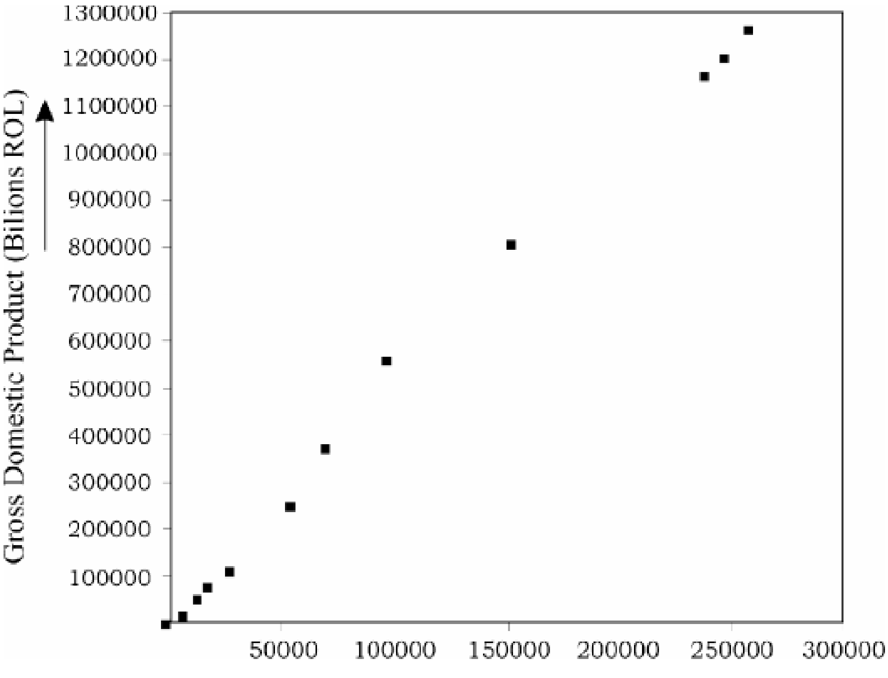


Figure 4. Gross Domestic Product of Romania vs. Gross Capital Formation for 1990-2004 period.

For more details on Economic Amplifier see the paper: *Economic Amplifier a New Econophysics Model* by Ion Spanulescu and Anca Gheorghiu published in arXiv:0707.3703 [pdf] (2009).

4.2. The entropy law and the economic processes[1]

As we already mentioned, in the late middle of 20th century, the applied mathematics and statistical physics have been mostly used for analyzing economic processes.

Based on natural sciences such as physics or chemistry, with stable laws, some economic phenomena and processes can be better explained, especially the macroeconomic processes. We appreciate that among the natural sciences, physics is the only one that can be accessed for good understanding of the economic phenomena and processes.

The Romanian scientist N. Georgescu-Roegen was one of the parents for applying thermodynamics in analyzing economic processes, especially for the development of ecological economics. In his research, N. Georgescu-Roegen used as the main starting point the second law of thermodynamics and also the entropy law, which is applicable to irreversible processes such as real processes from nature, economy or society etc.

Based on the second law of thermodynamics, the entropy of the isolated system, which evolved through irreversible processes, is growing during the transformation of the systems. The transformations of the real physical processes and systems are irreversible so, their entropy increases in every moment.

The isolated systems cannot come back alone in their initial stages with lower entropy because this evolution contradicts the second principle of thermodynamics.

L. Boltzmann has used statistical calculation and the thermodynamic probability of the gaseous system's microstates to discover the well known formula:

$$S = k_B \ln W \tag{7}$$

where k_B represents the Boltzmann's constant. This equation link the entropy S of a system with the thermodynamic probability of its state, W, and represents the statistical interpretation of the entropy.

---

[1] This is the title of the N. Georgescu-Roegen's book that appeared in Harvard University Press, Cambridge, 1971

Starting with Boltzmann's ideas, the physicists have considered the entropy as a measure of disorder in nature or in the structure of things.

The entropy law applied for the technical and operational activities proves that all human practical activities have the effect of useful energy consumption, energy waste increasing and pollution, which is characterized by a complete disorder in things' structure. From this point of view N. Georgescu-Roegen has firmly stated that the natural resources are limited and also that the contemporary economic activities generate pollution and this can result in the destruction of civilization.

