Econonatology: The Physics of the Economy in Labour 31st October 2002

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Abstract

A fear of crashes preoccupies stock market observers, both investors and economic decision makers (governments, banks). This is reflected in major efforts to predict future stock values. However, an economical system under prolonged stress may have in its nature to plunge to lower performance levels but recover without suffering damage. To support this claim, we draw parallels between two complex systems: that of the heart, as observed through the rate of heartbeat, and the economy, measured by the stock index record. The ultimate stress situation of fetal heartbeat during labour provides a conceptual basis for accommodating heavy crashes. It also suggests a different perspective for evaluating crashes and post crash recovery in order to diagnose, and (ultimately) prognose, 'economic health', in addition to monitoring the stock index value.

1 Introduction: Traditional objective - Predicting the crash

It is the unstated holy grail of the sciences and engineering in dealing with the economy to discover a law or design machinery capable of predicting stock market crashes. Similarly econophysics has not escaped this trend - efforts have been made to identify crash precursors, and predictive models based on critical behaviour have been proposed (to various degrees of testability) [1–8]. Most data is, of course, analysed a posteriori, leaving the actual assessment of the capability of crash prediction open to new studies on new data.
Such analyses take into account only the largest crashes. This is both due to the fact that such are the most spectacular and damaging, and because there is only a very limited number of crashes that can be analysed by hand in the same way as the approaches mentioned. In view of the scale invariance, this approach does not, however, seem correct - large crashes should not be different from small crashes at a smaller scale (higher resolution). The crashes, large or small, should, in view of the scale invariant paradigm, be equally well predictable and should follow the same mechanism. This issue, the abundance

of small scale crashes for prognosis testing, has not been explored to anywhere near a satisfactory degree. One of the possible explanations for this fact is that the large scale crashes may actually follow a different mechanism than the bulk of smaller crashes, constituting the scale invariant index structure. This is the subject of an ongoing debate, as to whether the large crashes are 'outliers' or belong to the scale invariant distribution [9–13].

In the context of this debate, it may be interesting to compare to the index crashes the dramatic events of heartbeat 'crashes' in a fetus at the time of birth. These crashes are generally considered to fall outside the 'normal' statistical range of heartbeat dynamics. They are the result of temporary hypoxia as a result of an 'external' cause, like e.g. obstruction of the umbilical cord, or as a result of the 'internal' response of the system to prolonged deficiency of oxygen.

In this article, we further elaborate on the reasons for comparing the neuro-anatomic system of heartbeat regulation with the market in section 2. This is followed, in section 3, by arguments regarding why monitoring the market evolution during and after crash may be more interesting than trying to predict the level of the index. We close in section 4 by drawing out future possibilities on monitoring the 'health' status of the economy.

2 Econophysics versus cardiophysics?

There are a number of reasons why one may want to have a simultaneous look at the cardiac and economic systems. Both exhibit complex behaviour classified as scale invariant and multifractal [14–17]. Both can be seen as systems of a number of coupled oscillators, subject to stochastic regulation. Both consist of antagonistic actors; in the neuro-regulatory cardiac system, in addition to the pacemaker, the periodic pulse generating node, heart rhythm is driven by sympathetic and parasympathetic nodes, in constant imbalance. The sympathetic system slows down the heart rate, while the parasympathetic one accelerates it. One might think that during activity, only the parasympathetic system would be active, while during leisure or sleep only the sympathetic one would be in action. Contrary to this, both systems are at work at any moment in time. In fact, it is a constant, simultaneous 'struggle' of both systems which gives rise to the actual heartbeat ratio, characterised by continuously changing dynamics [18–20,17].

This scenario resembles a view of the market with *pessimists* who sell and *optimists* who buy stock options at any given instant. The number of actors changes as the market changes. Some pessimists join the optimist group and vice versa. Additionally, there is leakage of information, or simply similar action, clustering the behaviour of agents in both the pessimistic and the optimistic groups. This leads to continuously varying number of *active* agents [1]

[1] Passive observers do not play role in shaping the instantaneous index value -

