FEAR, RUMOUR AND FASHION DYNAMICS SEEN AS SECOND ORDER PHASE TRANSITIONS

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Abstract. *The aim of the paper is to demonstrate that some methods taken from the statistical thermodynamics may be applied in order to model several social phenomena for which, for the time being, we have qualitative descriptions only. Some limitations and warnings related to the interdisciplinary transfer of concepts between physics and socioeconomic sciences are briefly analysed in the Introduction. In the second section we study the fear/rumour propagation process in the stock market space. The speculative bubbles are seen as non-equilibrium patterns resulted from the reaction-diffusion mechanism. In the third section we study the fashion fluctuations, seeing them as noise induced transitions in a system in which the interaction among individuals is described by means of the classical Ising-spin model. In spite of several unavoidable limitations, the models offer useful quantitative explanations to the phenomena and fit well the empirical data.*

Keywords: *small-world network, minimal path length, clustering coefficient, phase transition*

1. INTRODUCTION

Actually, sociologists seem not to show great interest in the sociophysics itself and thereby sometimes this activity is quoted with ironical comments, as “reinventing the wheel”. Nonetheless, more and more sociologists notice the activity of the physicists on social networks, and the new methods of solving some classical problems of sociology such as the small world problem, the information and contamination spreading in various networks, the preferential attachment, and so on. We note here that the leading authors in sociophysics, such as Serge Galam, Dietrich Stauffer, Janus Holyst and others published some of their early work in sociology journals. Also, they paid much attention to references to sociological and psychological literature.

If some agreement is possible between the sociologists and the physicists, it is probably about the need of a more intense exchange of information [1]. For example, many sociologists know about the physics of the networks, but they are less informed about the fact that many more methods of the statistical mechanics were succesfully applied in the study of the human collectivities. It would be worth mentioning here the self-organization in complex systems, the Ising-like models, and the quantum theory. Even if the results tend to be more in the form of general theorems and bonds than specific results for particular problems, they are attracting growing interest, especially for the new viewpoints they generate for old questions.

Some inherent difficulties of such an undertaking are pointed out in [2]. Modeling dependence in the social sciences has to take into account circumstances that differ substantially from those encountered in the natural sciences. Firstly, experimentation is usually not feasible and is replaced by survey research, implying that the explanatory variables cannot be manipulated and fixed by the researcher. Secondly, the number of possible explanatory variables is often quite large, unlike the small number of carefully chosen treatment variables frequently found in the natural sciences.

To begin with, let us analyse four basic concepts as taken from the statistical mechanics to describe social systems: spins, interaction, temperature and phase transition.

a) *Spins and opinions*

In social sciences the term opinion is not yet very precise. In sociophysics we represent opinions by spins. A spin is a variable assigned to an actor or agent. There is usually a large set of agents i, distributed in lattice sites or graph nodes; then, we have spin variable si. As a rule, in the sociophysical papers, spins can be of two values, +1 or ˜1, but the spin variable has been generalized to capture the situations when we have more than two opinions. The spectrum of possibilities is either discrete or continuous. In both cases we can also look for magnetic analogies; the respective models are the Potts model [4] and the classical Heisenberg model [3] reduced to one variable. Multidimensional approach was already used (see e.g. [5], [6]), and presumably will be used in many other papers.

b) *Interaction*

In physics, the only way for an object to exist is to have energy: a possibility of doing work. In social sciences, there is nothing like energy: no energy conservation, no energy measurement. In physics, the way to detect the interaction between objects is to observe correlations between their states. In this sense, physical interaction is detectable also in sociology. In sociology, one speaks about four levels of theoretical description of interpersonal interactions [1]. At the first level, the interaction is described as a chain of impulses and reactions. At the second level, interaction is undersood as social exchange. The above-mentioned concept of reciprocity applies correctly here. At the third level, meanings of interactions are as exchange of information by means of human contacts. At the last level of abstraction, we find the theory of social roles and labeling. In sociophysics, most of these subtleties are lost. Within the magnetic analogy, the interaction between partners is reduced to the energy of a mutual interaction.

c) *Temperature and noise*

In physics, temperature is inseparably connected with energy. In thermal equilibrium the probability of appearance of a given state depends on the ratio E/T, where E is the energy of this state. As noted above, there is no energy in social sciences; then it seems that the temperature cannot be present there. However, there is also a more general view on temperature: we often refer to "social temperature" as a measure of the degree of randomness in agent decision-making.

d) *Phase transition*
What a sociophysicist likes most to obtain is a phase transition. The reason is that he knows that social theories are qualitative. A change of phase, as for example a revolution or a paradigm shift, should be perceptible in a society even without measurements.

For the social systems, the time series are often short and noisy. Most social data have a quarterly or at most monthly frequency. When social time series have been produced for a very long period, there is usually strong evidence against stationarity. It is all the more interesting to notice that at given times such series exhibit a behavior like that of the power laws. The interest in searching power laws in the description of complex, collective phenomena is caused by the fact that these power laws are universal, that is to a large degree independent of the microscopic details of the phenomenon. As such, they are typical features of a collective mechanism like the phase transitions: many observables behave as universal power laws in the vicinity of the transition point [3]. Also, the interest in power laws is related to an important property of power laws, namely scale invariance: the characteristic length scale of a physical system at its critical point is infinite, leading to self-similar, scale-free fluctuations. Long ago, physicists noted, in several contexts, the possibility of a „critical state", in which independent microscopic fluctuations can propagate so as to give rise to instability on a macroscopic scale. This is a state in which chain reactions initiated by local disturbances neither damp out over a short distance (the "subcritical case"), nor propagate explosively so that the system cannot remain in that state (the "supercritical case"). Often this has seemed to depend upon parameters being carefully "tuned" to their exact critical values.

However, theories of phase transitions demand some ingredients which are impossible to occur in the social world. First is the so-called *thermodynamic limit*: the transition is well defined only in infinite systems [7]. In an infinite system there is always a finite probability that the phase will be changed due to fluctuations of some uncontrollable quantities. This is particularly true in social reality, where each system has its finite lifetime; from hours for an electoral meeting or years for a stategic alliance among countries, to centuries for an empire. For some models of relevance in the social sciences the system size plays an important role in the final outcome of the dynamics. Some changes of behaviour can appear when the number of agents in the model takes a finite value. Those changes of behaviour can be related to the apparent phase transitions that appear in some physical models. However, the effects can be meaningful in social sciences.

Here we must note another problem, connected with the previous one: the condition of equilibrium. In physics, the notion of equilibrium, although only intuitive, is well established. In a social system, equilibrium is never attained. Some correspondence to this difficulty exists also in statistical physics, for example in the theory of spin glasses. In such cases, one usually intends to assume that there are two kinds of processes: very quick, and those are over before an experiment started, and very slow, and those do not change.

Taking into account the above considerations we can conclude that sociophysics will never substitute sociology. What econophysicists and sociphysicists can do best is to give quantitative "clothes" to some rather qualitative conceps from social sciences, but, of course, these clothes may be too tight or too loose. The test of validity of the model apropriateness is always the agreement with the empirical data and the ability of leading to correct predictions. In the next sections we will try to model some qualitative phenomena such as fear/rumour propagation and fashion fluctuations by means of some methods taken from statistical thermodinamics, namely the reaction-diffusion mechanism (Section 2), Ising-spin models and noise induced phase transitions (Section 3). Some concluding remarks are drawn out in the last section.

