Institute of Physics

What have gases, random walks and Einstein got to do with banks and trading floors? Everything it seems

Physics and finance

$$\frac{1}{2}\sigma^2 S^2 \frac{\partial^2 V}{\partial S^2} + rS\frac{\partial V}{\partial S} - rV = 0$$

VISIONS 4

BRIEFING PAPERS FOR POLICY MAKERS

Physics and quantitative finance

You might be surprised to hear that physics and money have anything in common. But they do. Managing money, just like a physics experiment, means dealing with numbers and varying quantities. And the connection goes deeper. Physics is actually about developing general descriptions – mathematical models – of the world around us. The models may describe different types of complexity, such as the movement of molecules in a gas or the dynamics of stars in a galaxy. It turns out that similar models can just as well be applied to analogous complex behaviour in the financial markets. Indeed, banks now recognise that they have real practical use – for instance, in pricing financial deals by modelling the markets as 'almost random' processes and then calculating probabilities of future market movements; or in identifying patterns or trends in the market which may be used to develop profitable trading strategies.

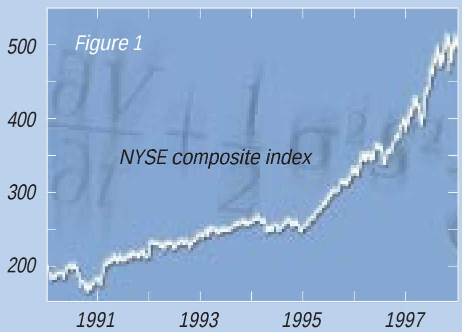
Rocket scientists in the City

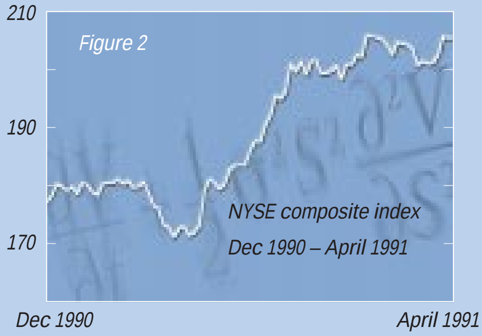
In fact, physicists' knowledge and skills are now in great demand in the City. A trained PhD physicist will be familiar with the advanced mathematics (usually of the statistical kind) needed not only to model currency and stock movements, but also the complex financial products derived from them (called derivatives), and even aspects of trading behaviour. What is more, physicists have an edge over their equally numerate colleagues, the economists and mathematicians, in that they are used to solving problems pragmatically, by combining any useful mathematical and computing tools that come to hand with observations of real situations – the markets.

Today, the big investment banks all have their quota of physicists, or 'rocket scientists' as they are affectionately known, and the City alone is recruiting at least a 100 young PhDs every year. Increasingly, other institutions – high-street banks, financial regulatory bodies, consultancy firms, building societies and insurance companies – are also employing people with a rigorous training in physics.

One area of banking where physicists work involves developing new types of financial products. These are often the derivatives mentioned earlier such as 'options' and 'futures'. A stock option, for example, is the right but not the obligation to buy a stock at a certain time in the future at a price agreed today. This costs a small amount of money called the premium. Obviously, if the stock becomes more valuable in the interim, the

Physics models market prices
Figure 1 shows daily closing prices at the New York Stock Exchange from 1990 to1997, while Figure 2 shows the prices just for December 1990 to April 1991 – revealing a lot of 'hidden structure'. Figure 3 shows prices based on a physicist's model where there are many competing traders with a limited amount of market information.The resulting pattern agrees well with that in Figure 2.





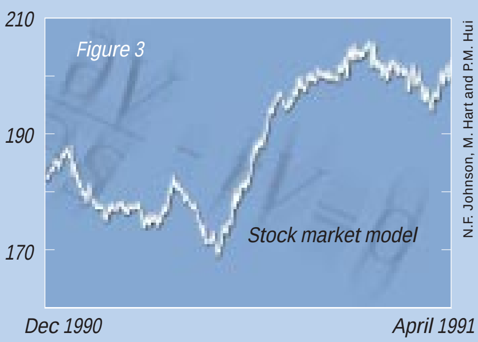
THANKS GO TO JESSICA JAMES OF THE FIRST NATIONAL BANK OF CHICAGO AND NEIL JOHNSON OF

option will make money for the owner. It's a way of 'hedging' risk. The trick is for a bank to get the pricing of the derivative's premium right, and this done using physics-related models such as the Black-Scholes equation (see Box). Derivatives may form the basis of an individual investor's portfolio, or part of a bank's multi-billion dollar trading strategy designed to exploit minute changes in market movements or price relationships.

