

Title: **Is Black-Scholes Irrelevant?**

Summary: The newly emerging science of studying complex systems is being applied to global finance markets by a new joint academic/commercial venture, the Oxford Centre for Computational Finance. Multi-agent-based models are used to create artificial markets and to perform dynamic tests of new methods for option pricing and the like. At the same time, this laboratory for analysis of live-market data is gearing to provide sponsoring organizations with more immediate commercial benefits, such as new types of derivatives and stress-tested algorithms that fine-tune Black-Scholes and other traditional option-pricing methods.

Running Black-Scholes¹ backwards to determine the implied volatility of markets has always been a less-than-satisfactory guide to future market behavior. But since September 11, 2001, historical studies of past data have been revealed to be far worse than unsatisfactory. “Meaningless” or “dangerously misleading” seem to be far more apt terms to describe how regulatory bodies, investors, and trading institutions alike have been saddled by this limitation.

Coincidentally, within a month of September 11, a new approach to analyzing real-time market data that had been in the planning stages for some time was unveiled at the launch of the Oxford Centre for Computational Finance (OCCF) at the University of Oxford, UK. OCCF, a joint venture between industry and academia, provides a laboratory for studying today’s (rather than yesterday’s) financial markets. OCCF is designed to support the world’s financial markets through development of mathematical theories that are tested in this live laboratory such that the dynamics emerging from today’s markets are better understood. An underlying OCCF goal is to facilitate faster reaction to extreme market events, such as predicting and dealing with market crashes and evaluating all forms of market risk.

This article outlines the general approaches to research being conducted in these unique studies of real-time market data. Below is some background on the players involved in OCCF and how this live laboratory is created.

Oxford Centre for Computational Finance

OCCF is an active, ongoing partnership between academia, the information technology (IT) industry, and the finance industry that was instigated by the Numerical Algorithms Group (NAG), a worldwide organization dedicated to developing quality mathematical and statistical components and 3D visualization software. NAG’s vision was to bring together resources and capabilities that had not been together in the same place before, so that new mathematical models and insights could be developed and applied, both by individual financial firms and at the regulatory level. On the one hand, various academic areas in the hard sciences, engineering, and mathematics had been developing new analytical models, but rarely had the appropriate hardware, data, or software needed to adequately test these new theories. On the other hand, the press of business on Wall Street and in New York City was and is such that there is scant time for the type of basic research needed to extend the frontier of knowledge and to develop entirely new modeling techniques. OCCF was conceived as a vehicle that would transcend these historic limitations.

Thus, OCCF is a collaboration between the Oxford Departments of Physics, Math and Computing, with the support of three founding industrial partners (NAG, IBM, and Sun). NAG provides analytical and

¹ Black-Scholes theory provides a method for pricing derivative securities, taking into account the volatility of price movements of the underlying security and the returns of alternative riskless investments. It was first published in 1973 by Fisher Black and Myron Scholes.

visualization software to OCCF. IBM Data Management Solutions Informix Products provides the real-time data management infrastructure. Sun Microsystems provides an UltraSPARC-based hardware platform and associated software. Market Information Services (MIS) and Reuters also play pivotal roles in the initiative, providing the integration services and data feeds, respectively. Also, finance organizations looking to undertake specific confidential research are able to sponsor doctoral and post-doctoral research that remains within the confidential domain of the sponsor.

At this time, OCCF is pursuing three different levels of inquiry with its live laboratory to analyze real-time market data:

1. Application of methods from the emerging field of complexity that is studying similarly complex systems in scientific areas such as biology, physics, and ecology.
2. Development of independent and improved estimates of the market's real volatility.
3. Developing and stress-testing advanced algorithms to be applied to current theories such as Black-Scholes.

Science of Complex Systems

Numerous theories from emerging studies of complex dynamic systems involving many interacting particles or "agents" (such as people, data-packets, and nodes) are being tested in OCCF's live market-data laboratory. The study of complexity is essentially the study of non-linear, non-equilibrium dynamic systems involving many interacting entities. These studies of complex systems actually transcend the finance arena and are also of great importance to new research in diverse fields such as fluid dynamics, immunology, ecology, sociology, and artificial intelligence.