2. FEAR AND RUMOURS: NON-EQUILIBRIUM PATTERNS IN THE STOCK MARKET SPACE

2.1 *The concept of rumour*

The subject of rumour formation is getting strategic importance at all levels of society. Control and possible handling intended to manipulate information are now major issues in social organizations including economy, politics, defense, fashion, and even personal affairs. Especially with the existence of Internet, which provides a support to anybody to say anything, and then consequently to be possibly heard by millions of people. To be read can imply to be automatically perceived like truth, and retransmitted as such to others.

However, information shared by a very great number of people does not obviously prove its authenticity by anything. Still, it can induce quite concrete and sometimes dangerous follow up acts. It may also happen that once a point of view on some specific issue has been widely adopted, the presentation of objective facts proving its falseness, does not produce the abandonment of this same false point of view. By contrast, a rumour can prove to be true while at first set, false by official media. The frontier between a rumour and information turns out to be very fragile.

An interesting analysis of rumour formation may be found in one of S. Galam's papers [8] in relation to the astonishing wide adhesion of French people to the rumour claiming "No plane did crash on the Pentagon on September the 11". In this paper a generic explanation is given, in terms of a model of minority opinion spreading. Using a majority rule reaction-diffusion dynamics, a rumour is shown to invade for sure a social group provided it fulfills simultaneously two criteria. First, it must be initiated with a support beyond some critical threshold which, however, turns out to be always very low. Then it has to be consistent with some large collective social paradigms of the group.

The dynamics of the rumour processes that take place both in small-world networks and in complex heterogeneous networks has been intensively studied in the literature of the last fifteen years (see some starting points in [9] and [10]). It was demonstrated that the propagation of a rumour on a network exhibits critical behaviour at a finite randomness of the underlying graph. The transition occurs between a regime where the rumor "dies" in a small neighborhood of its origin, and a regime where it spreads over a finite fraction of the whole population.

Now let us have a look at how markets and securities may react to news and rumors. Fortunes change fast in the stock market – so, it is critical for investors to stay abreast of investment news in addition to stock quotes and charts. As we saw in the fall of 2008, financial services stocks were hammered, sometimes on the basis of market news alone [11]. There are arguably no better examples of how investment news can impact stock prices than the recent crisis in financial services stocks. Here are a few examples: On September 11, 2008 Lehman Brothers (LEH) announced it was actively seeking a buyer. Right after the announcement, its shares plummeted 45%. What happened in fact? Lehman's announcement made it clear they were having troubles finding a suitor. Having to advertise your willingness to be bought is not usually considered a bullyish signal. True to expectations, on September 15 Lehman filed for bankruptcy, the largest bankruptcy in U.S. history.

In the same week, insurer American International Group (AIG) began admitting that its balance sheets were similarly threatened by the subprime mortgage crisis. Between September 10 and September 16, when the government announced a feverishly constructed rescue plan for the insurer, AIG's stock plunged about 80%.

You can see the rise and fall of hope versus fear in XLF, the Exchange-Traded Fund (ETF) tracking the financial services industry. After the U.S. government made an announcement on its bailout package, the ETF bounced up and down accordingly. When the first bailout package was rejected by Congress in late September, the bad news meant bad news for stock prices in the financial sector, too – the XLF dropped almost half its value as investors waited impatiently for the verdict from Congress. When a revised bailout package finally passed, the market news perked up as well, stabilizing XLF.

A curious fact – and one that is crucial to understanding stock prices – is that good news does not always translate to a jump in stock price; in fact, often the good news will produce a slight drop in a stock price. That happens because unofficial news, also known as "rumors", can have as much impact on stock prices as official news announcements. The stock market often anticipates these news stories and "prices in" its expectations accordingly. When those expectations are confirmed with actual investment news, the price may temporarily drop. Of course, the reverse applies, too: if rumors swirling around a stock are not proven true, investors may respond in surprising ways. If the surprise is a good one, stock prices can be driven upward as a result. That is why it is key to watch the investment news online and see how headlines influence stock quotes.

2.2 *Reaction-diffusion processes in the stock market space*

Here we propose macroscopic modelling of the formation of patterns (or "dissipative structures") in the one-dimensional space of the prices on the interdealer broker markets). In the framework of the chemical model which we develop, the stocks of the shareholders A and B will be called α and β respectively, and have the role of the chemical concentrations. We call ϕ the spectral density of the intermediated transactions (i.e. the number of the transactions per unit of price). The quantity ϕ has here the significance of the concentration of the intermediate product *X.* With these notations, the financial brokerage mechanism can be writing formally:

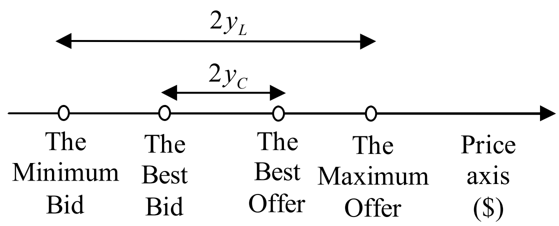
$$\mathrm{A} \underset{k_1'}{\overset{k_1}{\rightleftarrows}} \mathrm{X}; \quad \mathrm{X} \underset{k_2'}{\overset{k_2}{\rightleftarrows}} \mathrm{B}, \qquad (1)$$

The mechanism described by (1) allows us to use a phenomenological approach ([12]).

We focus on the dependence of ϕ of the bid-offer spread (we use here this notion as it has been defined in [13]). The bid-offer spread is done as:

y = (offer price) – (bid price).

In order to clarify some quantities that we use, it is worth to have in mind the one-dimensional representation:



Making a suitable change of the variables, we can set the extreme values of the spread symmetrical with respect to the origin of the prices axis:

$$-y_L \le y \le y_L \qquad (2)$$

The spectral density of the transactions will satisfy the Dirichlet boundary conditions:

$$\phi(-y_L) = \phi(y_L) = 0 \qquad (3)$$

The financial brokerage between A and B unfolds in accordance with the mechanism described through Eq. (l) only if the spread is framed by certain limits related to:

Best Spread ($2y_C$) = (Best Offer) – (Best Bid), that is:

$$-y_C \le y \le y_C, \qquad (4)$$

where $y_C < y_L$.

For: $-y_L \le y \le -y_C$ and $y_C \le y \le y_L$, the spectral density of transactions becomes less than a critical value ϕ_C, involving the reduction of the brokerage mechanism to the form [14]:

$$\mathrm{A} \xleftarrow[k_1']{} \mathrm{X}; \; \mathrm{X} \xrightarrow[k_2]{} \mathrm{B} \qquad (5)$$

This mechanism reflects the fact that when the spectral density of transactions decreases (which implies, in financial language, a higher "volatility" of prices), the shareholders retire their assets from respective market.

According to the chemical reactions theory, taking into account both the first and the second mechanism, the deal rate will be:

$$\frac{\partial \phi}{\partial t} = k_1\alpha - k_1'\phi - k_2\phi + k_2'\beta, \qquad \phi \ge \phi_C$$

$$\frac{\partial \phi}{\partial t} = -k_1'\phi - k_2\phi, \qquad \phi \le \phi_C.$$

Conveniently scaling:

$$\frac{\partial \phi}{\partial t} = -\phi + \phi_h\theta(\phi - \phi_C), \qquad (6)$$

where θ is the step Heaviside function.