At the heart of investment is evaluating and managing the risks involved in trading currencies and pricing products – so as to maximise returns for a given level of risk, and to achieve the optimum spread of risk between financial institution and customer. Many rocket scientists are involved in this side – in calculating interest rates and prices in the future. Just like in the physics lab, they test their models by simulating them on a computer to see how closely they correlate with the real data coming from the trading floor.

One of the most exciting aspects of financial physics – or 'econophysics' – is that no models as yet perfectly represent the market and there is still a lot of fundamental research to be done. This is where the ingenuity of the research physicist comes into its own. While some rocket scientists are constantly refining and improving their pricing models in the competitive world of derivatives, others are looking at new ways to analyse trends and patterns.

One of the most important aspects here is volatility – the amount of fluctuation in the market. Financial analysts need a good model of volatility in order to predict risk. At the moment there is no satisfactory way to predict financial crashes. One way is to look for patterns that can be quantified. However, market movements are highly nonlinear – that is, the changes are not directly proportional to the time over which they happen – and the resulting charts look very random. However, academic physicists have developed tools for extracting useful information from what appears to be just 'noise'. One technique, associated with chaos theory, is multifractals. A fractal is a shape that can be broken down into bits which are a reduced-scale version of the whole. This property of self-similarity can be applied to the ups and downs of stock prices and give some estimates of the probability of how the market might change in the future.



New science from finance

Perhaps the most challenging area of econophysics is to develop a so-called microscopic model of financial markets. Just as the kinetic theory of gases (a model based on averaging the effects of all the collisions of the gas particles) underlies the equations describing the overall behaviour of a gas in terms of its temperature, pressure and volume, so it may be possible to devise a global financial model based on the average interactions of individual traders.

The volatility of a market, which is analogous in some ways to the temperature of a gas, depends on what all the traders are doing. However, you can't make assumptions based on the average behaviour of the traders because profit typically comes from doing the opposite of everyone else at the appropriate time – a so-called minority game. Furthermore, unlike gas particles, traders have memories which modify their behaviour over time. Researchers in econophysics say this kind of behaviour requires entirely new physical models to describe it. They are looking at many kinds of ideas – from spin glasses (models based on magnetism) to evolutionary game theory, neural networks, and theories of learning and pattern recognition. It is possible that a new kind of physics will be developed, for which finance provides the standard example. These new models could then be applied in many other scientific areas such as information technology, biochemical systems and even theories of mind – thus reinforcing the central role of physics in explaining the world.

CLOSE CONNECTIONS OF THE MATHEMATICAL KIND

In many ways a market behaves like a fluid or a gas, and it is not surprising that bankers use concepts like 'liquidity' and 'volatility' to describe a financial state. In fact, the connection between physics and finance goes back a long way. In 1900 Louis Bachelier, studying price fluctuations in the Paris Stock Exchange, first uncovered the mathematics behind a favourite physicist's concept, that of the 'random walk', which Einstein later independently used to model the diffusion of particles in a gas.

In the 1960s and 1970s, three Americans – a physicist Fischer Black, an economist Myron Scholes and an engineer Robert Merton – came up with an equation to predict price changes which related financial variables: time, price, interest rates and volatility. It formed the basis of a huge new financial industry in derivatives. Scholes and Merton were awarded the Economics Nobel Prize in 1997, Black having died two years before. The equation – called the Black-Scholes equation (see below) – looks very like heat diffusion equations used in physics.

$$\frac{\partial V}{\partial t} + \frac{1}{2}\sigma^2 S^2 \frac{\partial^2 V}{\partial S^2} + rS\,\frac{\partial V}{\partial S} - rV = 0$$

OXFORD UNIVERSITY FOR THEIR HELP WITH THIS PAPER

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