These studies of the markets as a complex system are trying to understand the strange complex movements within certain markets and across markets, such as when they move together and when they do not, why volatility is sometimes high and sometimes low, and how factors like price and volume are contributing to these effects. This approach applies a dynamic view of the market. Instead of saying that a market on average behaves a certain way and then building finance theories based on that idea of an average, the view of the market as a complex system starts with the premise that it does not know at what scale the market behaves in a certain average way.

The live data feeds and analysis are key to understanding the market as a complex system. While many commercial firms have live feeds into existing models, OCCF goes beyond that by using dynamic models for its market analyses. OCCF's artificial market (agent models) builds up a picture and recreates the dynamics of the true market. For example, a commercial firm with live feeds may use Black-Scholes calculations based on an average single number to estimate market volatility. However, dynamic studies of the market clearly show that one cannot truly use one single number, as that number inevitably changes over the time scale by which you look at the market.

Currently, OCCF is applying non-equilibrium game-theory² to gain insights into markets as an evolving population of interacting objects where individual members (agents) adapt their interactions and behavior according to their past experiences. The general theme of this branch of econophysics research is to study how complex behavior (complexity) emerges in a system as the number of interacting objects making up that system increases. Of particular interest is the situation where agents repeatedly compete

² The game theory referred to is a mathematical model describing a population of traders who are continually competing to win in a market. The traders have limited information about each other. They take decisions (e.g., buy, sell, do nothing) based on the global information represented by the past history of price changes, as well as external news. Their decisions then produce the next price change, which then feeds back to the entire population of traders via the updated price--and so on, producing a never-ending "game" with losers and winners.

for a limited resource. Multi-agent-based analyses are unlike traditional research in that physicists liked to break complicated problems into simpler pieces. Now, it is appreciated that an understanding of physics of entities at a lower level does not necessarily imply the same when a large number of such entities are put together to form a system at a higher level. Unexpected novel phenomena emerge as the complexity of the system increases.

Currently, this research uses the development of multi-agent market models to study how financial market movements may be simulated, predicted and hedged against. In these agent-based market simulations, traders equipped with simple buy/sell strategies and limited information compete in speculative trading. This has allowed study of different market clearing mechanisms and the demonstration that realistic out-of-equilibrium clearing processes lead to dynamics that closely resemble real financial movements, with fat-tailed price increments, clustered volatility, and high-volume autocorrelation.

Replacing the “synthetic” price history used by these simulations with data taken from real financial time series shows that the agents can collectively learn to identify moments in the market where profit is attainable. Hence on real financial data, the multi-agent simulation as a whole can perform better than random and could therefore be used as the basis for an automated real-time trading system. Building on these simulations, OCCF also employs general risk-control formalism in conjunction with agent-based models to examine market risk and subsequently extract hedging strategies beyond the Black-Scholes paradigm.

Actually, what is important in market data, as in other arenas where studies of complexity are proving useful (i.e., immunology, ecology, sociology), is the large changes, such as market crashes. These large shifts are what upsets the system and dictates what happens to it for a long time thereafter. For example, the changing rate between dollars and yen ordinarily does not have any effect on the IBM stock price, but in a moment of crisis, they become interdependent. Everyone presumes that large changes happen randomly, even though the market produces its own dynamics most of the time even in the absence of significant news like 9/11. While exogenous extreme events such as 9/11 cannot be predicted, the endogenous changes may be somewhat predictable.

Thus, using multi-agent-based models, OCCF is exploring whether a large change is somehow encoded in the makeup of a particular system and intrinsic to that particular complex system. This will help guide regulators to the best possible policies to manage spike events by playing out scenarios based on manipulating each agent vs. tweaking of the global system vs. leaving the system to organize itself.

Although more theoretical at this stage of research, the multi-agent-based modeling of market activity holds great promise for practical insights in the future. Because OCCF's data is live, it avoids many potential academic pitfalls from relying on past data. Artificial markets are trained on real data and then projected forward to come up with forecasts. This means any testing of new models can be done truly “out of sample”, and the usual criticisms that model testing may be yielding false positive results when it is done on a selected dataset are negated.