N. Georgescu-Roegen was one of the first contemporary scientists which pointed out some similarities between the economic and natural (physical) phenomena or processes.

4.3. An Econophysics model for the migration phenomena [27]

The migration phenomena have many reasons, but the economic reasons are very important. Usually, the mass movements of the people from one place to another (region, country etc.) are motivated by the economic attraction for the attraction centres or the richest regions, with the highest level of society's development.

In the case of modelling of **the migration phenomenon** from economic and social causes, we resorted to an electrostatic model using Coulomb's formula [29]:

$$F_e = \frac{q_i}{4\pi\varepsilon_r}\frac{Q_j}{R^2} \tag{8}$$

where F_e represents the electrical attraction force between electrical charges q_i and Q_j [29].

For modelling the phenomenon of migration from poor neighbour regions (countries) i to rich regions (countries) j, with a powerful attraction characterized by a high socio-economic status (big material resources and capital, developed logistics, information superstructures, banking, comercial or educational etc.) we will appeal to the notion of **migration field** (similar with the electric or electrostatic field) E, which is determined by the ratio of the electrical force (from electricity) F_e of the an attractor and the charge q_0 on which acts the field produced by the attractor [29]:

$$E = \frac{F_e}{q_0} \tag{9}$$

where F_e is electrical attraction force defined by (8).

For the migration field, E_m, we have introduced an analogous expression:

$$E_m = \frac{F_a}{q_i} \tag{10}$$

where F_a is attraction force exercited by the rich region (country) j symbolized by notation A_j on the population q_i from the poor region (country) i noted by A_i (Figure 5).

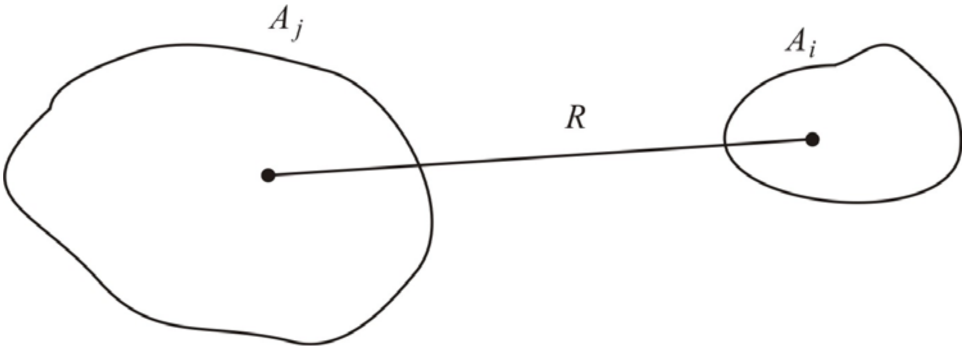


Figure 5.

Similarly with the equation (8) one can define the migration attraction force F_a as [27,29]:

$$F_a = \frac{q_i}{4\pi\varepsilon_m} \frac{K_j \sum_{j=1}^{n} q_j}{R^2} = \frac{q_i Q_j}{D_{ij}} \tag{11}$$

where:

$K_j \sum_{j=1}^{n} q_j = Q_j$ – represents the “economic power” of the rich region (country) j, with the population $\sum_{j=1}^{n} q_j$;

K_j – represents the wealthy factor and:

$D_{ij} = 4\pi\varepsilon_m R^2$ – represents the economical distance (transportation cost, accommodation, documents cost etc.) between two regions, R being the physical distance between regions (countries) A_i and A_j [27].

In the expression (11) ε_m represents the "environment's permissiveness"[2] of the environment between regions *i* and *j* [27].

We can make a similarity with the attraction forces of electrostatics if we consider the poor region (country) *i* as a region with "negative" sign (as "negative charge") and the rich region (country) *j* as a region with "positive" sign (as a "positive charge") (see Fig. 5).