This picture has become very useful in the description of pattern formation and propagation in the active (excitable) media. A distributed active medium can be viewed as a set of active elements, the traders, each element being a system with two or more possible steady states (e.g., selling

/buying/waiting), representing small parts of a continuous system, interacting among each other through trading. We assume that the interactions between the different elements that compose the active medium are local in time and also that the variation in space is not too extreme. This implies that we can neglect the memory effects, as well as the space derivatives of order higher than two. Within the formalism of the reaction-diffusion model the general form of the macroscopic equation for the case of only one relevant macroscopic variable ϕ will then be:

$$\frac{\partial\phi}{\partial t} = F\left(\phi, \frac{\partial\phi}{\partial y}, \frac{\partial^2\phi}{\partial y^2}, \ldots\right)$$

Expanding this in terms of the spatial derivatives, taking into account that the medium is isotropic and neglecting higher order derivatives, the equation reduces to:

$$\frac{\partial\phi}{\partial t} = F(\phi) + D\frac{\partial^2\phi}{\partial y^2} \qquad (7)$$

The first term on the r.h.s. of the Eq. (7) describes the behaviour within each cell corresponding to one of the active elements (usually called "the reactive part"), while the second corresponds to the interaction of the different cells with each other.

The development of the model follows the canonical procedure. First a suitable reference state ϕ_S which is an exact solution of the Eq. (7) is identified. The choice of ϕ_S is motivated by physical arguments. Typically ϕ_S is a state describing the "simplest" behaviour observed in the system – a quiet market, without crashes or large price variations. Within the same paragraph the stability of ϕ_S is tested against perturbations. The next paragraph includes a model describing the propagation of pattern in one-dimensional systems and a method for the experimental testing of the model.

2.3 *Pattern Formation. The Stability of Steady-State Solutions*

The first step is to look for stationary solutions, which are to consider $\frac{\partial\phi}{\partial t} = 0$. Eq. (7) reduces to:

$$D\frac{\partial^2\phi_S}{\partial y^2} + F(\phi_S) = 0 \qquad (8)$$

(For simplicity, we will drop the index of ϕ_S where no confusion is possible).

For the one-dimensional problem considered, the reactive term (or the "force" $F(\phi)$ can always be derived from a potential $V(\phi)$, according to:

$$F(\phi) = \frac{d}{d\phi}V(\phi) \qquad (9)$$

Taking into account Eq. (6), the stationary equation for our model will be:

$$\frac{d^2}{dy^2}\phi(y) - \phi(y) + \phi_h\theta[\phi(y) - \phi_C] = 0, \qquad (10a) \text{ or:}$$

$$\frac{d^2}{dy^2}\phi(y) + \frac{d}{d\phi}V(\phi) = 0, \qquad (10b)$$

where:

$$V(\phi) = \int F(\phi')d\phi' = \begin{cases} -\frac{1}{2}\phi^2 & \text{for } \phi \le \phi_C \\ V_h - \frac{1}{2}(\phi - \phi_h)^2 & \text{for } \phi \ge \phi_C \end{cases}$$

with: $V_h = (1/2)\phi_h^2 Z$; $Z = 1 - 2\phi_C/\phi_h$. (11)

To find the form of the stationary solutions, one may distinguish two different regions:

1) The regions of "cold" deals (non-speculative transactions), where $\phi(y) \le \phi_C$, and Eq. (10) reduces to:

$$\frac{d^2}{dy^2}\phi(y) - \phi(y) = 0 \qquad (12a)$$

with solutions having the general form:

$\phi(y) = A_C \exp(y) + B_C \exp(-y)$;

2) The regions of "hot" deals (speculative transactions), where $\phi(y) \ge \phi_C$, and Eq.(10) becomes:

$$\frac{d^2}{dy^2}\phi(y) - \phi(y) + \phi_C = 0 \qquad (12b)$$

with general solutions of the form:

$\phi(y) = A_h \exp(y) + B_h \exp(-y) + \phi_h$.

Imposing the Dirichlet boundary conditions (3), we get the analytical steady-state solution:

$$\phi_S(y) = \phi_h \begin{cases} \dfrac{\sinh(y_C)\sinh(y_L + y)}{\cosh(y_L)} & \text{for } y \in [-y_L; -y_C] \\ 1 - \dfrac{\cosh(y)\cosh(y_L - y_C)}{\cosh(y_L)} & \text{for } y \in [-y_C; y_C] \\ \dfrac{\sinh(y_C)\sinh(y_L - y)}{\cosh(y_L)} & \text{for } y \in [y_C; y_L] \end{cases}$$

The points $\pm y_C$ are determined by the matching conditions at $y = \pm y_C$, $\phi_S = \phi_C$, resulting:

$$y_C^{\pm} = \frac{1}{2}y_L + \frac{1}{2}\ln\left[Z\cosh(y_L) \pm \sqrt{Z^2\cosh^2(y_L) - 1}\right] \qquad (14)$$

Note the possibility of existence of two solutions, which are two possible roots $y_C^{\pm}$ depending on the value of *Z*.

We can now analyse the stability of the structures that we have found, adding to ϕ_S a small perturbation:

$$\phi(y,t) = \phi_S(y) + \varphi(y,t) \qquad (15)$$

Substituting this into Eq. (10) and linearizing in $\varphi(y,t)$, we obtain:

$$\frac{\partial}{\partial t}\phi(y,t) = \left[\frac{d^2}{dy^2}\phi_S(y) - \phi_S(y) + \phi_h\theta(\phi_S(y) - \phi_C)\right] + \qquad (16)$$
$$+ \frac{\partial^2}{\partial y^2}\phi(y,t) - \phi(y,t) - K\sum_j \delta(y - y_j)\phi(y,t)$$

The term within the large parentheses is zero, as it must be from the stationary condition, reducing Eq. (16) to an equation for $\phi(y,t)$. The parameter *K* arises from the discontinuities (due to the presence of the step $\theta(y)$ function) at

$y_j = \pm y_C$,

and is given by:

$$K^{\pm} = \phi_h \left|\frac{d\phi_S(y)}{dy}\right|^{-1}_{y=y_C^{\pm}} = \frac{\cosh(y_L)}{\sinh(y_C^{\pm})\cos(y_L - y_C^{\pm})} \qquad (17)$$

We further propose:

$\varphi(y,t) = \varphi_0(y)\exp(-\gamma t)$, (18a)

leading in each region to solutions of the form:

$\varphi_0(y) = a\exp(\lambda y) + b\exp(-\lambda y)$. (18b)

Replacing Eqs.(18) into the equation for $\varphi(y)$, we find:

$\gamma = 1 - \lambda^2$. (19)

The coefficients a and b from (18b) depend on the region and they are determined through the same boundary conditions as for the stationary solutions (13). Without loss of generality, we can choose $y_L = 1$;

The form of the perturbation (for $y > 0$) will be:

$$\varphi_0(y) = \phi_h \begin{cases} 1 - \dfrac{\cosh(\lambda y)\cosh[\lambda(1-y)]}{\cosh(\lambda)}, & \text{for } 0 < y < y_C; \\ \dfrac{\sinh(\lambda y_C)\sinh[\lambda(1-y_C)]}{\cosh(\lambda)}, & \text{for } y_C < y < y_L. \end{cases} \qquad (20)$$

There are many ways to study the connection between the eigenvalue λ and the value of y_C. The simplest is by imposing the natural requirement: $\varphi_0(0) << \phi_S(0)$ which leads to:

$$\frac{\cosh[\lambda(1-y_C)]}{\cosh(\lambda)} >> \frac{\cosh(1-y_C)}{\cosh(1)}.$$

At the limit $y_C \to 1$, the inequality is fulfilled when $\lambda << 1$ (i.e. $\gamma > 0$), indicating that the corresponding stationary solution (with the larger dissipation) is stable. For small values of y_C (at the limit $y_C \to 0$) we find $\varphi_0(0) \geq \phi_S(0)$. The corresponding solution (with the sign "**-**"in Eq.(14)) is unstable.

