Abstract: This paper proposes a framework for exploring the main research approaches of the financial markets, conducted in the past years by statistical physics specialists. It also presents the global financial developments in the last few years, as well as a review of the most important steps in the development of the physical and mathematical modelling of the socioeconomic phenomena. In this regard, we analysed research findings published in the notable international journals. Our research demonstrated that the econophysical models developed in the past few years for the description of the financial phenomena and processes do not provide satisfactory results for the construction of complete solutions able to answer the nowadays financial challenges. We believe that research instrumentation of statistical physics has developed significantly lately and the research approaches in this field should continue and should be enhanced.

Keywords: econophysics; financial developments; modeling

JEL Classification: G15; C18

1. Introduction

This paper is a first research approach conducted jointly by a finance specialist and a physicist. The need for a closer cooperation between the 2 categories of researchers was highlighted in 2011 by Christophe Schinckus, who said that the approaches for the facilitation of the scientific communication between physicists and financial economists should be intensified for the following reasons: (a) physicists can develop models that describe financial phenomena, using specific tools, but are often unable to give an economic sense to the results of their research, being able to answer only the question “how does the phenomenon occur?”; (b) financial economists frequently use less complex tools compared with physicists because they try to give a social explanation to financial phenomena, but they are capable to answer the question “why does the phenomenon occur?”.

The effort of the researchers in the socioeconomic field is currently focused on determining similarities, on the physical and mathematical modelling of the constitutive elements of the social systems, of the relationships between these elements, and on the observables of interest. It is obvious that the hypotheses based on similarity are not unique; they strongly depend on the actual information available (the access to economic and social databases, as we know, more or less restricted for various reasons, mainly in order to provide confidentiality required by the law), on the field of specialty of the members without a socioeconomic background of the research teams (physicists, mathematicians, computer scientists, chemists, biologists, etc.), due to which the modelling obtained is not unique. Thus various theoretical models are obtained for one and the same problem in the field of the socioeconomic phenomena; the validation of one or another being given only by the superior consistency between the theoretical forecasts provided and the reality.

The certain result of the successes achieved in the past decades is incontestable: the behaviour of the socioeconomic systems is not completely random or unpredictable, due to the fact that it is subject potential universal laws that can be discovered by connecting as many data as possible and from the similarities discovered from the regularities thus observed. Specialists’ interest in using statistical physics in the research of banking, stock and foreign exchange markets has enhanced on the background of the latest financial crisis that has affected world economy.

The purpose of this paper is to assess the main research approaches of the financial markets, conducted in the past years by statistical physics specialists. For a better understanding of such approaches, we prepared a presentation of the global financial developments in the last few years, as well as a review of the most important steps in the development of the physical and mathematical modelling of the socioeconomic phenomena. Importance of our research resulting from updating the literature reviews in econophysics field and assessing the latest trends in modeling financial phenomena. Our research seeks to classify theories not listed, but to list them and make a short summary of each idea the literature.
2. Metodology

The first step in the research paper process was extracting from the ISI database and other international databases of all articles in the field of modeling financial phenomena, in order to achieve a critical analysis of articles. The resulting literature included approximately 50 articles published in recognized journals in the field. Each item has been inventoried to classify information submitted for further analysis. We have examined and categorized items collected using a unified approach and focused on the goal of our research. According to this approach, the inventory consisted of classifying articles under the following criteria:
- methods used;
- assessment tools / techniques;
- results obtained.

The second step in the research paper process was analysing main aspects of evolution of global financial markets during 2011-2015. In this regard, In this respect, we consulted Global Financial Stability reports published by the International Monetary Fund. For argument's sake surprised trends, we accessed the statistics provided by the World Bank. Based on this data more graphs were made.

3. Global financial developments in recent years

The financial crisis occurred in 2008 generated the increase in the general interest in the research of problems related to the fluctuation of liquidity on global financial markets, the assessment of risks related to financial operations, the behaviour of investors and operator on capital markets, etc. In the past 5 years, international financial markets became much more stable, on the background of the regulation measures of the financial sector adopted by central banks, as well as of the much more prudent behaviour showed by the participants to these markets. Significant differences concerning the characteristics of the financial environment can be noticed between the emerging countries and the developed ones. In this respect, the studies carried out by the International Monetary Fund concerning the global financial developments are relevant (tabel 1):