Calculating the force of attraction on a variable q_i symbolizing a single emigrant from the region (country) i, we have from (10):

$$F_a = q_i E_m \tag{12}$$

or (see equations (10) and (11)):

$$F_a = \frac{q_i}{4\pi\,\varepsilon_m} \frac{Q_j}{R^2} = q_i E_m . \tag{12'}$$

From equations (12) and (12') we can find the expression of the migration field E_m:

$$E_m = \frac{Q_i}{4\pi\varepsilon_m R^2} = \frac{Q_i}{D_{ij}} \tag{13}$$

whose intensity is proportional to the economic power Q_j of the region (country) *j* and inversely proportional to the economic distance D_{ij} between the two regions (countries).

Knowing the intensity of the attraction forces (see eq. (12')), we can calculate the net migration flow given by migrant's mass M_{ij} from the poor ("negative") region (country) *i*, to the rich ("positive") region (country) *j*:

$$M_{ij} = C_o \cdot F_a = C_o \frac{q_i Q_j}{D_{ij}} \tag{14}$$

where: Q_j – symbolizes the economic power of the rich region (country) j, and:

C_o – represents the proportionality coefficient which depends also of the number of emigrants from the region (country) *i*, to the region (country) *j*.

---

[2] Term proposed by the authors, by similary with the electromagnetic permitivity from physics.

Wealth factor K_j in the equation (11) can be considered in the form of:

$$K_j = a(GDP_j - GDP_i) + b(u_i - u_j) + c\,(w_j - w_i) \qquad (15)$$

where:

GDP_j – represents the gross domestic product of the country j;

GDP_i – represents gross domestic product of the country i;

$u_i - u_j$ – the difference between the unemployment rates in the countries i and j;

$w_j - w_i$ – the difference between the wage rates in the countries j and i.

a, b and c – represent proportionality coefficients.

Taking into account the expression of Q_i from the equation (11), the equation (14) can be written in the form:

$$M_{ij} = C_o \frac{q_i K_j \sum_{j=1}^{n} q_j}{D_{ij}} \qquad (16)$$

where K_j is given by equation (15).

4.4. The Macrostate Parameter, an Econophysics Approach for the Risk Analysis of the Stock Market Transactions [28]

4.4.1. Economic value, simple volatility and normalized volatility

As it was shown in the our previous paper [28], besides its intrinsic economic value, characterized by **utility** value and **trade** value, an **informational** type value which determines the denomination, role and importance of the product or service, can be ascribed to any good, service or product.

The utility value as well as the trade value are tighter tied upon the mass or order concept or things construction, whereas the own information value of a material good is not physically palpable having an immaterial aspect like a wave, therefore a waved (pulsating) aspect: we have or we have not the respective information about the product or service considered. In this vision, in the case in which the number of information is large and concentrated upon some objects or economic “targets” etc., it can be spoken about an informational fascicle (beam) with dual aspect, similar to a photon beam (from physics) or other elementary particles (electrons etc.) characterized by a determined motion mass, impulse etc.

For the stock-markets analysis, the proper instruments of technical analysis which can provide valuable information about the evolution of the various transacted assets are used. Among the instruments used in the technical analysis, the most applied by simple investors are simple graphs to indicate the prices evolution or the volumes transacted, the simple volatility or return, simple averages or Bollinger bands and lesser other indices or stochastic oscillators which are approached by the specialists or broker societies, financial analysts etc.

In our papers, for volatility, usually the equation that expresses the assets price difference at two successive moments is used [28]:

$$Vol = p_t - p_{t-1} \tag{17}$$

where t represents the present time, and $t-1$ is the time at the previous moment, separated from t by the time unity (minute, hour, day, month etc.).

From the stock-markets analysis it is sometimes established that, although some assets with high prices are well appreciated, having an increasing tendency of the price, they are characterized by a diminished liquidity because of smaller transaction volumes, leading to ampler price oscillations, i.e. more risky for investors. That is why for a more complete assessment of the evolution of the assets it is appropriate to take into account the result of multiplying the share price p with the trading volume V estimated by the parameter:

$$a = pV. \tag{18}$$

Thus, for a more complete understanding of the share's evolution from the point of view of the price and transacted volumes, the parameter a given by (18) can be assimilated to the impulse of a information-particle (which symbolize the respective financial information) defined by the product pV similar to the impulse of a material particle defined by equation $p = mv$ from the elementary physics [28]. Such an index can deliver ampler useful information regarding the "inertia" degree or stability of an asset (shares, financial instruments etc.) than the price, p, or the transacted volume, V, taken separately.