2.4 *Some Extensions: Pattern Propagation*

An important property of the patterns is the space-time propagation described by the solution of Eq.(7) in its complete form. Some results can be obtained taking over a particular kind of solutions such as the *solitary waves* ([**3**]). We will give further a briefly discussion about the theoretical approach of the phenomenon.

The solitary waves are functions of the spatial (y) and temporal (t) coordinates, not independently, but through the combination:

$\xi = y - ct$. (21)

In terms of the new variable ξ, Eq. (6) adopts the form:

$$\frac{\partial^2}{\partial \xi^2}\phi(\xi) + c\frac{\partial}{\partial \xi}\phi(\xi) - \phi(\xi) + \phi_h\theta[\phi(\xi) - \phi_C] = 0 \qquad (22)$$

Let us concentrate on the situation where the potential $V(\phi)$ has a bistable form as it is given by Eq. (11), and solve Eq. (22) with the boundary conditions:

$\phi \to 0$, for $\xi \to -\infty$ (23a)

$\phi \to \phi_h$, for $\xi \to \infty$ (23b)

The resulting wave, or moving pattern, is called a *trigger wave* (or *front*), because its propagation triggers the transition from one stationary state of the system (say $\phi = 0$) to the other (say $\phi = \phi_h$). This kind of waves has been observed, for instance, in chemically reacting media or as electrical activity that propagates along the axonal membrane [12]. There is a point $\xi = \xi_C$, at which $\phi(\xi_C) = \phi_C$. Due to translation symmetry, we can choose, without loss of generality, $\xi_C = 0$. The form of the solutions is:

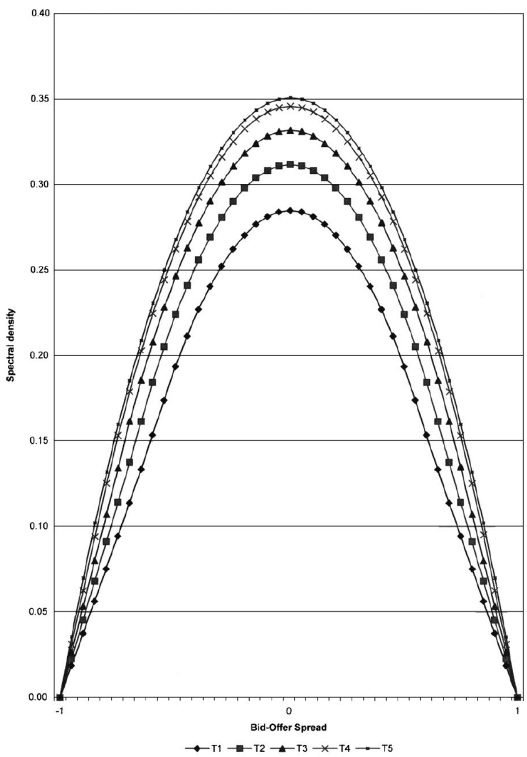
$$\phi(\xi) = \begin{cases} \phi_C \exp(\omega\xi), & \text{for } \xi < 0; \\ (\phi_C - \phi_h)\exp(\omega\xi) + \phi_h, & \text{for } \xi > 0, \end{cases} \qquad (24)$$

where: $\omega_{1,2} = -\dfrac{c}{2} \pm \sqrt{1 + \dfrac{c^2}{4}}$. (25)

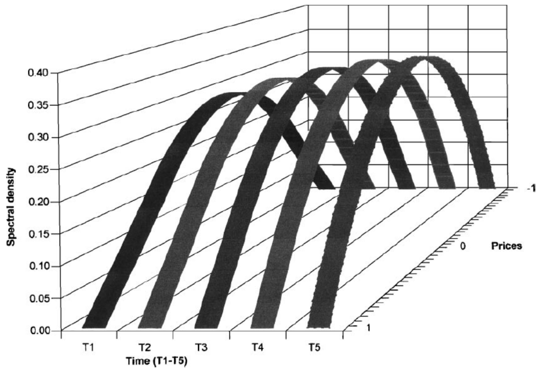
The propagation velocity c can be related to:

$$\Delta V = \int_0^{\phi_h} F(\phi')d\phi' = \frac{1}{2}\phi_h(\phi_h - 2\phi_C) \qquad (26)$$

The correspondence between the two quantities is based on the interpretation of Eq. (22) as the movement equation of a particle in the force field $F(\phi)$ derived from the potential $V(\phi)$; In such an analogy ϕ is the spatial coordinate and c plays the role of the friction coefficient. The sign of ΔV is related to the sense of movement on the axis (Figure 1). For $\Delta V = 0$, ($\phi_h = 2\phi_C$), the velocity is zero, and there is no propagation.



(a)



(b)

FIGURE 1 a) A plane representation of the patterns ("speculative bubbles") in the 1-dimensional space of stock market prices. The curves represent the spectral density of transaction (number of transaction per unit of price) f, plotted depending on the bid-offer spread y, in accordance with Eq. (13), for different trading days [14]. **b)** A spatial representation of the patterns. One can see the time propagation.

Finally, the model developed in this section describes the stock market speculative bubbles as thermodynamic instabilities and treats them in the reaction-diffusion formalism. Although any essay of this kind is to a certain extent speculative, it could provide an alternative way to explore some complex economic phenomena, leading to the possibility of some predictions, which are potentially useful for the practitioners in the financial field.

In order to shed more light on the mechanisms described by Eq. (1) and Eq. (5), let us consider the following situation: the investor A needs money to extend his business and offers shares (stocks), while the investor B wants to invest money profitably. The both will appeal to the stock market, where their transaction will be intermediated by the broker X. The difference between the selling price (offer) and the buying price (bid) is the broker's premium usually called bid-offer spread, y. This is the general framework modelled by Eq. (1). Note that to a large extent our model is "minimal": in the real stock markets there are many brokers (or brokerage firms) and a huge number of stocks is traded each moment so that, at least for y and ϕ, a statistical description is more adequately. In our thermodynamic framework, we take for granted this aspect. When the number of transactions becomes small, the market is – in financial terms – without liquidity. For a while the broker will pay *his own* money to A and will sell to B shares from *his own* stock. Essentially, this is the meaning of the mechanism described by Eq. (5). Our model associates with such situations critical values of density, ϕ_c, and bid-offer spread, y_c.