<table>
<thead>
<tr>
<th>Publishing date</th>
<th>Aspects</th>
</tr>
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<tbody>
<tr>
<td>April 2011</td>
<td>many advanced economies are struggling with the legacy of high debt and excessive leverage; sovereign balance sheets are under strain in many advanced economies; many banks remain insufficiently capitalized and vulnerable to rising funding costs; capital inflows to emerging markets have rebounded but remain volatile.</td>
</tr>
<tr>
<td>September 2011</td>
<td>sovereign balance sheets remain fragile in a number of advanced economies despite steps toward fiscal consolidation; low interest rates and tight credit spreads; a series of shocks have recently buffeted the global financial system.</td>
</tr>
<tr>
<td>April 2012</td>
<td>credit risks have retreated from high levels; the global financial regulatory framework is being strengthened; the risks to global financial stability remain elevated.</td>
</tr>
<tr>
<td>October 2012</td>
<td>favorable developments in financial markets, risks to financial stability; lower risk appetite of investors.</td>
</tr>
<tr>
<td>April 2013</td>
<td>global financial and market conditions have improved appreciably; banks have taken significant steps to restructure their balance sheets; improving global and national financial sector regulations.</td>
</tr>
<tr>
<td>October 2013</td>
<td>emerging markets are facing a transition to more volatile external conditions and higher risk premiums; the global banking system is phasing in stronger regulatory standards.</td>
</tr>
<tr>
<td>April 2014</td>
<td>emerging market economies are transitioning to more sustainable growth in the financial sector; normalization of U.S. monetary policy.</td>
</tr>
<tr>
<td>October 2014</td>
<td>the economic benefits are becoming more evident in some economies; increasing global financial stability risks.</td>
</tr>
<tr>
<td>April 2015</td>
<td>the financial stability risks are rising and rotating; rapidly depreciating exchange rates.</td>
</tr>
<tr>
<td>October 2015</td>
<td>strengthening macro financial environment in advanced economies; emerging market vulnerabilities remain elevated, risk appetite has fallen, and market liquidity risks are higher.</td>
</tr>
</tbody>
</table>

Source: International Monetary Fund, Global financial stability reports, 2011-2015
Certain statistical information supplied by the World Bank proves that, in the past few years, global financial markets have undergone contradictory developments. In this respect, we selected a few representative indicators:

- The bank capital to assets ratio is a measure of bank's financial health (figure 1). This indicator is the ratio of bank capital and reserves to total assets.

![Figure 1. Evolution of the bank capital to assets ratio in some countries](source: Authors’ calculations based on Data-Indicators (The World Bank))

- Interest rate spread is the interest rate charged by banks on loans to private sector customers minus the interest rate paid by banks for demand, time, or savings deposits. A high interest rate spread shows that the priority of the banks is to obtain profit from the difference between the bonus interest (for loans) and the one paid (for deposits). In certain economic circumstances, a high interest rate spread shows the need of the commercial banks that have accumulated bad loans and must create provisions to increase the interest lending rate/to decrease the interest deposit rate in order to improve the level of profits (figure 2).

![Figure 2. Evolution of the interest rate spread in some countries](source: Authors’ calculations based on Data-Indicators (The World Bank))

- Market capitalization is the share price times the number of shares outstanding for listed domestic companies. Market capitalization is the best indicator for assessing the size of the capital market (figure 3).
The global financial developments in the past few years show that each international financial market can have a different behaviour under the impact of numerous influence factors.

4. Physical and mathematical modelling in the economic theory

The first modelling of the socioeconomic systems were purely mathematical. Several authors (Mantegna and Stanley, 2000) consider two reference moments in the initiation of this phase: the introduction, around the year 1890, of the power functions by Vilfredo Pareto, and the publication, in 1900 of the paper Théorie de la speculation by Louis Bachelier, under the guidance of the mathematician and physicist Jules Henri Poincaré. In spite of all the deficiencies shown over time, the two purely statistical models of the distribution of the individual incomes from a stable economy, and respectively, of the derived tools represented reference models for almost three quarters of a century. They were improved by hypotheses and various developments, however, the results obtained were not able to replace the quasi-total failed attempts to build physical models of the various socioeconomic systems.

Meanwhile, the field of probabilities and mathematical statistics established by Poincaré allowed for unprecedented progress in the modelling of thermodynamic systems, (starting with Boltzmann’s papers on the molecular kinetic theory of gases and with the explanation of the Brownian motion by Einstein), marking the birth of statistical physics. Moreover, from the 1950’s, the development of the computer technology allowed for building databases of considerable size and for the numerical solution and simulation of the solutions of nonlinear differential equations, which also led to the approach of seemingly chaotic and self-organizing phenomena, occurred far from any equilibrium state, which proved to be no exceptions in the macroscopic universe (non-linear thermodynamics, the physics of dynamical/complex systems, the physics of chaos).