Considering the parameter a given as result of multiplying the price p and trading volume V, i.e. $a = pV$, we can define the normalized volatility, Vol_n, as (see rel. (18)):

$$Vol_n = \frac{p_t V_t - p_{t-1} V_{t-1}}{p_{t-1} V_{t-1}} = \frac{a_t - a_{t-1}}{a_{t-1}}, \tag{19}$$

where:

p_t is the closing price from the day *t*;

V_t is the number (volume) of transacted shares in the day *t*;

V_{t-1} is the number (volume) of transaction shares in the day $t-1$;

P_{t-1} is the closing price from the day $t-1$.

4.4.2. The macrostate parameter for the stock-market transactions

As in the proposed model [28], we consider that all the information from the stock-market field can be assimilated with the particles of a gas of impulses $p = mv$, confined in a precinct ("financial boiler") that is the very stock-market (spot markets, forward markets etc.). In this situation it is plausible enough to apply the same principles, laws and results from thermodynamics, kinetic-molecular or statistical physics to describe the assemble of particles' states, called microstates, in which the information – particles that symbolise all information about the assets (or other financial instruments) from the virtual precinct which can be exist at various moments. Every "particle-information" contained in the financial boiler (virtual precinct) is characterized by a microstate in which the particles that symbolise all information about the assets (or other financial instruments) from the virtual precinct which can exist at various moments. Every "particle-information" contained in the financial boiler (virtual precinct) is characterized in a first phase by the parameter $a = pV$ where p represents the price and V – represent volume of transacted shares as we have seen in the previous section.

After a determined time, as a result of the succession of a numerous microstates which appear because of the agitation and the mixture of the constituent particles, the system reaches an equilibrium state which is a **macrostate** that can be described by measurable macrostate parameters [32].

By financial (or economic) microstate we understand the virtually particles assemble, which represents all information and decisions materialized in the share's price and the transacted volume for all the day, hour or minute of transaction).

So, if we consider parameter $a = pV$, a microstate for the capital market is given by the price and share's volume situation assemble at a given moment *t*. If this microstate is altered by a single transaction of a single investor, the assemble of microstates will be modified resulting a new picture of the stock-market situation, i.e. a new microstate. These changes are practically infinitely numerous (it can be a big number N of transactions) so the microstates number should be extraordinary big and can be interpreted and statistically evaluated by a similar formula like the one given by L. Boltzmann for the microstates of a thermodynamic system (mix of gases) which defined the entropy of a thermodynamic system (see formula (7) and [32]):

$$S = k_B \ln W. \tag{20}$$

In equation (20), $k_B = 1.380.662 \times 10^{-23}\,\mathrm{J/K}$ represents the Boltzmann's constant, and:

$$W = \frac{n!}{n_1!n_2!n_3!\ldots}$$

is the thermodynamics probability to realize a microstate of the system.

Starting from the definition (20) of entropy $S = k_B \ln W$ from thermodynamics, we can introduce a similar parameter named **macrostate parameter**, for the stock-markets:

$$P_M = k_m \ln W_m \tag{21}$$

where W_m represents a probability in succeeding a new microstate of the stock market and k_m is a constant which is specific for that stock-exchange market and for that type of transacted share.

On the other hand, the entropy S is tied to the thermodynamic temperature, T, by a equation like [32]:

$$\mathrm{d}S = \frac{1}{T}\,\mathrm{d}Q$$

or for the finite variations, by the expresion:

$$S = \frac{\Delta Q}{T} \tag{22}$$

that is to say that the thermodynamic entropy is proportional to the reverse of the temperature T.