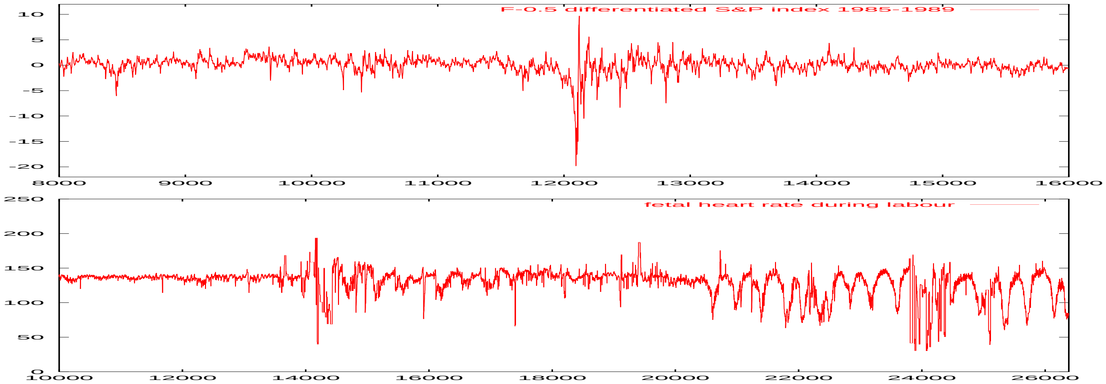

Figure 1. Top: a fractionally differentiated S&P500 record F(-0.5) about four years long centred at the '87 crash. Bottom: a fetal heartbeat rate record during labour, about ten hours long.

in the system, which may be related to the number of effectively active degrees of freedom of the abstract market system under consideration.

In particular, in the market scenario, polarisation of opinions leads to clusters of agents effectively reducing the number of *independent* degrees of freedom in the system [21]. The resultant behaviour of the stock becomes (anti-)correlated and bends towards anti-persistent fractional Brownian motion characterised by $H < 0.5$. The number of effectively active degrees of freedom for a fully developed economic system is likely to be somewhere in the range of $10 - 100$.

The behaviour of the healthy heartbeat is dominated by the coherent, concerted action of the inputs within the nodes of the two antagonistic systems (sympathetic and parasympathetic), leading to an extremely high level of anti-persistence at the range of $H = 0.0$ to $H = 0.1$ (for the normal healthy heartbeat at rest). In the case of pathology, exercise or stress, this behaviour becomes less anti-persistent and less (anti-)correlated, potentially indicating less coherence in the functioning of the two antagonistic systems and thus possibly the increase of the effective independent degrees of freedom in the system. It can be speculated that the range of the degrees of freedom entering the healthy cardiac system is extremely low (less than 10, probably closer to 2) while for pathology it grows above this range [22].

The similarities drawn between both systems of market self-regulation and heart neuro-regulation can be expanded even further. In the condition of extreme stress during labour, the heartbeat of the child being born can be shown to undergo dynamical evolution which can resemble, and be compared to, severe stock market crashes.

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similarly the pacemaker node is irrelevant to the shape of the heart rate record - pacemaker rhythm only would yield a constant line of fixed heart rate.

3 A different perspective - What happens after the crash?

It has been previously recognised thata post-crash behaviour may provide relevant means of completing financial time series analysis [11]. In a very recent shift of interest towards the analysis of intra- and post-crash behaviour, this counterpart of the traditional crash-precursory behaviour has been proven to constitute a meaningful 'diagnostic' tool [12].

The focus of perinatology is always after-crash oriented: it is the good health of the baby delivered which is the goal and the objective of the labour and the decision making process involved. Monitoring the fetal heart rate observation is a critical component of the decision making process, and in fact the only means to assess fetal well-being during delivery. There is, however, no one-to-one relationship between the level of heart rate and its characteristics and the state of the fetus.

