# Mapping markets to the statistical mechanics: the derivatives act against the self-regulation of stock market

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Mapping the economy to the some statistical physics models we get strong indications that, in contrary to the pure stock market, the stock market with derivatives could not self-regulate.

| Economics. | Statistical physics. |
|---|---|
| Money. | Energy. |
| Value. | Free energy. |
| The capitalization of stocks. | Work. |
| Volatility. | Local temperature. |
| Market's Kolmogorov complexity. | Entropy |
| Infinitely effective market. | Hamiltonian Statistical mechanics. |
| Self-regulating real market. | Thermostat, 0-th law,2-nd law of thermodynamics. |
| Accidental arbitrage. | Maxwell Demon. |
| Strong usage of derivatives, crisis. | Strong Born-Openheimer interaction [10], violation of thermodynamic laws. |

TABLE I: The correspondence between economics and statistical physics.

**Introduction**. How can we understand the crisis? Shall we revise the whole economic theory of highly effective self-regulating market with "infinitely rational agents" in favor of more modern theories (behaviorial economics")? Our idea is that there is no need for a radical change in economic theory. We should just borrow more ideas from statistical physics, and the reflection concept of Marxist philosophy.

In recent decades it has been well realized that some aspects of financial markets could be analyzed well with the methods of statistical physics, especially the idea of scaling for the fat tails of distributions [1]. The scaling is identified in statistical physics with the universality of critical phenomena near the second order phase transition point. This rather technical approach was certainly useful. Nevertheless, statistical physics is much richer discipline than only second order phase transition theory. In [2] has been observed the similarity of money and free energy. V. P. Maslov identified the entropy of market with its complexity [3], and I just borrow his idea for the Table 1, giving the correspondence between statistical physics and economics. A fruitful mapping of the wealth distribution and international trade to thermodynamic has been done in [4, 5]. The thermodynamic approach was very successful here, because in this narrow field there is an equivalent of the first law (the conservation of money). We are interested in a more general situation.

In our article [6] we tried to identify different classes of universality of complex systems, rather than consider only the second order phase transitions. One can use several variables to identify the universality class (the systems from the same class should share the same criteria): a. The subdominant behavior of free energy or some entropy; b. intrinsic information -theoretical aspects (heterogeneity of agents, ferromagnetic-antiferromagnetic couplings, gauge invariance). These concepts could be useful for investigation of simple markets.

Let as analyze the economics using the further ideas borrowed from statistical physics and philosophy. In Table 1, we give some correspondence between two areas. The connection between the II law of thermodynamics and no-arbitrage property of market is known. Perhaps we should take Thomson's formulation: it is impossible get a work (income) from a system in the equilibrium.

A fundamental concept for analyzing any serious phenomenon in physics and in interdisciplinary science is the concept of reflection, well realized in the Marxist philosophy.

There is an objective reality, identified sometimes with the substance of materia, and its reflection- the subjective reality. It is not an abstract philosophical concept. On the contrary, it is highly concrete and useful for applications in statistical physics.

Another concept we need, is an amount of motion invented by philosophers De-Cartesius and Leibnitz. It has been identified in classical mechanics first with momentum, later with energy.

**Statistical physics.** The reflection and amount of motion are explicit in statistical physics. There is a hierarchy of motions: at the background level - a microscopic motion of molecules with some energy. This is an objective reality. The system quickly goes to some equilibrium and it is possible to define the temperature (0-th law of thermodynamic).

At the next level, we have a thermodynamics (with an observer, as has been realized by W. Heisenberg) with free energy. Using the idea of Gibbs, one calculates the

partition (a probability like quantity), then, taking its logarithm, the free energy. The free energy is the manageable amount of motion on a macroscopic level.

**Advanced case.** There are physical systems, where the free energy of one system is a partition of another system [7] . In spin glasses there is a simple description of a hierarchy when there is a fast relaxation, and a quite complicated in case of relaxation with the same rates on both levels of hierarchy. There is a hierarchy of time scales, or hierarchy of interactions. Sometimes there are some problems with ergodicity (spin-glass phase) but even for such a situation we have valid thermodynamical expressions for a free energy, therefore the "amount of motion" is well defined [8],[9].

In [10] has been carefully investigated the statistical physics problem of interaction between slow and fast variables. It has been considered two level hierarchy system. If A influenced B, and there is amount of motion (energy) for B, it is possible to define well the amount of motion for A (free energy), and the thermodynamic approach with corresponding free energy is valid for A. It is possible to have an alternative situation, when there is a backward influence of B to A. Such case arose when the interaction energy between A and B is strong as the energy of A, and the effective interaction A-B at some moment of time depends from the state of A in the previous period. Then, as a result, the system is becoming non-ergodic and it is impossible to construct proper thermodynamics (the second Law is broken).

**Self-regulating market.** Now we have goods. They have some value (amount of motion), this can be expressed via money. The companies have some values, expressed in the stocks. Thus we have a simple case of reflection, expressed as a reflection from an objective reality (goods, factory) to the subjective reality. The money is a simple form of motion. Till now everything is similar to the theory of thermodynamics. The idea of a self-regulating market is quite reasonable from the statistical physics point of view. It is similar to the 0-th law of thermodynamics with the idea of thermostat and Gibbs distribution.