Similarly, for the financial markets, to abstract a proportionality factor ΔQ, the reverse of P_M parameter represents the stock-exchange market temperature T_m, which is also an important macrostate parameter for the stock-markets analysis:

$$T_m = \frac{1}{P_m}. \tag{23}$$

As it was mentioned before, for the informational precinct (i.e. "financial boiler") the parameter $a = pV$, is similar to the impulse $p = mv$ of the material microparticles which, in the case of the financial virtual precinct, is generally close tied to the volatility and especially to the normalized volatility Vol_n, defined by (19) equation. So, in our considerations, instead of simple "impulses" of gas particles whose assemble motion determines the temperature of the medium from the precinct, it will be appealed to the normalized volatility defined by (19) expression in order to determine stock-market temperature $T_{m.}$

As specified, a microstate of the stock-market is given by the assemble of total prices and trade volumes for a transacted share at a given moment *t*. The assembly of the share's information microstates can be represented like an assembly of the impulses of the particles in a gas which gives the dimension of the macrostate, that means, the temperature of the environment or of the precinct which contents the studied "gas". The "virtual precinct" that we have proposed for the evolution of share's transaction is a three-dimensional one, with the following coordinates: share's price, transacted volume and time period *t*. In other words, for the temporal dimension takes into account, we can determine the microstates of each day (or hour etc.) of transaction and a macrostate parameter representing the sum of all microstates reported to the totality of their number, *N*, that could be define of the financial entropy P_M.

Consequently, the sum of all microstates, defined by the normalized volatility reported to number of microstates (that means of the total transactions), N, gives dimension of the agitation (disorder) on the market for a given period, as a macrostate parameter:

$$P_M = \frac{\sum \text{normalized volatility}}{N} = \frac{1}{N}\sum_{t=1}^{N} \frac{a_t - a_{t-1}}{a_{t-1}} \tag{24}$$

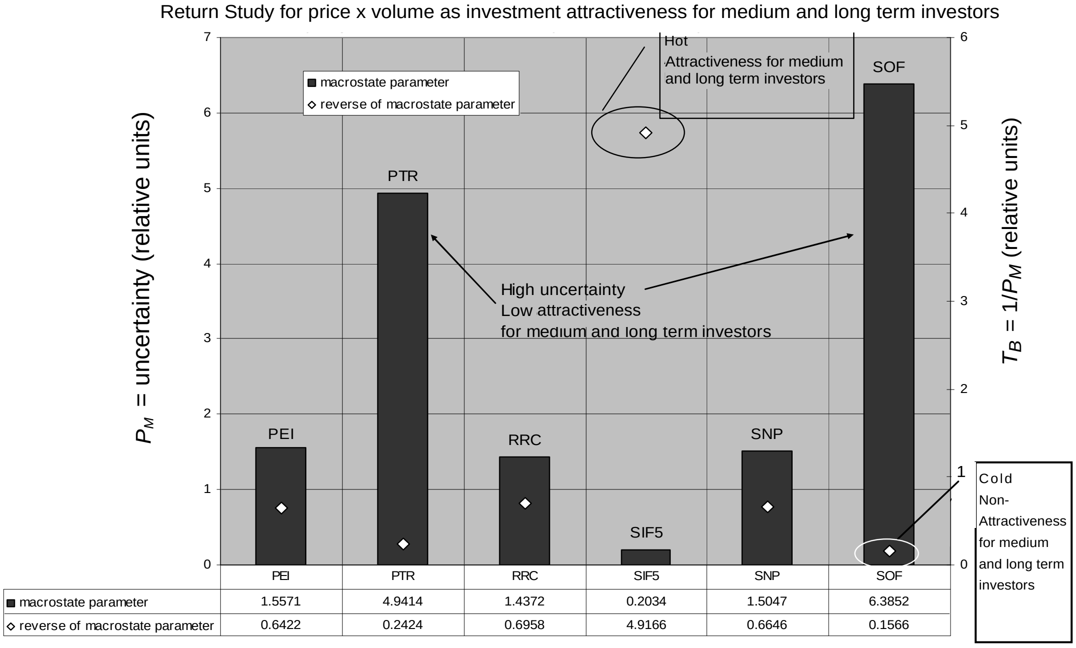
where a_t symbolises the product between price and volume at time *t* (see equation (18)).

Comparing the formula (24) with the expressions (21) and (20) for entropy, we can write also the equality [28]:

$$P_M = \frac{1}{N} \sum_{t=1}^{N} \frac{a_t - a_{t-1}}{a_{t-1}} = k_m \ln W_m = S_e \tag{25}$$

where S_e represents the financial (or economic) entropy being determined and equal to the macrostate parameter P_M.