A speculative bubble occurs when, as a reaction to various rumours, the large majority of certain stocks are bought in order to be resold later on, exceeding to a large extent their underlying value. The famous economist John Maynard Keynes used "the beauty contest" as a parable describing such situations: In order to predict the winner of a beauty contest, objective beauty is not much important, but knowledge or prediction of others' predictions of beauty is much more relevant. Speculative bubbles disappear gradually or collapse unexpectedly generating financial crashes.

3. MODELLING FASHION: SPIN MODELS AND PHASE TRANSITION

3.1 *The concept of fashion*

"Fashions have changed", "in fashion", "old-fashioned" are phrases frequently used in the street, on TV or in newspapers. But what fashion are we talking about? The fashion of ideas, artistic fashion or, more prosaically, dress fashion? When we talk about fashion, do we consider it to be the result of a creative process (either intellectual or industrial), or a method of communicating a certain "way of life" which would correspond in economics to the level of information? The simplest way to understand the fashion is postulated in early sociophysics literature [15]: every time a new outlet appears on the market, it can, under certain specific conditions, invade the market. Each creator competes for a finite population of agents. Hence, the "old" outlet can be completely dominated and disappears.

The word fashion (or *mode*) originates in the Latin word *modus*. *Modus* means the non-existing limit. Its equivalent in the English language is *fashion* and means "method, form, style, mode; behavior, lifestyle of the gentle class, and upper class". In Romania, *moda* first came into use once with Westernization, and developed mostly under the influence of French culture. The reason for this was, partly, the dominance of French culture in the social and governmental life of the Ottomans.

It is possible to divide fashion in the sense of temporary novelty in the social life into three groups [16]:

1- The temporary novelty with the need for a change and fancy in beautification, e.g. mini-skirt fashion

2- The social favor for a certain period of time, over keenness for an object

3- Objects fitting to the novelty and social favor temporarily, like the hat fashion.

As seen from the items above, fashion can change forms, as in item 1, or disappear, as in item 3.

Or else, fashion that that disappeared can be fashionable again after a certain period of time.

The general meaning of fashion is determined by the two antonyms, namely, the fashionable and the unfashionable. These terms indicate that some of the changes in social forms are more accepted and considered more as compared to others.

The word *fashion* recalls clothing in the first place. However, philosophy, art, music, house decoration and many social sciences also constitute components of fashion. Every changing area of the social life is open to the interest of fashion ([17]).

The common statement in the definitions of marketing developed by scientists is the "development of ideas of manufacture, and the production, pricing, adhering and distribution of the manufacture". Which manufacture(s) must be produced? In what quantity and for which consumer mass must it be produced?

Answers to these questions and the results of the investigations on other marketing components can help for making the required decisions. As is known, manufacture with a certain physical structure and servicing that is not manufacture have equal importance as regards the satisfaction of human needs.

FASHION, which plays and important role in the decisions of marketing, consists in product(s) (services) that the majority of consumers in the target market adopt the buying behaviour for reasons of prestige, personal satisfaction, gaining status, or similar reasons. Here, social psychology plays an important role rather than individuality, and if the fashionable products in the market are accepted as FASHION by the group of consumers in numbers exceeding the average, others also follow the majority they accept as a reference standard [18].

When handling the concept of *fashion* as regards the marketing above, "fashion" can be created also in the other layers of the society following the opinion leaders along the axis of novelty.

The word "fashion" generally calls to mind clothing, in the first place, and it is the "woman" who uses fashion in the most efficient way possible. Therefore, wise operations develop their marketing strategies to create fashionable products to ensure profit maximization within a short time, because these products have the highest selling potential as long as they remain in the market.

The history of fashion starts with the history of humanity and continues with the transformation of dressing to a fact of being accepted beyond the need. Individuals have reflected the characteristics of the society they belong to, their personalities and lifestyles in their clothing. Very important changes in the area of fashion happened especially with the advent of the Industrial Revolution. Serious increases in the trade of clothing were seen in the late 1870s after the invention of the sewing machine in 1825 and the invention of the first synthetic dye in 1856. This became widespread throughout the world in the 1870s and serious increases were observed in the trade of clothing, and the prices of the clothes fell. [19]

Fashion pages in newspapers started to be common in 1850s, and the foundations of the expensive 'haute couture' made for the upper classes were established by the English fashion designer Charles Frederick Worth. Worth opened the first fashion house in Paris in 1857 and therefore the understanding of the nameless concept, which was women having their dresses designed by tailors, left its place to the understanding of presenting the fashion designers new collections for each season. With Worth, a "Fashion System" in the modern sense was established that was affordable for most people. The production of clothing for the elite that started in the workshops of Worth became to spread in many European cities [20]. Starting from the year 1871, paper dress patterns prepared by Ellen Butterick provided great ease for sewing. Following this, sewing the shoes also with sewing machine and mass production was started. Consumption of ready-made clothing started thus.

Liberalization seen in the world in recent years and particularly the collapse of the USSR and the free market economy has enlarged the alternative markets in the international markets and the operations entered a ruthless competition with domestic and foreign competitors in their own markets and in foreign markets. Following this, the global markets and global competition were introduced. The economic changes appearing as a result of political changes and particularly the stunning developments in information technologies have revealed the need for radical changes in all the functions and the understanding of management of operations.

Very much as in the movie industry or the industry of industrial design, fashion activity depends on the level of creativity of the designers. It also depends on the level of public recognition of this creativity. Nike certainly shares this assumption, paying Michael Jordan, the famous US basketball player, a stunning 20 million dollars in 1992, for endorsing Nike running shoes.

Fashion improves neither efficiency nor the marginal utility of the consumption. Clothes belong to a class of goods whose functional properties are fundamental in their consumption. It is easy to understand why I need to buy a dress, or a pair of jeans. It is harder to explain why I choose Adidas shoes, or Levi's jeans. Moreover, it seems very difficult for an economist to explain why women ask for short skirts one year, long skirts the year after, and then short skirts again the year after that. Some theoricians may talk of erratic preferences, but the desire to be in fashion could justify Janssen and Jager's argument [21] that "...in satisfying their need for identity, people may change their behaviour without changing their preferences".

3.2 *The Ising-spins modelling*

Firstly, let us review some basic features of the phase transitions. The processes of boiling-condensation, melting-freezing, and congelation-sublimation involve changes in entropy (S) and volume (V). According to Ehrenfest, such transitions are classed as changes of phase of the first kind (or the first order): whereas the Gibbs function remains constant during a change of phase, its first derivatives S and V change abruptly. A distinction of a phase change of the first kind is that the new phase is formed gradually: The fraction of the new phase gradually increases as more of the latent heat of the respective phase change is put into or withdrawn out of the system.

There exist phase changes of higher orders, in which S and V retain their values constant during a phase change. In the process T (temperature), p (pressure) and E (internal energy) likewise remain unchanged. If, during a phase change, c (the specific heat) and the other caloric coefficients are incremented or decremented by a finite amount, such phase transitions are called transitions of the second kind (or of the second order) because each of these quantities can be defined as a second derivative of the Gibbs function. An example is the transition from the state of superconductivity to the normal state in the absence of a magnetic field.