The results obtained, somewhat in an unexpectedly good consistence with the recorded reality, together with the fact that the only fundamental hypothesis in the statistical modelling of the thermodynamic systems is the one of the large number of constituents (statistical spatial or temporary groups) – their nature is by no means involved – led to the obvious idea of the above-mentioned potential similitude, of the potential universal validity of modelling in the inanimate world. In the past three-for decades from the emergence of statistical physics we can say that several sets of methods of approach were outlined (it would have been too much to call them models of socioeconomic systems yet) that led to a number of tangible results. Most of them were transpositions of the results obtained in thermodynamics and in the statistical physics. In a brief listing of these methods (Rickles, 2007; Schinckus, 2010; Chen and Li, 2012; Mimkes, 2012; Huang, 2015; Zapart, 2015) that is by no means exhaustive, we can mention:

- the statistical methods of the power functions (Lux, 1996; Gopikrishnan et al. 1999; Rachev and Mittnik, 2000; Plerou et al., 2004; Scarfone, 2007; Gabaix, 2007; Yakovenko and Rosser, 2009; Kristoufek, 2014; Vakhtina and Wosnitza, 2015 etc.); The method implies determining the temporal variation of certain economic parameters (usually prices of physical quantities such as the volume of trade, assets, property, shares, profits, number of investors, etc.) from the available database. By means of interpolations, temporal variation series of certain characteristics of interest are obtained. From the interpolation of all or part of the series we can obtain exponents of power functions that eventually capture, due to their repetitive nature in space or time, the macroscopic regularities of the phenomena observed. Subsequently, in the attempt to understand the governing structure and mechanisms of the analysed socioeconomic systems (in order to develop models that should allow for the forecast of the future behaviour), justified hypotheses are creates concerning the similitude between the analysed systems and statistical groups of various material natures (ideal gases, real gases, fermionic or bosonic spins, etc.) with a similar dependence of the distribution of certain corresponding characteristics.

- the study of socioeconomic systems as systems with linear behaviour (evolving close to macroscopic equilibrium states); The studies of this type are applicable exclusively to “usual” socioeconomic phenomena that do not
imply high gradients of the analysed characteristics. The research methods are those specific to the linear thermodynamics (entropic studies, definitions of the densities of macro extensive dimensions, the calculation of the flows involved, the determination of certain kinetic coefficients, etc.).

- the study of socioeconomic systems as complex dynamic systems (far from any macroscopic equilibrium) by means of nonlinear thermodynamic methods: Certain socioeconomic systems show large short-term variations of characteristics of interest (social and economic crises, stock market crashes, financial bubbles, etc.) which lead to the certain conclusion that we are dealing with complex dynamic systems that evolve far from any equilibrium state under the action of high gradients, and their evolution is nonlinear. Moreover, the self-organization of these systems opened in various structures that can be modelled using fractals, under the action of external flows of extensive sizes, also confirms this conclusion. Consequently, based on the above-mentioned similarity and correspondence, researchers in this field are led to resort to the principles and methods of nonlinear thermodynamics, a branch of physics closely connected with other fields that actually emerged from it as well or generated highly topical mathematical fields (dynamic systems, complex systems, chaos theory, fractals, etc.)

- the study of socioeconomic systems as complex dynamic systems by means of networks: random graphs, trees, intelligent networks (Albert and Barabasi, 2002; Barabasi et al., 2002; Garlaschelli and Loffredo, 2004; Palla et al., 2005; Kocakaplan et al., 2013; Nobi et al., 2014 etc.): From the macroscopic analysis of the systems, hypotheses are developed on the topology of the networks modelling them within the analysed phenomena. The subsequent construction allows for a highly intuitive representation, and especially, based on the mathematical and informatics methods, for the analysis and forecast of the evolution over time of the characteristics of interests. At this moment we can say that there are three types of networks that describe with satisfactory results the complex socioeconomic systems: the random graph, small-world networks, and scale-free networks.