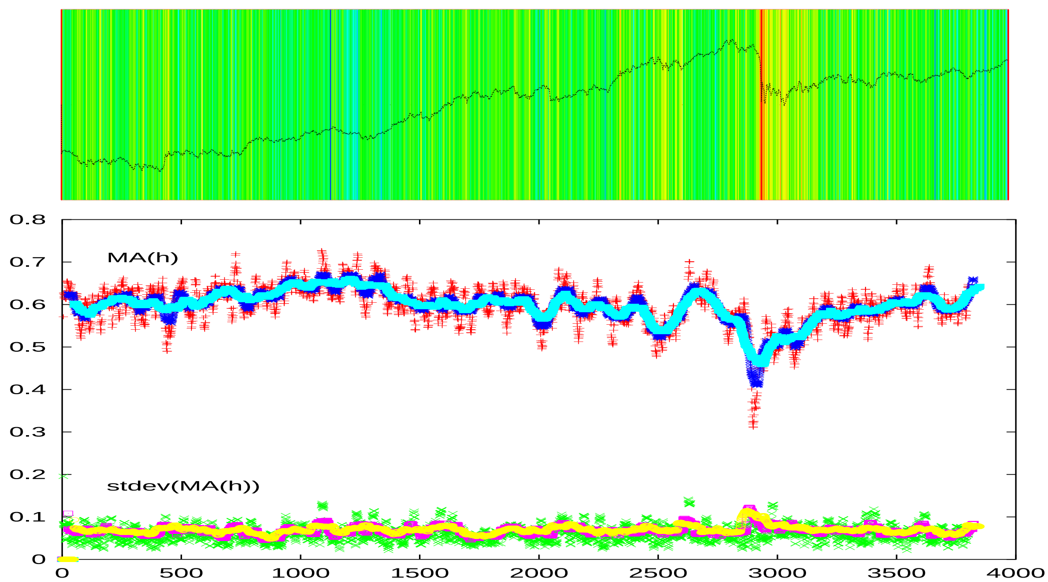

Figure 2. Local roughness expressed in colour range in the upper plot. In the lower plot, the corresponding numerical values smoothed with moving average filters of three lengths. Standard deviation in each MA filter length plotted below.

The healthy heart of the fetus has the ability to slow down the heart rate in the condition of temporary hypoxia (insufficiency of oxygen) during labour. This effect, sometimes informally referred to as the 'whale effect', leads to so-called decelerations in the rate of heartbeat. Whales, by slowing down their heart rate, temporarily slow down their metabolism during stays underwater. Similarly the fetus adapts to the temporary deficiency in oxygen by slowing down the heart rate without damage to the neural system. The onset of deceleration does not, therefore, provide sufficient information about the condition of the fetus. Repeated decelerations over a prolonged period of time may indicate hypoxia as well as diminished dynamic range of the variability of the heart rate. The dynamics of recovery from the decelerations is another important criterium by which fetal well-being may be estimated. At the other end of the spectrum are the sudden shots of adrenaline, 'rallies' in financial terms, when the heartbeat suddenly rises for a short period of time. This is generally a good sign and is not associated with tachycardia. It proves the dynamic capability of the fetal heart and the ability to cope with the extreme stress which the fetus undergoes.

Thus, both decelerations and accelerations are features normally found in heartbeat records during labour resulting in the birth of a healthy child (positive fetal outcome). The decelerations are an indication of possible hypoxia but do not necessarily indicate that there is a need for intervention. The fetus may well cope with the temporary deficiency of oxygen without any damage to its neural system. The actual decision that the obstetrician takes is based on a number of observations, among them the rate of recovery from decelerations. Other observations include the baseline level of heart rate, the variability level, the recent history of heart rate, etc.

A simple transformation of the record of the fetal heart rate during labour shows a striking resemblance to financial records - the linearly integrated record of the heartbeat plunges upon encountering a series of decelerations.