An example of a higher order phase change is the lambda phase change, so called because the $c = f(T)$ curve looks like the Greek letter "lambda" (Figure 1). Examples of the lambda phase change are the transition from the ferromagnetic to the paramagnetic state or from He I (the ordinary, viscous state of helium) to He II (a peculiar state called superfluid). The lambda transition proceeds without an abrupt change in density (the density curve has a quiet peak around the λ-point), without evolution or absorption of latent heat, and is accompanied by a sudden change in specific heat ([22]).

As has been shown in econophysics literature, there are many similarities between the physical complex systems and the collective behaviour of various groups of individuals. We may ask now about the key to these similarities. Our Ariadne's thread is that complex systems often reveal more of their structure and organization in highly stressed situations than in equilibrium. This point of view is influenced by the concept of criticality developed in statistical physics in the last four decades in order to describe a class of cooperative phenomena, such as magnetism and melting, and our hypothesis is that the group of individuals behaves as a many-body system driven out-of-equilibrium. In the next subsection we would like to defend the thesis that the crashes of some market shares have fundamentally similar origins, which must be found in the collective organization of the individuals leading to a regime known as a "critical" point.

As we have claimed in the previous subsection, a new fashion arises when a large group of individuals decide simultaneously to buy a certain product instead another one.

One curious fact is that the agents in this group typically do not know each other. They did not convene a meeting and decide to reject the old-fashioned product. Nor do they take orders from a leader. In fact, most of the time, these agents disagree with one another. The key question is: by what mechanism did they suddenly manage to organize a coordinated buy-off?

As in Ref. [22], we propose the following answer: all the individuals in the world are organized into a network (of family, friends, colleagues, etc.) and they influence each other *locally* through this network. Each of them is directly connected with γ nearest neighbours, and there are only two forces that influence his opinion:

(a) the opinions of these γ people;

(b) an idiosyncratic signal that he alone receives.

Our working assumption is that agents tend to *imitate* the opinions of their nearest neighbors, not contradict them. Clearly, the force (a) will tend to create order, while force (b) will tend to create disorder. The main story that we are telling on is the fight between order and disorder. As far as asset prices are concerned, a crash happens when order wins (every agent has the same opinion: selling), and normal times are when disorder wins (buyers and selling disagree with each other and roughly balance each other out). This is exactly the opposite of the popular characterization of crashes as time of chaos.

In our microscopic modelling we consider the traders network as an arrangement of N fixed points forming a n-dimensional periodic lattice (n = 1, 2, 3). At each site of this lattice is attached a number S_i , (i = 1,…,N), taking only two values: S_i = +1 (the spin "up"; selling option) and S_i = -1 (the spin "down"; buying option). A set of numbers $\{S_i\}$ specifies a configuration of the whole system. The energy corresponding to this configuration, in absence of external fields, is :

$$E_i = -\sum_{\{ij\}} \varepsilon_{ij} S_i S_j$$

where $\{ij\}$ appoints a pair of nearest spins and ε_{ij} is their interaction energy. Because $\{ij\}$ and $\{ji\}$ are not distinct, the sum will have $\gamma N/2$ terms, with γ being the number of nearest neighbours of a given spin.

Although the configuration of the system depends on N numbers, when we consider $\varepsilon_{ij} = \varepsilon = \text{const.}$, the energy of a given state depends only on two numbers : the long-range order parameter L and the short-range order parameter σ:

$$\frac{1}{N} E(L,\sigma) = -\frac{1}{2}\varepsilon\gamma(2\sigma - 2L + 1)$$

The parameters L and σ can be computed in the framework of various approximations of the initial (Ising) model. We suggest here the Bethe–Peierls (or "quasi-chemical") approximation.

Let us consider the n-dimensional periodic lattice mentioned in the subsection 2.2 and its corresponding energy:

$$E\{S_i\} = -\sum_{\{ij\}} E_{ij} S_i S_j \qquad (27)$$

where $S_i = \pm 1$, i = 1,…, N. We have already established that the sum have $\gamma N/2$. In a given configuration $\{S_i\}$ we call:

N_+ = the total number of spins "up";

N_- = the total number of spins "down".

Each pair of spins from the sum belong to on of the kinds: (++), (- -), (+ -), the last being no distinct from (- +). The corresponding number of pair will be N_{++}, N_{--}, N_{+-} . These numbers are not independent. The relations between them can be established as follows:

a) we link by lines a spin "up" with its nearest neighbours. Repeating for all the spin "up" we obtain γN_+ lines.

b) the number of double lines will be N_{++} and the number of simple lines, N_{+-} . Therefore

$\gamma N_+ = 2N_{++} + N_{+-}$

c) interchanging the indices "+" and"–"we have :

$\gamma N_- = 2N_{--} + N_{+-}$

The equations:

$$\begin{cases} \gamma N_+ = 2N_{++} + N_{+-} \\ \gamma N_- = 2N_{--} + N_{+-} \\ N_+ + N_- = N \end{cases} \qquad (28)$$

have the solutions:

$$\begin{cases} N_- = N - N_+ \\ N_{+-} = \gamma N_+ - 2N_{++} \\ N_{--} = (\gamma/2)N + N_{++} - \gamma N_+ \end{cases} \qquad (29)$$

so we can write:

$$\sum_{\langle ij\rangle} S_i S_j = N_{++} + N_{--} - N_{+-} = 4N_{++} - 2\gamma N_+ + \frac{\gamma}{2} N \qquad (30)$$

Note that although the system configuration depends on N numbers, the energy of a given state depends only on two numbers: N_+ and N_{++} (We can consider $\varepsilon_{ij} = \varepsilon$ = constant). The number N_+/N measures the "long range" order, while the number $N_{++}/(\gamma N/2)$ measures the "short range" order. The raison for this terminology is the following: having given a random distribution of spins and knowing that a certain spin is "up", the number $N_{++}/(\gamma N/2)$ is the fraction of nearest neighbours having the spin "up", thus involving a local correlation between spins: the other number, N_+/N, does not imply correlations between the nearest neighbors, but represents the fraction of spins from all the lattice having the orientation "up". We define the long-range order parameter L and the short-range order parameter σ through the relations:

$$\frac{N_+}{N} = \frac{1}{2}(L+1) \quad ; (-1 \le L \le 1) \qquad (31)$$

$$\frac{N_{++}}{(1/2\gamma N)} = \frac{1}{2}(\sigma + 1); \quad (-1 \le \sigma \le 1)$$

Replacing into Eq.(4), we get:

$$\sum_{\langle ij\rangle} S_i S_j = \frac{1}{2}\gamma N(2\sigma - 2L + 1) \qquad (32)$$

and the energy per spin, from Eq.(1), becomes:

$$\frac{1}{N} E(L,\sigma) = -\frac{1}{2}\varepsilon\gamma(2\sigma - 2L + 1) \qquad (33)$$