**The heterogeneity of agents.** While this aspect of economics is usually ignored, there are special situations when the heterogeneity of agents is crucial, as has been suggested in [11], see an econophysics example [12]. In statistical physics it is well known that the ensemble of systems could not be replaced by a single system with "typical" coupling in case of spin-glass phase, and the Berry phase could not be revealed by an electronic Hamiltonian with a typical position of atoms. In [6] has been assumed to identify the financial market data with the phase transition point between ferromagnetic and spin-glass phases, which could not be described by a homogenous set of agents. This is a transition point strongly influenced by disorder[13]. In principle one could look for different such points from different universality classes to capture the market data. The heterogeneity of agents is one of three principal points to identify the models: first and most important is the character of reflection, second: the subdominant term of free energy, and third: intrinsic information transition mechanisms (heterogeneity of agents, a gauge symmetry for the ensemble of quenched couplings and magnetization). If the model is not chosen according to these three criteria, then it does not belong to the universality class of market, and could not be considered as a realistic one.

**Financial derivatives.** They are subjective realities, connected with underlying assets (stocks) as objective realities. The relaxation time is very short, there is no hierarchy. This is a crucial point. When there is a strong backward interaction (both hedging and speculation), the situation highly resembles the statistical physics problem of [10] with strong backward interaction. Therefore, in case of strong backward interaction between underlying assets and derivatives the market should not self-regulate.

The Maxwell demon phenomenon is well known in statistical physics. It is as improbable there, as arbitrage situation in markets. In case of extensive organization of Maxwell demon like situations the whole statistical physics will cease to work, like the crash of the market in case of permanent arbitrage.

It is not clear by statistical physics analogy whether the derivatives create arbitrage situation, but what the analogy tells is that the unrestricted usage of derivatives could create strong non-ergodicity. Such derivatives are something different than an amount of motion, therefore they could not self-regulate. The usefulness of unrestricted usage of derivatives has been questioned in [11]. The authors of [11] realized that new dangerous connections could be created by derivatives.

**Hot design**. For the classic problem of gamblers ruin it is well known that unlimited optimization of total return leads to ruin with probability one [14]. Carlson and Doyle have proposed a model [15] for designed systems which they call highly optimized tolerance, or HOT design, to avoid some dangers (faults) in an optimal way. What was found in [15], the HOT design systems are robust to perturbations they were designed to handle, yet are fragile to rare perturbations and design flaws [16]. The economists claim the usefulness of derivatives to avoid some fluctuations of markets. It is funny that the derivatives bring, as a good illustration of HOT design idea, to the crash of a whole economy. The idea of economics that the derivatives are used only for hedging contradicts to the practice of markets (due to problem with liquidity of market). A solution of the problem is the restricted optimization only [16].

**Conclusions.** While statistical physics has been applied to financial market in many articles, this is the first work with deep application of statistical physics to financial markets with derivatives. To model correctly the economy, we should consider the statistical physics mod-

els with the same character of complexity. A perfect market economy resembles the statistical physics with a Hamiltonian type of interactions, and the self-regulating market is a system with a thermostat (thermodynamic state). While widely questioned in recent years [17], the idea of self regulating market for real economy with partial rationality of agents is not a worse hypothesis than the usage of statistical physics without proving the ergodicity or mixing property.

We analyzed the market with derivatives using the analogy with the model in [10]. In [10] a strong backward interaction between slow and fast variable is considered which is similar to unrestricted usage of derivatives in markets. Using the Liouville theorem, in [10] is proved the violation of thermodynamics second law. While the similarity of market with statistical physics is rather restricted (there is no an equivalent of the thermodynamics First law and the Liuoville theorem), the result of [10] is a strong indication that financial markets with unrestricted usage of derivatives could not self-regulate. We have the same conclusion from the analogy with HOT design problem [15]: trying maximally neutralize some risks in complex system (for hedgers in market), one creates a danger for the global crash of the system. It is important that HOT design problem exist for a rather general situation when one tends to unlimited optimization (certainly the case of stocks market with derivatives). The danger of unrestricted optimization (sybaritism versus unrestricted usage of derivatives in our case) has been well recognized long ago before [15, 16] by Epicures: " No pleasure is a bad thing in itself, but the things which produce certain pleasures entail disturbances many times greater than the pleasures themselves",[18]. There are no any known example of self-regulating system with double reflection (a process like to the transition from energy to free energy) with strong interaction. Why markets with derivatives should be an exception? Therefore should be restriction against their unrestricted usage, like the constrained optimization" design to avoid the global crash of the system [16].

Even when the systems are entirely Hamiltonian, they do not necessarily bring to the thermodynamics state with the Gibbsian distribution. Furthermore, the crises in economy happened before the invention of derivatives. Nevertheless, the constraint against the unrestricted usage of derivatives removes a quite realistic danger of crisis. In any case, there is a need to perform very careful testing of microscopic market models, considering their relaxation dynamics [12] to verify our criticism of the myth of economics about self-regulating stock market with derivatives.

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