At this moment we are drawing the attention on certain important aspects. First of all there is a tendency to identify econophysics with the exclusive application in economy of the study models and principles from the statistical physics (Bucsa et al., 2011; Schinckus, 2013). In our opinion, such a point of view is at least restrictive and neglects the significant results obtained from the expansion to socioeconomic phenomena of the models and methods of analysis and forecast developed in other physics branches (mechanics and quantum mechanics, electromagnetism, atomic and nuclear physics, etc.) and even in other branches of science (mathematics, informatics, biology, ecology, cybernetics, etc.). For example, there are, in the specialised literature, many uses of the mathematical theory of graphs in modelling socioeconomic systems (Albert and Barabasi, 2002; Barabasi et al., 2002; Garlaschelli and Loffredo, 2004; Palla et al., 2005; Oya et al., 2014; Kocakaplan et al., 2013), of the fractal theory (Budinski-Petković et al., 2014), or of the studies based on entropic functions calculated starting from Shannon’s information theory (Oh et al., 2015; Vogela and Saravia, 2014). We find attempts to use mechanical oscillations in the analysis and description of business cycles (Boumans, 1992) or to define “econometric potentials” in the modelling of trade on which, similarly to mechanical potentials, minimum dynamic equilibrium conditions should be applied that could provide variation curves of the economic parameters (Marmont Loboa and de Sousa, 2014). Other approaches imply defining a unique and “natural” economic unit”, Walras’ unit, similar to Planck’s unit in the quantum mechanics (Drefilla, 2007), or the direct application of the concepts of the quantum mechanics in economy (Jimenez and Moya, 2005; Nastasiuk, 2014). There were attempts to assimilate the behaviour of the foreign exchange market to the turbulent flow in a gravitational field (Ghashghaie et al., 1996). The capital market behaviour can be put in satisfactory correspondence with the adaptive one at macroscopic scale of the ecologic systems; the artificial neural network model from informatics was relatively successfully used in modelling and forecasting economic systems in which the linearity assumptions are not confirmed (Saldaaoui and Rabbour, 2014) etc. Secondly, it can be noticed that some authors (Bouchaud, 2002; Ball, 2006; Chakraborti et al., 2011; Feng et al., 2012; Schinckus, 2013) promote the idea of the existence of two separate research methods in econophysics:

- classical reductionism (statistical econophysics) – it is assumed that the socioeconomic systems are homogenous and composed of particles (“zero-intelligence agents” – items without thinking and therefore incapable to learn), with purely random behaviour/interaction by excellence;

- the agent-based method (agent-based econophysics) – the socioeconomic systems are deemed to be heterogeneous, made of distinctive elements and capable of learning, therefore, their behaviour/interaction is no longer random, and distinctive hypotheses are needed in relation to the modelling.

We should notice, in this respect that, through their studies, Landini and Uberti in 2008, deemed that the economic actors have various behaviours and thus have a decisive influence on the overall behaviour. However, for the aggregation of individual behaviours they resorted to a method found in the statistics of heterogeneous systems and known as the mean field method. Nevertheless, this method can be reduced to the classical statistical method, as soon as it is considered (through hypotheses justified based on the data resulted from the empirical observation) the random dynamic fractions in the space of the phases of the modelled system (the proportions describing the unitary behaviour of homogenous agent systems). Thus, in our opinion, the distinction between the two methods is an artificial one, the principles (the one of the high number of components and the correspondence and similitude one) and the approach methods being the same. The distinctive way of building statistical collectives reflects not only an approach at the micro level that is more accurate in the case of the agent-based method, which can also be found in the usual statistical applications based on net heterogeneous systems, leading to model with an increased level of complexity, but also with a correspondence closer to the observations made at macro level.

Within the same concept, it is also claimed that the objectives of the two methods themselves are also different. For example, the econophysical statistics would use the data found in available databases with the purpose of
determining regularities in the behaviour of the socioeconomic systems, while the agent-based econophysics would generate these data itself through complex modelling based on the distinctive behaviour of each composing agent. This is an opinion we deem as erroneous as well: both methods start from the analysis of the macro behaviour, more specifically from the analysis of the available data concerning the socioeconomic systems and the conditions external to them, the ultimate purpose being the construction of a model at micro level that should explain the regularities observed and, subsequently, allowing for forecasts as consistent with the reality as possible. It is wrong to believe that the agent-based method can ignore the data resulted from the analysis of the studied phenomena and systems, having as sole purpose the modelling of the socioeconomic agents and the interactions between them. According to the above-mentioned considerations, such modelling is impossible even at the main level, as long as the researcher is both an element of the system and an observer of this system.

5. Recent contributions of the statistical physics in the research of banking, stock exchange and foreign exchange markets

Under the circumstances of the turbulences that have affected world economy in recent years, an increasing number of specialists have focused their research approaches on the identification of early warning systems, more specifically on the identification of financial crisis early warning systems, by means of statistical physics tools. Starting from the premise that the extensive financial connections between countries played a significant role in the spreading and deepening of the world financial crisis, Minoiu et al. (2015) highlighted that increases in a country’s own connectedness and decreases in its neighbours’ connectedness are associated with a higher probability of banking crises after controlling for macroeconomic fundamentals. The authors believe that the inclusion in financial crisis forecast models of information on financial connectivity would generate much better results. Using theories of dynamical systems, Castellacci and Choi (2014) modeled financial crises and contagion in a multi-agent system comprising multiple economies. In their opinion, the model could be applied in the case of the sovereign debt crisis in the Euro Area, while the model was going to be tested on the occasion of future research approaches.