In Figure 6, the macrostare parameter P_M and its reverse $1/P_M$ for several Romanian companies transacted at Romanian Stock-Exchange Market in 2004 are represented.



	PEI	PTR	RRC	SIF5	SNP	SOF
■ macrostate parameter	1.5571	4.9414	1.4372	0.2034	1.5047	6.3852
◇ reverse of macrostate parameter	0.6422	0.2424	0.6958	4.9166	0.6646	0.1566

Figure 6. The macrostate parameters P_M and $1/P_M$ for the some companies transacted at Romanian Stock-Exchange Market (BVB) in 2004.

If we look at chart where the diagrams of the macrostate parameter P_M are represented (Fig. 6), we can directly see how it can be used. Its value is showing us the degree of uncertainty for uncertain shares although they have a large volume of trading (see SOF or even PTR cases). We can conclude that for these shares, the macrostate parameter P_m or financial entropy S_e is larger mostly due to chaos induced by the market because of low prices and large transacted volumes despite of strong uncertainty of company evolution and lowly liquidity.

As it have been in previously paper [28], from what was shown it is seen that, practically the macrostate parameter is a measure of the uncertainty from the economic point of view and a measure of the disorder (entropy) in the stock-markets from econophysics point of view. In other words the economic uncertainty can be measured by the macrostate parameter, which is the entropy equivalent from physics.

Taking in account these considerations, from the above mentioned paper [28] we extended our study on the 40 companies quoted at I and II categories of the BVB (Romanian Stock-Exchange Market) and applying the methodology described above, using of the macrostate parameter, the investment risk scale for the companies enlisted during 2006 year is established (Fig. 7). The financial results of the companies corroborate with their hierarchy on the macrostate parameter value for the 2006 year (Fig. 7) verified the theoretical considerations of foundation of the econophysics model for the risk estimation in the Romanian stock-exchange market [28].

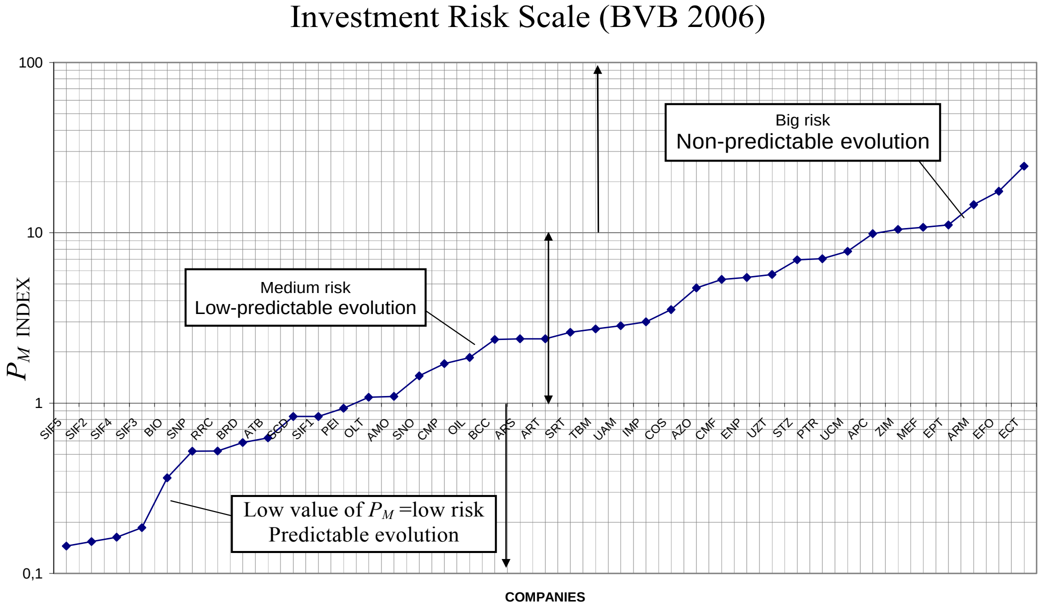


Figure 7. Investment risk scale for the 40 Romanian companies quoted at Bucharest stock-exchange market (BVB) during 2006 year.