Now, let us call $P(s, n)$ the probability of n nearest neighbours to have the spin "up", if the central spin is "s". Thus, P(+1, n) refers to the configurations containing n pairs (++) and ($\gamma - n$) pairs (+ -); P(-1, n) refers to the configurations with n pairs (+ -) and ($\gamma - n$) pairs (- -). For n given, there are C_γ^n manners to choose the n spins from the γ nearest neighbors. We suppose that:

$$P(+1,n) = \frac{1}{q} C_\gamma^n \exp[\beta\varepsilon(2n - \gamma)] z^n \qquad (34)$$

$$P(-1.n) = \frac{1}{q} C_\gamma^n \exp[\beta\varepsilon(\gamma - 2n)] z^n \qquad (35)$$

where $\beta = 1/kT$ (k = Boltzmann`s constant; T= temperature), q is a normalization constant and z is a parameter characterizing the n spins sublattice. Imposing the normalization of the probability:

$$\sum_{n=0}^{\gamma}\left[P(+1,n)+P(-1,n)\right]=1 \quad (36)$$

we obtain :

$$q=\left[\exp(-\beta\varepsilon)+z\exp(\beta\varepsilon)\right]^{\gamma}+\left[\exp(\beta\varepsilon)+z\exp(-\beta\varepsilon)\right]^{\gamma} \quad (37)$$

Taking into account the signification of $P(+1, n)$ we get:

$$\frac{1+L}{2}=\frac{N_{+}}{N}=\sum_{n=0}^{\gamma}P(+1,n)= \quad (38)$$

$$=\frac{1}{q}\left[\exp(\beta\varepsilon)+z\exp(-\beta\varepsilon)\right]^{\gamma}$$

$$\frac{1+\sigma}{2}=\frac{N_{++}}{(1/2)\gamma N}=\frac{1}{\gamma}\sum_{n=0}^{\gamma}nP(+1,n)= \quad (39)$$

$$=\frac{z}{q}\exp(\beta\varepsilon)\left[\exp(-\beta\varepsilon)+z\exp(\beta\varepsilon)\right]^{\gamma-1}$$

The last equations express L and σ in the terms of the only variable z, which can be computed by solving (graphically) a transcendental equation. Then, Eqs. (12) and (13) give us L and σ and Eqs.(7) leads to the internal energy, E. The specific heat (the derivative of E), for $T > T_c$ is given by:

$$\frac{c}{kN}=\frac{2\gamma\varepsilon^{2}}{(kT)^{2}}\frac{\exp(2\varepsilon/kT)}{\left[1+\exp(2\varepsilon/kT)\right]^{2}} \quad (40)$$

We found that the specific heat (the derivative of E) exhibits a jump (Figure 3) at:

$$kT_{C}=\frac{2\varepsilon}{\log(\gamma/(\gamma-2))} \quad (41)$$

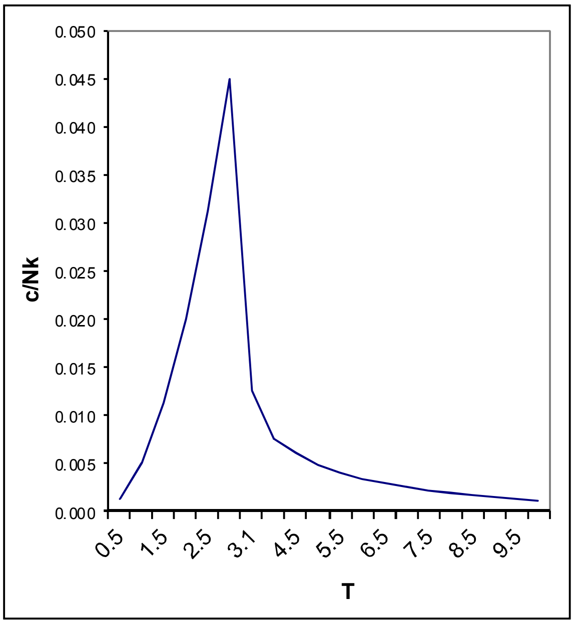


FIGURE 3. The specific heat of liquid ^{4}He as a function of temperature T at the pressure P = 0.227 MPa. The region of liquid states for ^{4}He is divided by $T_c \cong$ 2.2K into two sub-regions: ordinary (viscous) helium or He I (on the right) and superfluid helium or He II (on the left) ([23])

FIGURE 4. New passenger car registrations in November in EU. Source: [24]

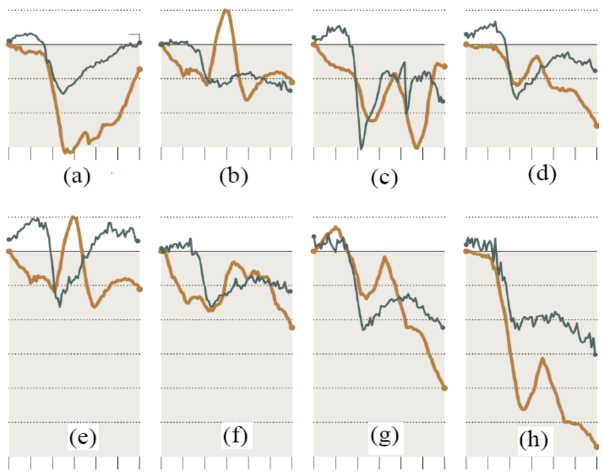


FIGURE 5. Change in industrial production and car sales: (a) US; (b) UK; (c) Japan; (d) Euro Zone; (e) Germany; (f) France; (g) Italy; (h) Spain. The United States reported a 2.2 percent rise in industrial production in 2012, pushing the rate past the 2006 average for the first time since the downturn began in late 2007. Production has also exceeded the 2006 level in Germany, although it began to slip in late 2012, but other major developed countries are still below that level. Car sales have recovered to some extent in the United States and Japan, but are still falling in much of Europe. Source: [25]

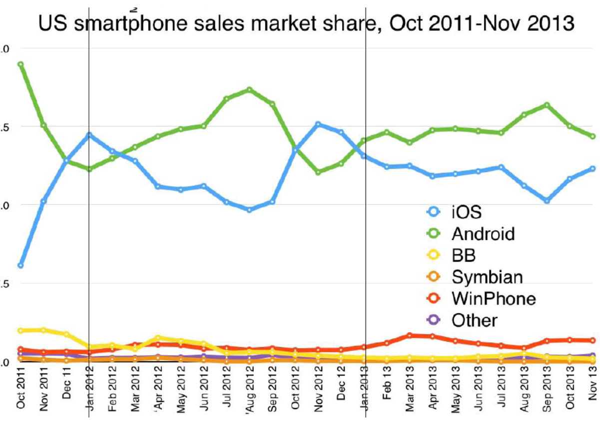


FIGURE 6. Market share for US smartphone sales.
Source: [26]

There are some remarkable similarities between the shape of curves plotted in Figure 3 (the experimental result for a particular phase transition), and, on the other side, Figures 4-6 (the marketing data).

3.2 *Noise-Induced Transitions between Non-Equilibrium Steady States*

Physicists have noted, in several contexts, the possibility of a "critical state", in which independent microscopic fluctuations can propagate so as to give rise to instability on a macroscopic scale. This a state in which chain reactions initiated by local disturbances neither damp out over a short distance (the "subcritical" case) nor propagate explosively, so that the system cannot remain in that state (the "supercritical" case). In this section we propose studying the role of the fluctuations in the neighbourhood of the critical points that seem to appear at the end of an economic cycle [27].

