Information Sciences 179 (2009) 478–484

Contents lists available at ScienceDirect

Information Sciences

journal homepage: www.elsevier.com/locate/ins

Quantum probability and financial market

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ARTICLE INFO

Article history:
Received 14 April 2008
Received in revised form 23 June 2008
Accepted 3 July 2008

Keywords:
Billionaire investor George Soros
Financial crises
Market fundamentalism
Market self-stabilization
Efficient market hypothesis
Classical probability
Quantum probability
Bohmian model
Financial pilot wave
Bohm–Vigier stochastic model

ABSTRACT

Can the mathematical formalism of quantum mechanics and, in particular, quantum probability be applied outside of physics? The answer is positive. In this paper, we apply methods of quantum mechanics for mathematical modelling of price dynamics of the financial market. We propose to describe behavioral financial factors (e.g., expectations of traders) by using the pilot wave (Bohmian) model of quantum mechanics. On the one hand, our Bohmian model is a quantum-like model for the financial market, cf. with works of W. Segal, I.E. Segal, E. Haven, E.W. Piotrowski, J. Sladkowski. On the other hand, (since Bohmian mechanics provides for the possibility to describe individual price trajectories) it belongs to the domain of extended research on deterministic dynamics for financial assets. Our model emphasizes the complexity of the financial market: the traditional description of price dynamics is completed by Schrödinger's dynamics for the pilot wave of expectations of traders. This is a kind of socio-economic model for the financial market.

1. Introduction

At the end of January 2008 billionaire investor George Soros said the world was facing the worst financial crisis since World War Two and the US was threatened with recession, according to an interview with the Austrian daily Standard: "The situation is much more serious than any other financial crisis since the end of World War Two". He said over the past few years politics had been guided by some basic misunderstandings stemming from something which he called "market fundamentalism" – the belief financial markets tended to act as a balance. "This is the wrong idea," he said. "We really do have a serious financial crisis now."

In this interview we are interested in Soros' attack against market fundamentalists and especially the idea about self-stabilization of the financial market. From the econophysical viewpoint the latter is a consequence of application of models of classical statistical mechanics. In general "self-stabilization optimism" is supported by the classical probabilistic models of financial market, starting with Bachelier [4] and dominating in modern financial mathematics, see e.g., the books of Mantegna and Stanley [42] and Shiryaev [47]. In particular, the postulate on the efficient market hypothesis plays the fundamental role in justification of market fundamentalism.

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doi:10.1016/j.ins.2008.07.001

1.1. Efficient market hypothesis

In economics and financial theory, analysts use random walk and more general martingale techniques to model behavior of asset prices, in particular share prices on stock markets, currency exchange rates and commodity prices. This practice has its basis in the presumption that investors act *rationally and without bias*, and that at any moment they estimate the value of an asset based on future expectations. Under these conditions, all existing information affects the price, which changes only when new information comes out. By definition, **new information appears randomly and influences the asset price randomly**. Corresponding continuous time models are based on stochastic processes (this approach was initiated in the thesis of Bachelier [4] in 1890), see, e.g., the books of Mantegna and Stanley [42] and Shiryaev [47]for historical and mathematical details.

This practice was formalized through the *efficient market hypothesis* which was formulated in 60s, see Samuelson [45] and Fama [17] for details:

A market is said to be efficient in the determination of the most rational price if all the available information is instantly processed when it reaches the market and it is immediately reflected in a new value of prices of the assets traded.

Mathematically the efficient market hypothesis was supported by investigations of Samuelson [45].

1.2. Deterministic chaos?

First we remark that empirical studies have demonstrated that prices do not completely follow random walk. Low serial correlations (around 0.05) exist in the short term; and slightly stronger correlations over the longer term. Their sign and the strength depend on a variety of factors, but transaction costs and bid-ask spreads generally make it impossible to earn excess returns. Interestingly, researchers have found that some of the biggest prices deviations from a random walk result from seasonal and temporal patterns, see the book [42].

There are also a variety of arguments, both theoretical and obtained on the basis of statistical analysis of data, which question the general martingale model (and hence the efficient market hypothesis), see, e.g., [3,5,9,10,15,27]. It is important to note that efficient markets imply there are no exploitable profit opportunities. If this is true then trading on the stock market is a game of chance and not of any skill, but traders buy assets they think are underevaluated at the hope of selling them at their true price for a profit. If market prices already reflect all information available, then where does the trader draw this privileged information from? Since there are thousands of very well informed, well educated asset traders, backed by many data researchers, buying and selling securities quickly, logically assets markets should be very efficient and profit opportunities should be minimal. On the other hand, we see that there are many traders who successfully use their opportunities and perform continuously very successful financial operations, see the book of Soros [48] for discussions.[1] There were also performed intensive investigations on testing that the real financial data can be really described by the martingale model, see [5,9,10,15,27]. Roughly speaking people try to understand on the basis of available financial data:

Do financial asset returns behave randomly (and hence they are unpredictable) or deterministically (and in the latter case one may hope to predict them and even to construct a deterministic dynamical system which would at least mimic dynamics of the financial market)?

Predictability of financial asset returns is a broad and very active research topic and a complete survey of the vast literature is beyond the scope of this work. We shall note, however, that there is a rather general opinion that financial asset returns are predictable, see [5,9,10,15,27].

On the other hand, there is no general consensus on the validity of the efficient market hypothesis. As it was pointed out in [10]: "... econometric advances and empirical evidence seem to suggest that financial asset returns are predictable to some degree. Thirty years ago this would have been tantamount to an outright rejection of market efficiency. However, modern financial economics teaches us that others, perfectly rational factors may account for such predictability. The fine structure of securities markets and frictions in the trading process can generate predictability. Time-varying expected returns due to changing business conditions can generate predictability. A certain degree of predictability may be necessary to reward investors for bearing certain dynamic risks".

1.3. Behavioral financial models

Therefore it would be natural to develop approaches which are not based on the assumption that investors act *rationally and without bias* and that, consequently, new information appears randomly and influences the asset price randomly. In particular, there are two well established (and closely related) fields of research *behavioral finance and behavioral economics* which apply scientific research on human and social cognitive and emotional biases[2] to better understand economic decisions

[1] It seems that Soros is sure he does not work at efficient markets.

[2] Cognitive bias is any of a wide range of observer effects identified in cognitive science, including very basic statistical and memory errors that are common to all human beings and drastically skew the reliability of anecdotal and legal evidence. They also significantly affect the scientific method which is deliberately designed to minimize such bias from any one observer. They were first identified by Tversky and Kahneman as a foundation of behavioral economics. Bias arises from various life, loyalty and local risk and attention concerns that are difficult to separate or codify. Tversky and Kahneman claim that they are at least partially the result of problem-solving using heuristics, including the availability heuristic and the representativeness heuristic.