5. Conclusions

To investigate the economic phenomena and processes, some methods, theories or models borrowed from other sciences, particularly from the exact sciences (physics, mathematics) or natural and social sciences etc, are widely used. Thus have been born and developed some border sciences as econometry and more recently econophysics, the latter having a variety of branches or subdomains. In this paper we attempted a systematization of different subdomains or branches of econophysics. Thus, all subdomains that use statistical mathematics and statistical physics methods are grouped in the major domain of **statistical econophysics**, while econophysics subdomains and models that use models inspired by phenomena and laws from other domains of physics (other than statistical physics) or from other sciences are grouped in the major domain of **phenomenological econophysics** (see Figure 1).

The phenomenological econophysics models were developed based on analogies between economic processes and laws, and phenomena and laws from fundamental or applied physics (electronics) especially of Electricity, Condensed Matter, Thermodynamics or Engineering (econo-engineering models). The conclusions and the mathematical equations that have been established for substantiation of these models find their applications in economic practice and checks and implicitly justifies the validity of economic laws deducted semi-empirically or based on practical observations. In this paper we gave some examples of such correspondences between the laws or equations found for such phenomenological econophysics models and the economic regularities or models established by different researchers.

In most models of statistical econohysics is presented the **static situation** of laws or state of the economic processes or phenomena, found in the form of the normal distribution laws of Gauss type, exponential, logarithmic, or power distribution law, Boltzmann-Gibs, Fermi-Dirac or Bose-Einstein distributions etc., especially for the study of stock-markets, of wealth or income distribution, of resources distribution (money, gold, oil etc.) of the different categories of products etc.

Phenomenological econophysics models have the property that based on the analogy between empirical economics phenomena or laws and the laws and phenomena of fundamental physics (other than statistical of Physics) can be developed a model or mathematical equations confirming the practical approaches and the laws from the analyzed economic domain.

As shown in the examples of phenomenological econophysics models mentioned in this paper, mathematical equations established in the each model confirm the economic lawfulness determined empirically from the economic practice. This fact supports the economic laws used in practice, showing that, as have been done so far, are the most appropriate laws for the analyzed economic processes or phenomena.

REFERENCES

[1] Nicholas Georgescu-Roegen, *The Entropy Law and the Economic Processes*, Harvard University Press, Cambridge, Massachussetts, 1971.

[2] S. Galam, *Sociophysics: a review of Galam models*, Int. J. Mod. Phys. C **19**, 409440 (2008)

[3] Serge Galam, *Market Efficiency. Anticipation and the Formation of Bubbles-Crashes*, Proc. of ENEC 2012 International Conference on Econophysics, New Economy and Complexity, 30 May-1 June, 2012, Victor Publishing House, Bucharest, Romania, 2012, p. 39.

[4] Bikas K. Chakrabarti, Anirban Chakrabarti, Arnab Chatterjee (Eds.), *Econophysics and sociophysics: trends and perspectives*,WileyVCH, 2006.

[5] V. M. Eguiluz, M. G. Zimmernann, *Transmission of Informatics and Herd Behavior: An Application to Financial Markets*, Physical Review Letters, **85**, 5659-5662 (2000).

[6] X. Li, Y. Y. Jin and G. Chen, *Complexity and synchronization of the World trade Web*, Physica A **328**, 287-296 (2003).

[7] M. Gligor, M. Ignat, *Econofizica* (in Romanian), Economica Publishing House, Bucharest, 2003.

[8] M. A. Serrano and M. Boguna, *Topology of the world trade web*, Phys. Rev. E **68**, 015101 (2003).

[9] D. Sornette, *A Complex System View of why Stock Markets Crash*, Essay, in New Thesis, 01(1) 5-17 (2004).

[10] R. N. Mantegna, Z. Palagyl, H.E. Stanley, *Applications of Statistical Mechanics to Finance*, Physica A **274**, 216 (1999).

[11] R. N. Mantegna and H. E. Stanley, *An Introduction to Econophysics*, Cambridge University Press, Cambridge, 2000.

[12] A. A. Drăgulescu and V. M. Yahovenko, *Evidence for the exponential distribution of income in the USA*, Eur. Phys, J.B **20**, 585-589 (2001).

[13] A. A. Drăgulescu and V. M. Yahovenko, *Statistical mechanics of money*, Eur. Phys. J. B **17**, 723-729 (2000).