Let us consider, for the sake of simplicity, a single production process P, which produces a flux y of a certain commodity C. In the simplest form, the rate of increasing of the net product flux depends on the actual flux:

$$dy/dt = ky \qquad (42)$$

Eq. (42) allows for either an exponentially growing or decaying of the net product flux because it does not take into account some marginally effects such as *market saturation*: as more quantities of C enter the market, the offer increases so the price decreases, which in turn influences dy/dt. It is so more naturally to consider k as a function on y:

$$k = \beta - \gamma y$$

Here, the second term includes the competition effect and is similar to the "struggle for life" term in the Malthus-Verhulst model of population dynamics.

Substituting in (42) and re-scaling, we obtain the nonlinear differential equation (NLDE) of the process in the canonical form:

$$dq/dt = -q^2 + \zeta q \qquad (43)$$

According to the stability theory, for $\zeta < 0$, Eq. (43) has only one stationary solution $q^0 = 0$, which is stable. At $\zeta = 0$ a transcritical bifurcation appears (Figure 7): the solution $q^0 = 0$ becomes unstable and a new stable steady state branch arises, with $q^0 = \zeta$. The qualitative change suffered by the system when it goes through the bifurcation point is similar to a thermodynamic phase transition. According to the bifurcations theory terminology this is a "soft" transition.

The parameter ζ is supposed to be subject to fluctuations, being a Gaussian white noise with mean ζ_0 and variance σ. The stochastic differential equation (SDE) associated to Eq. (7.2) is:

$$dq = (-q^2 + \zeta q)dt + \sigma q dW \qquad (44)$$

or:

$$dq = f(q)dt + g(q)dW$$

where W is a stochastic Wiener process. (For simplicity we have dropped the index of ζ.).

In the same way as in the deterministic case, we compute the stationary solutions of the Eq. (44), i.e. the stationary points of the SDE, imposing:

$f(q) = g(q) = 0$.

One such point is $q = 0$ signifying that the ceasing of production (the collapse or the bankruptcy) is always possible for a system described by such equation.

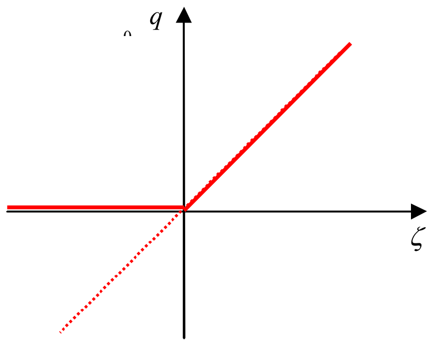


FIGURE 7. The transcritical bifurcation of the solutions in Eq. (43)

The question that naturally arises is whether, in addition to the stationary point $q = 0$, the SDE (44) has another stationary solution. The simplest way of solving this problem is analysing the Fokker-Planck equation (FPE) associated to SDE:

$$(\partial/\partial t)P(q,t) = -(\partial/\partial q)[(\zeta q - q^2)P(q,t)] + \\ + (\sigma^2/2)(\partial^2/\partial q^2)[q^2 P(q,t)] \qquad (45)$$

The stationary solution of this equation has special interest:

$$(\partial/\partial t)P_{st}(q,t) = 0;$$

$$P_{st}(q,t) = P_{st}(q)$$

where $P_{st}(q)$ will be considered a probability density if and only if it is normalizable, i.e. its integral over the range $[0, \infty)$ is finite. The stationary solution of the FPE, having the form:

$$P_{st}(q) \sim q^{2\zeta/\sigma^2 - 2}\exp(-2q/\sigma^2)$$

is found to be integrable over $[0, \infty)$ only if $\zeta > \sigma^2/2$. With other words, the stationary probability distribution exists only if $\zeta > \sigma^2/2$.

After normalization we get:

$$P_{st}(q) = \\ (2/\sigma^2)^{2\zeta/\sigma^2 - 1}\Gamma^{-1}(2\zeta/\sigma^2 - 1)q^{2\zeta/\sigma^2 - 2}\exp(-2q/\sigma^2) \qquad (46)$$

A remarkable aspect of the result is the drastic change in the character of the stationary distribution for $\zeta = \sigma^2$: if $\sigma^2/2 < \zeta < \sigma^2$, $P_{st}(q)$ is divergent for $q = 0$, while for $\zeta > \sigma^2$, $P_{st}(q = 0) = 0$.

Summarizing the previous sections and taking into account also the influence of the external noise, the following behaviours of the system are to be predicted:

a) For $\zeta < 0$, the stationary point $q^0 = 0$ is stable, making up the thermodynamic branch of evolution, on which the fluctuations are damped and do not lead to structural changes into the system. This feature can be extended for $0 < \zeta < \sigma^2$ (the domain of small fluctuations) where we have a new stable solution $q^0 = \zeta$ after the crossing through the transcritical bifurcation at $\zeta = 0$.

b) The critical value $\zeta = \sigma^2/2$ can be considered a threshold over that the stationary probability distribution $P_{st}(q)$ arises. For $\sigma^2/2 < \zeta < \sigma^2$, $P_{st}(q)$ is divergent for $q = 0$. Even if the solution $q = 0$ is no more stable, it remains the most probable. For $\zeta > \sigma^2$ a new change occurs in the aspect of $P_{st}(q)$, and the value $\zeta = \sigma^2$ becomes a transition point produced only by the external noise (In concordance with the usual classifications this is a "hard" transition).

We consider that second kind of transition is related to the shift of the economic system between two non-equilibrium steady states. As the phenomenon is induced by random fluctuations, the outcome is indeterminate; it is not unique and predictable. Nonetheless, it is reasonable the assumption that the distribution of transitions depends on the distribution of fluctuations. This relation could explain the empirical fluctuations reported in the marketing pages of various journals [24-26].

4. SOME CONCLUDING REMARKS

In this paper we analysed some interesting social phenomena such as fear/rumour effects and fashion fluctuations. These phenomena were intensively studied over the last few years using small-world network theory and simulations. Here we proposed an alternative way of modelling, using methods taken from statistical thermodynamics.

In the introductory section, we analysed some inherent difficulties related to the transfer of the conceps from physics to sociology. A subtitle of this section could be "What should we know before to reject the application of thermodynamics in social sciences?". Or to accept it – whichever you like.

In the second section, we considered the formation of the speculative bubbles in the stock market as an effect of rumours propagation. Using a phenomenological approach, we described the formation and the propagation of the patterns (or "dissipative structures") in the stock market, the spatial coordinate being the bid-offer spread y, as a function of which the spectrum ϕ of deals is modelled. The stock market was considered a distributed active medium that is a set of active elements (the brokers) interacting with others through deals (typically, a diffusion process). The physical model used is the reaction-diffusion model. The reactive part of the reaction-diffusion equation is developed from a hot-spot mechanism, with a characteristic jump when ϕ passes the critical value ϕ_c. Solving the stationary equation according to the Dirichlet boundary conditions, we found the "hot deals" regions, meaning regions of speculative transactions.

The nonlinear modelling touched in the third section offers strong tools to investigate both the individual and the global socio-economic complex systems. Nevertheless, it is worth to mention that this approach appears often as a "black box" which leads to a "convenient" set of outputs for a well-tuned set of inputs. The underground economic meanings of the control parameters and, in principal, the economic relevance of the non-linear equations fitting the empirical dataset, remain open questions for future studies.

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