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Econophysics and the Current Economic Turmoil

By H. Eugene Stanley

Almost every physicist by now has heard of the fast-growing subdiscipline of "econophysics", a field characterized by collaborations between physicists and economists and focused on asking if new insights or even laws could emerge if the concepts and approaches of statistical physics were brought to bear on questions that originate in economics. And almost everyone, physicist or nonphysicist, has by now heard that the economies of every country–large or small, Eastern or Western–are witnessing truly huge fluctuations. So it is natural to ask

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"Does econophysics have anything to say about the current financial/economic turmoil?''

The answer to this question is a resounding "Yes!" since econophysics is statistical physics applied to the economy, and fluctuations are the substance of statistical physics. In economics, the probability density function (pdf) of price changes has been studied for over 100 years, ever since the PhD thesis of Bachelier in 1900 analyzed real data–without benefit of computers. Then, to understand the pattern he witnessed, he introduced a model which today we call the drunkard's walk. This is the model immortalized to the general public in the aphorism "random walk down Wall Street.''

Approximately 50 years ago, as more data became available, it became clear that the drunkard's walk fails to describe all the data. The term "fat tail" was used to describe the mathematical counterpart of this statement, that the pdf of price changes contains many more events in the tail than predicted by the Gaussian pdf characterizing the drunkard's walk. Nonetheless, more than 99 percent of the then available data were reasonably approximated by a Gaussian, so a terminology grew up where events corresponding to these fat tails became known as "rare events," or sometimes "tsunamis." Since there was no theory for them, some argued, and since they are indeed very rare, we can as well ignore them. The word "outlier" is sometimes used to describe a data point that does not conform to the widely used Gaussian distribution of price fluctuations.

Then along came the physicists, starting about 15 years ago when the neologism "econophysics" was coined by this author to describe efforts to apply physics approaches to this and other questions of interest in economics. This field can trace its roots to Newton and Copernicus, two physicists who worked extensively on economics problems, and to a number of others over the centuries who applied to economics the fundamental approach of physics. First, to be eternally skeptical of everything–especially in this case of the practice of calling something that does not agree with a theory an "outlier" or "tsunami." And, perhaps most importantly, to collect as many data as possible before making any theory to interpret them.

Unlike traditional topics in physics, where collecting data often requires imagination and sometimes years of painstaking labor, in the case of price changes every transaction of every stock is recorded and stored. Apparently all the data were not analyzed, so two Boston University graduate students, Parameswaran Gopikrishnan and Vasiliki Plerou (now happily married!), set about to acquire and analyze the data on every transaction...such a voluminous data set that their University computer system had to acquire a significant addition to its storage capacity.

When they analyzed these data–200 million of them–in exactly the same fashion that Bachelier had analyzed data almost a century earlier, they made a startling discovery. The pdf of price changes was not Gaussian plus outliers, as previously believed. Rather, all the data–including data previously termed outliers–conformed to a single pdf encompassing both everyday fluctuations and “once in a century” fluctuations. Instead of a Gaussian or some correction to a Gaussian, they found a power law pdf with exponent -4, a sufficiently large exponent that the difference from a Gaussian is not huge; however, the probability of a “once in a century” event of, say, 100 standard deviations is exp(-10,000) for the Gaussian, but simply 10^{-8} for an inverse quartic law. If one analyzes a data set containing 200 million data in two years, this means there are only two such events–in two years!

Now which is better, the concept of “everyday fluctuations” which can be modeled with a drunkard’s walk, complemented by a few “once in a century” outliers? Or a single empirical law with no outliers but for which a complete theory does not exist despite promising progress by Xavier Gabaix of NYU’s Stern School of Management and his collaborators? Here we come to one of the most salient differences between traditional economics and the econophysicists: economists are hesitant to put much stock in laws that have no coherent and complete theory supporting them, while physicists cannot afford this reluctance. There are so many phenomena we do not understand. Indeed, many physics “laws” have proved useful long before any theoretical underpinning was developed . . . Newton’s laws and Coulomb’s law to name but two.

And all of us are loathe to accept even a well-documented empirical law that seems to go against our own everyday experience. For stock price fluctuations, we all experience calm periods of everyday fluctuations, punctuated by highly volatile periods that seem to cluster. So we would expect the pdf of stock price fluctuations to be bimodal, with a broad maximum centered around, say, 1-3 standard deviations and then a narrow peak centered around, say, 50 standard deviations. And it is easy to show that if we do not have access to “all the data” but instead sample only a small fraction of the 200 million data recently analyzed, then this everyday experience is perfectly correct, since the rare events are indeed rare and we barely recall those that are “large but not that large”.

The same is true for earthquakes: our everyday experience teaches us that small quakes are going on all the time but are barely noticeable except by those who work at seismic detection stations. And every so often occurs a “once in a century” truly horrific event, such as the famous San Francisco earthquake. Yet when seismic stations analyze all the data, they find not the bimodal distribution of everyday experience but rather a power law, the Gutenberg-Richter law, describing the number of earthquakes of a given magnitude.

There is another problem with accepting an empirical law that quantifies the probability to experience a financial shock of a given size. Many scientists, especially economists, feel that it is better to really understand a law before proposing it. However imagine what must have happened when earthquake specialists uncovered the Gutenberg-Richter law describing the number of earthquakes of a given magnitude. San Francisco last experienced a truly huge earthquake in 1906. Do we ignore the Gutenberg-Richter law that informs us the precise probability of another San Francisco earthquake of comparable magnitude because we do not understand it? Or do we design San Francisco buildings so that they withstand once-in-a-century earthquakes?