[14] J. J. Ramsden and Gy. Kiss-Haypál, *Company size distribution in different countries*, Physica A **277**, 220-227 (2000).

[15] A. A. Drăgulescu and V. M. Yahovenko, *Exponential and power-law probability distributions of wealth and income in the United Kingdom and The United States*, Physica A **299**, 213-221 (2001).

[16] R. L. Axtell, *Zpif distribution of U.S. firm sizes*, Sience, **293**, 1818-1820 (2001).

[17] Yan-Bo Xie, Bo Hu, Tao Zu and Bing-Hong Weng, *Power Law Distribution of Wealth in a Money-Based Model*, in arXiv:cond-mat/0405288 v1, 13 May 2004.

[18] K. E. Kürten and F. V. Kusmartsev, *About Distribution of Money in a Free Market Economy*, Proc. of ENEC 2010 International Conference on Econophysics, New Economy and Complexity, 20-22 May, 2010, Bucharest, Romania, Victor Publishing House, 2010, pp. 7-21.

[19] T. Kaizoji, *Scaling behavior in land markets*, Physica A **326**, 256-264 (2003).

[20] E. Kürten and F. V. Kusmartsev, *When Rich Get Richer then Arises Financial Crisis and Bose-Einstein Condensation in a Wild Economy*, in Proc. of ENEC 2011 International Conference on Econophysics, New Economy and Complexity, 26-28 May, 2011, Bucharest, Romania, Victor Publishing House, 2011, pp. 103-124.

[21] N. Fellingham and F. V. Kusmartsev, *A study of the Distribution of of Vealth in a stochastic Non-Markovian Market*, in Proc. of ENEC 2011 International Conference on Econophysics, New Economy and Complexity, 26-28 May, 2011, Bucharest, Romania, Victor Publishing House, 2011, pp. 75-101.

[22] D. Sornette, *Why Stock Markets Crash – Critical Events in Complex Financial Systems*, Princetown University Press, New Jersey, 2003.

[23] J. C. Ferrero, *The equilibrium and nonequilibrium distribution of money*, International Workshop on "Econophysics of Wealth Distribution", Saha Institute of Nuclear Physics, Kolkata, India, 15-19 March, 2005.

[24] E. Oltean and F. V. Kusmartsev, *A study of Methods from Statistical Mechanics to Icome Distribution*, Proc. of International Conference on Econophysics, New Economy and Complexity, ENEC 2012, 30 May-1 June 2012, Bucharest, Romania, Victor Publishing House, Bucharest, 2012, pp. 7-37.

[25] I. Spânulescu, I. Popescu, V. Stoica and Anca Gheorghiu, *An Econophysics Model for investments using the Law of the Electric Field Flow (Gauss' Law)*, Proc. Int. of ENEC 2012 Conference on Econophysics, New Economy and Complexity, 30 May-1 June, Bucharest, Romania, Victor Publishing House, Bucharest, 2012, pp. 75-86.

[26] I. Spânulescu and Anca Gheorghiu, *Economic Amplifier – A New Econophysics Model*, arXiv: 07073703 (2009).

[27] Anca Gheorghiu and I. Spânulescu, *An Econophysics Model for the Migration Phenomena*, arXiv: 12020996 (2012).

[28] Anca Gheorghiu and I. Spânulescu, *Macrostate Parameter – A New Econophysics and Technical Index for the Stock Market Transaction Analysis*, Proc. of ENEC 2009 International Conference on Econophysics, New Economy and Complexity, 21-23 May, 2009, Bucharest, Romania, Victor Publishing House, Bucharest, 2009, pp. 71-87.

[29] I. Spânulescu, *Electricity and Magnetism (in Romanian)*, Victor Publishing House, Bucharest, Romania, 2001.

[30] John, M. Keynes, *The General Theory of Employment, Interest and Money*, The Royal Economic Society, 1973

[31] I. Spânulescu, *Semiconductor Devicess and Analogue Integrated Circuits* (in Roumanian), Victor Publishing House, Bucharest, 1998

[32] M. Toda, R. Kubo, N. Saito, *Statistical Physics*, Springer-Verlag, Berlin, Heidelberg, New York 1992.