New Derivative Products

If the best one can do with an option pricing model is to run it backwards through a theorem to extract a number for the market's implied volatility, that model is of limited use. In contrast, methods that allow one to run this process forwards to obtain realistic market prices for derivatives would be far more useful, as Black-Scholes was originally intended to do. All of this hinges on getting a better idea of market volatility, plugging this into an improved formula, and thereby getting something close to the actual market price. In turn, this would allow one to get a better idea as to when options and derivatives are underpriced/overpriced and an even better handle on the market's real volatility.

OCCF, using derivative theory being developed onsite in Oxford by Jeff Dewynne, Ph.D. and Sam Howison, Ph.D., has real option/derivative prices coming in with which to test more general option pricing formulae. This also allows firms enlisting OCCF services to better price-structured derivatives that are not openly traded on the market (OTC, or “over-the-counter”).

Unlike the exploration of non-equilibrium multi-agent game theory vis-à-vis global markets, this area of OCCF research is far less “blue sky”. OCCF can help institutions to invent new types of derivatives with less fear of mispricing. This has potential to help bring back several areas of the derivatives market that dried up with the Long Term Capital Management collapse when many got scared that the theoretical value of derivatives they were trading was unknown.

Stress-Tested Computational Techniques

Improving the numerical implementation of standard finance models defines the more “low tech” areas of OCCF research, though perhaps the research areas with potential for immediate practical effects. Even within extant standard theory of how to price American options, there is plenty of scope for developing more advanced algorithms and computational techniques in order to arrive at a more accurate price in a quicker and more reliable way. For example, the prices of all derivatives need to be tweaked to adjust for transaction costs of hedging for the option’s lifetime. This need for adjustment results from an underlying stock that one buys to hedge a position incurring a transaction cost, such that the more times one needs to buy stock, the more one incurs such transaction costs. This is an inefficiency that should be included in the option’s price, even if one is using a straightforward Black-Scholes calculation to determine that price. While commercial firms look at problems like this, and all have one or more solutions to patch up Black-Scholes, there is rarely if ever a circumstance where these different tweaks to the Black-Scholes formula are tested empirically with live market data. The advanced algorithms that are developed can be further stress-tested to establish and enhance their robustness.

Having developed the fancy “bells-and-whistles” algorithms, OCCF is poised to further test how these algorithms can be scaled down to run on lower-end platforms, even the traders’ handheld PDAs (personal digital assistants). Thus, stress-testing advanced algorithms under different commercial IT conditions is an immediate avenue for OCCF studies to have impact on the markets.

Commercial Applications of OCCF Artificial Markets

Beyond the immediate commercial benefits of generating improved computational techniques, OCCF’s artificial markets (agent-based models) could be made available to sponsoring finance firms seeking to benefit from this new approach. For example, when the real data of one market generates an artificial market that seems to produce the same behavior as the observed market, it can be used as a forecaster. That artificial market can thus be used to stress-test portfolio management, option pricing, and so forth *for the future*. In other words, a particular institution or portfolio can stress-test its strategy without the historic assumptions that the market is behaving on average as it was before.

A more futuristic goal for OCCF artificial market simulations is to train these markets on real data that can then be used to make global market-level forecasts. A crisis in one market tends to migrate to another market but not at the same time. Understanding the links in the complex system of global markets that controls both short-term and long-term behavior will no doubt be of interest to regulatory bodies seeking to keep markets as stable as possible. These macroscopic studies are also of interest to immunologists, ecologists, and many other researchers whose understanding of complex systems is seen as key to moving theories to the next level. In this way, the financial markets themselves truly become a scientific laboratory for cutting-edge complex systems research.

Conclusion

The newly emerging science of studying complex systems is being applied to global finance markets by a new joint academic/commercial venture, the Oxford Centre for Computational Finance. Multi-agent-based models are used to create artificial markets and to perform dynamic tests of new methods for option pricing and the like. At the same time, this laboratory for analysis of live-market data is gearing to provide sponsoring organizations with more immediate commercial benefits, such as new types of derivatives and stress-tested algorithms that fine-tune Black-Scholes and other traditional option-pricing methods.

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