The causes of the occurrence of high fluctuations of the stock exchange markets and the amplitude of the effects of the 2008-2009 financial crisis on the stock exchange markets have also been research topics in recent years. In this respect, Tobias Preis (2011) tried to highlight that physics concepts can be used to model how financial bubbles occur. By using the fractal analysis, Li and Liaw (2015) showed that the stock exchange markets in the developed countries and in the emerging countries have an opposite behaviour in the falling and rising phases of the stock markets after the financial crash. Analyzing the entropy density function in the return time series (during 2002-2011) for several financial markets (U.S., Korea, Germania), Oh et al. (2015) showed that the entropy density function of the S&P500 index during the subprime crisis recorded a significant decrease, compared to other time periods, while the other stock market indexes analysed did not record significant fluctuations. The authors believe that the stock market analysis model developed based on the entropy value could allow for early warning, before the occurrence of a financial crisis.

The analysis of the specialised literature of the past few years revealed new contributions in the research of banking, stock exchange and foreign exchange markets Oya et al. (2014) investigated the 24-hour periodicity of foreign exchange markets using a recurrence plot, and define an absolute measure for a key currency based on the strength of the periodicity. By means of this absolute measure, they proved that, after the financial crash of 2008, the credibility of the American dollar did not decrease significantly, and compared to the euro and to the Japanese yen, it increased. Investigating a systemic liquidity crisis which took place in Turkey in November 2000, Saltoglu and Yenilmaz (2015) showed that measures of market heterogeneity should be used to generalize the relationship between systemic risk and interconnectivity. Also, heterogeneity in the banking system could be used as a supplementary tool to monitor systemic risk dynamics. Vakhtina and Wosnitza (2015) tested the predictive power of the log-periodic power law using a database consisting of daily observations of the development of credit default swap spreads of 40 international banks for the period from June 2007 to March 2010. Having a number of limits that are mentioned in the paper, the model developed by the 2 authors could be used to predict situations where a very high number of clients of the banks withdraw their deposits, at the same time, based on concerns related to the bank solvency. Analysis of 54 worldwide stock indices and 48 worldwide bond indices from January 1, 1991 to January 1, 2007, using the probability density function, Podobnik et al. (2010) tested the relationship between the average growth rates and volatility of market capitalization and the level of market capitalization. They established a power-law relationship between the market capitalization of a country’s financial market and the gross domestic product of the same country. Hua et al. (2015) proposed an intraday stochastic model with linear variable diffusion coefficient as a lowest order approximation to the real dynamics of financial markets. In the authors’ opinion, based on this model, techniques could be developed by means of which the intentions to manipulate prices at stock exchanges could be identified.

6. Conclusions

The research of the socioeconomic phenomena/systems by means of the statistical physics tools have a certain deficiency: the absence of a significant quantity from the information required to fully describe the phenomena/systems in question. Under such circumstances, we can notice that any scientific modelling is carried out strictly within the framework outlined by the formal logic system. This framework defines an argument as valid if, starting from true and complete hypotheses, it leads to true conclusions. Obviously, the valid forms of the argument can be found by studying the formal conditions of human thinking. However, once a correct thinking schema is found, a true conclusion can be
certainly obtained only if the hypotheses and data from which we start – the argumentation – are true and complete. Otherwise, it is (very) likely to reach false conclusions based on a valid argument (it is shown that, through such an argument, the truth leads only to truth conduce, while the false involves anything). Moreover, scientists are well aware of the fact that, in most cases, an untrue or incomplete argumentation supplied by partial observations of a system or class of phenomena leads to conclusions that are inconsistent with the objective reality.

Consequently, the issue of the extent to which socioeconomic studies can lead to correct conclusions and ultimately, to mathematical models consistent with the reality is raised with increasing strength.

Recent contributions of statistical physics in the research of banking, stock exchange and foreign exchange markets answer, to some extent, the critical observations concerning economic research for the inability to forecast moments of financial instability and to prevent the outburst of financial crises.

Even if the econophysical models developed in the past few years for the description of the financial phenomena and processes do not provide satisfactory results for the construction of complete solutions able to answer the nowadays financial challenges, we believe that the research approaches in this field should continue and should be enhanced.

7. References