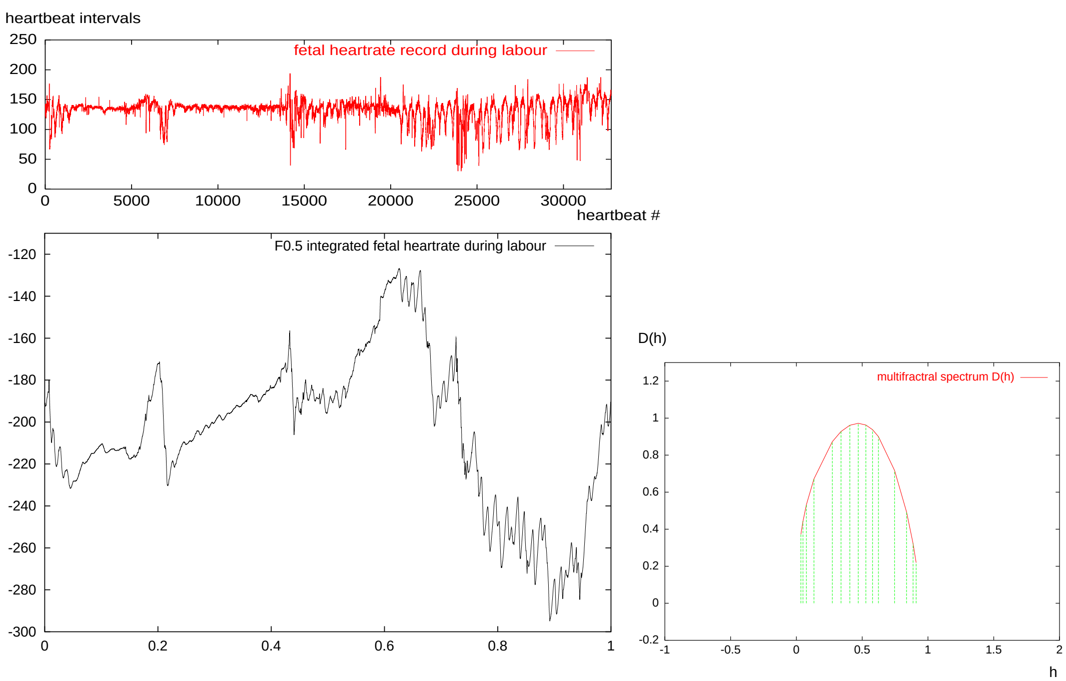

Figure 3. Top: the input time series: fetal heartbeat record. Left: fractionally integrated input heartbeat record. Right: the corresponding multifractal spectrum.

However, integration of the heart rate brings it into the range of a strongly correlated persistent record. In order to make a comparison with financial records, one needs to have a record centred at about $H = 0.5$, corresponding with non-correlated random walk. This can be achieved by fractionally integrating the time series. Fractional integration/differentiation is a linear operation which, just like integration or differentiation, preserves the non-linear component - the scale invariant, multiplicative cascade-like properties of the signal, together with the associated multi-scaling and the multifractal spectrum. The result is depicted in the figure 3, together with the associated multifractal spectrum.

As already mentioned above, the focus of perinatology is after-crash oriented: the obstetrician observes the heart rate online during the (series of) decelerations (usually using a relatively short window of $5-10$ minutes recordings; for comparison the record in figure 3 is about 6 hours) and in case of encountering decelerations, evaluates the risk of continuing with the natural delivery or orders intervention. This may mean taking a fetal blood sample to determine the level of oxygen in the blood of the fetus, or immediate delivery through Caesarian section. The decision making is based on a complex evaluation which considers both the history of the heart rate and its current instantaneous values and the values of its characteristics like baseline, accelerations and decelerations and the variability level. Additionally, external data about the history of the pregnancy and the history of the mother enters the reasoning and decision making process.

4 Conclusions - Can lessons be learned for economics?

Traditionally economical records are observed with pertinent fear of crashes, and new models and methodologies suggested to predict crashes. We argue that crashes, both multi-scale and the largest, are a natural component of market behaviour. However, both may differ in underlying mechanism. This conclusion is motivated by an analogy with another complex system which exhibits similar scope for critical behaviour. We identify another objective - the health of the economy which should be evaluated using the data from the stock market, just as the health of the baby - fetal well-being, is estimated from its heart rate. Looking into the dynamics of the crashes and the period of recovery from the crash may provide valuable information for determining both fetal and economic well-being in the cases under study. Some heavy crashes will be within the possibilities of the system to cope with, some will not, resulting in a degradation of the system.[2] It is the task of decision makers to estimate the risk of such system degradation and order the appropriate intervention in case there is a need for this. Such a decision making process is far from obvious and is not directly related to a single known characteristic observable from the system. In the case of fetal heartbeat, such a decision is not only taken on the basis of the current instantaneous level of decelerations or

[2] In case of the fetus it is cerebral palsy - various degrees of damage to the neural system. Economic parallels are difficult to draw, but heavy recessions, which ultimately lead to new economies (or wars), may be suggested.

variability. Neither in the case of the economy is it based on the instantaneous level of volatility etc. Such complex decision making in the economy may in fact profit from taking a similar path as that suggested in the obstetrics domain: the development of a decision support system [23]. Such a decision support system would be strongly based on the characteristics derived from available time series relevant to the economic system under study. To support the tasks of inference from the current and past system characteristics, it would use both models and heuristics learned from the experts as well as new observations derived from the data.

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