Similarly, do we ignore the inverse quartic law that fits all the data including once-in-a-century events? Or do we design a financial system that has safeguards to minimize the damage when one of these rare events actually occurs?

We cannot predict the future but we all know what already happened. Governments worldwide made no contingency plans, and when the current crisis finally appeared to not “just go away,” meetings of experts were called and policies hastily crafted. We cannot know at this stage if these policies are the best possible or not, but the speed with which they were crafted seems incommensurate with the fact that we physicists knew for 10 years the probability of shocks of this magnitude, just as we know the probability of an earthquake of a given magnitude. California buildings are required by government to be reinforced, but financial systems are not. Indeed, the haste with which current policies were adopted clearly has the potential for making a bad situation worse than it would be if more careful policies were proposed, back-tested on real economic data, refined, and discussed at all levels from many points of view, by individuals from the Paul Krugmans to the Alan Greenspans.

I now briefly address a second question, a question raised frequently by the news media: “There have even been accusations that physicists are to blame for what’s been going on, because they have allegedly invented the complex financial instruments that nobody else understands but that are now doing us in.”

It is indeed true that physicists have been among those who invented complex financial instruments. But so what? Physicists also invented many other things that others have used for destructive purposes. Bernoulli invented the principles underlying flight yet it is not customary to blame physicists for flight accidents caused by the failure of these principles (in, e.g., turbulent air conditions). Nor is it customary to blame physicists for the nuclear disaster at Chernobyl despite the acknowledged role that physicists have played since Frisch and Meitner first proposed the idea of nuclear fission. It is natural to want someone to blame for major disasters...whether the disaster is completely natural like Hurricane Katrina or man-made like the current economic crisis. Just as the fundamental flaw that made Hurricane Katrina the disaster it was involved not preparing for the unlikely event of a direct hit of a major storm, so also the fundamental flaw that causes much of today’s economic problems is not preparing for the unlikely event of a very large economic fluctuation.

In any case, the probability of a disastrous economic fluctuation seems to be fairly independent of time period, since Plerou and Gopikrishnan found that the same inverse quartic law holds for different time periods in history, dating back as far as the 1929 crash...long before physicists were as popular as they are now on Wall Street. So if it is the physicists who are to blame, how do we explain the fact that large and not-so-large crashes have been appearing with frequencies that are approximately time-independent?

But if one wants a scapegoat then you can look no further than the author of this article. The inverse quartic law is a quantitative, not a qualitative, law: it tells the exact probability of a crash of a given size. So before the inverse quartic law, one knew only the qualitative statement that rare events do occur, but not the exact probability of a rare event, making it easier to ignore since indeed the events are very rare. Why didn't we write letters to those with the power to plan exactly what to do when the "once in a century" bad news indeed occurs?

Physicists do not generally stop at extracting empirical laws from data. Additionally, they try to understand the laws. What can a physicist offer as a first step to begin to understand the fact that there appears to be scale-free phenomena at work in stock price fluctuations? I can offer a tentative picture–based largely on analogy with another scale-free phenomenon, a system near its critical point (now called a "tipping point" due to the popular book of this title by Malcolm Gladwell). Indeed, physicists often like to argue by analogy, on the "parsimony principle" (often credited to Feynman) that there are not that many fundamentally different phenomena.

Large strides were made in understanding the scale-free phenomena occurring in systems near their "tipping points" by the recognition of the fundamental role played by two variables: the interactions among the units comprising the systems, and the interaction of the units with an external force field. In economics, if the units are firms, the first is called the "herd effect" (if one unit changes, other units influenced by that unit are more likely to change), and the second is called the "news effect" (all units respond to external news). The complexity of this picture is that the units do not simply interact with equal strength with a small number of other units, but rather have interactions of both sign ("ferromagnetic" and "antiferromagnetic") with other units...much as in an Edwards-Anderson spin glass except that the distribution of interactions is not known and will certainly even vary over time. Similarly, the interactions with "news" can take on a huge range of strengths–some news is very good, good, bad, or very bad–and news affects different firms differently...much as in a random field Ising model.

Of course this model is not exactly solvable, which makes it not very attractive to economists who generally prefer models that are amenable to solution. Nonetheless, it is attractive to physicists because we have developed a fairly deep understanding about phase transitions in idealized models, not only "pure" nearest-neighbor Ising models in a uniform external field, but also complex spin glasses and complex random field Ising models. Certainly we know enough to understand why the "globalization" of recent years might serve to introduce more "ferromagnetic" bonds, and hence to increase the magnitude of the sort of "spin flips" that occur in big clusters near the critical point. And Albert-László Barabasi has taught us that the networks formed by agreements among leaders of economic institutions serve to establish still more long-range ferromagnetic interactions, again with the result that cluster flips could be more dramatic.

Many physicists have viewed the film by Fumiko Yonezawa of her simulations below the critical point of Ising models with nearest neighbor interactions bathed in a uniform magnetic field. One can never forget how all the spins are flipping nonstop but suddenly a huge cluster of spins which were mostly "up" suddenly flip and become mostly "down". The effect of additional long-range ferromagnetic interactions would be to increase the magnitude of these dramatic flips.

In short, this physicist's intuition is that an overconnected system is WORSE, not BETTER, in a metastable condition, for encouraging large fluctuations. So if this argument has any validity, then the fluctuations are larger, not because of physicists making up new instruments, but rather because of the links between corporations, and the links between countries.

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