Fifty Years of Black-Scholes and the Quant Revolution: A Viewpoint

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ABSTRACT

As the world of quantitative finance celebrates fifty years of the seminal work of Black-Scholes, I take an overview of how this area has emerged in terms of reach, applicability and sophistication, and provide my take on the way forward. Black-Scholes had laid the foundation of pricing and risk management practices which has driven the unprecedented innovation in the financial markets, over the last five decades, which I discuss in the first half of this article. In the second half of the article, I present forth my views in what would constitute the thrust areas of research and innovation in financial engineering in the near future, identifying and dwelling upon high-frequency trading, sustainable finance and FinTech.

INTRODUCTION

The year 1973 is arguably the most notable timepoint in the history of quantitative finance, due to the two seminal papers on option pricing, authored by Black-Scholes and Merton. The former is hailed as turning point, which led to a rapid and unprecedented expansion of the quantitative finance industry, attaching hordes of mathematicians and physicists into the fold of "quants". While theories of option pricing predate the work of Black-Scholes, what propelled their work into prominence was the establishment of the option pricing formula in a precise and rigorous manner, offering a scientifically credible framework for not only pricing of options, but also pricing theory in general, including derivatives, credit instruments and insurance.

The theory of Black-Scholes also brought into the mainstream the asset pricing modelling approach of geometric Brownian motion and the thesis of Louis Bachelier. The approach of option pricing has found great relevance in financial risk management practices, as a consequence of the identification of return and risk being the two foundational pillars of investment theory, due to Markowitz in 1952. In fact, Markowitz's modern portfolio theory is still widely used, bearing testimony to the resilience and robustness of the approach.

The fifty years of Black-Scholes has seen many milestones beyond the realm of what might have been envisioned at that point of time. Accordingly, in this article, I will highlight some of the important progress in

the area of quantitative finance, followed by a narrative on what in my view represent the current trends in financial engineering.

DEVELOPMENTS IN QUANTITATIVE FINANCE

In order to have a clarity on option pricing mechanism, we highlight the key characteristics of option as a financial derivative, namely, that it provides the holder (or buyer) of the option the right (but not the obligation) to buy or sell an underlying asset (such as a stock) from or to the writer (or seller) on or before a pre-determine future data, for a pre-specified price. The right to buy or sell the underlying asset constitute a call or a put option, respectively. Further, if the option can be executed (or exercised) any time on or before the pre-determine future date (expiration) then it is called an American option, while execution being permitted only at the expiration is called a European option. It is evident that in all scenarios the writer of the option is placed at a disadvantageous position given that they are under obligation without any concurrent right. This begets the question as to why one would want to write an option (in the first place) in such a seemingly losing proposition. And the answer lies in that the leverage enjoyed by the holder of the option comes at an up-front premium (known as the price of the option) which has to be paid to the writer of the option.

This is precisely the genesis of the work due to Black-Scholes, in that they were able to provide a closed form formula for determine the price of European type options, in terms of parameters known at the time of initiation of the option contract itself. What is more interesting, both from mathematical perspective as well as hedging (a risk-management approach) is the notion of replication strategy, which essentially means that the pricing of the option is done in such a manner (using the replication strategy) that the contingent liability for the writer of the option at the time of expiration will always equal the value of a "replicating portfolio" created and continuously reshuffled by the writer of the option using an initial investment which is exactly equal to the price of the option, which they receive upfront from the holder of the option.

An important mathematical idea that emanated from the option pricing theory (also as a result of the concept of the replicating strategy) is the risk-neutral probability (a direct application of the measure theory). The option pricing was then obtained using the evaluation of the expectation of contingent claim in a risk-neutral probability space.

Another important (and natural ally) of the concept of pricing is the portfolio theory. Portfolio theory provides the template for not only asset picking, but also asset allocation and a continuous process of performance analysis. This area initiated by the seminal work of Markowitz saw significant contribution from the likes of Sharpe, Lintner and Tobin. The mathematical framework for portfolio theory is very accessible, relying on mathematics at basic undergraduate level, including matrix theory and optimization, which leads to the

concepts of the efficient frontier and the Capital Asset Pricing Model (CAPM). As markets mature, asset management practices adopted by quants tend to become more passive, relying on the fundamental concepts of modern portfolio theory. In fact, the Sharpe ratio remains an important benchmark in the performance analysis practices.

Given the ever-expanding universe of financial derivatives and the concurrent shift of banking systems from the traditional commercial banking (with primary activities of accepting deposits and extending loans) towards investment banking, a robust (and continuously adaptive) risk-management framework is an integral part of the modern banking system. The key component of the global financial risk management practices are the Basel regulations. These regulations which began with capital structure in case of credit risk, progressively included capital provisions in case of market as well as operational risk, both resulting from the expanding scope of investment banking practices and consequent evolving risk factors. The 2008 financial crisis resulted in recognition and introduction of regulations pertaining to both liquidity and leverage. Currently, the Basel-III regulations are in effect, with Basel-IV regulations being rolled out from January 2023, and by 2027 banks will be required to hold at least 72.5% of the amount evaluated based on the standardized model, as capital, notwithstanding what is suggested by the internal models of the bank.

CURRENT TRENDS IN QUANTITATIVE FINANCE

Today, quantitative finance has become very diversified in terms of both the financial innovation, as well as the mathematical approaches. In this article, I would like to focus on three areas, which in my view are representative of the current trends in "quant", namely, high-frequency trading, sustainable finance and FinTech. The adoption of algorithmic trading (using quantitative models), as the predominant strategy can be traced back to Renaissance Technologies (with the celebrated mathematician Jim Simons at the helm), which has reportedly achieved sustained spectacular returns over the last four decades. Today many firms employ individuals from STEM background, who in turn act as the drivers of the unprecedented recent growth in high-frequency trading. The quant industry has been focusing (with a sense of urgency) on adoption of practices focused on sustainable finance, with the initiates in sustainable investment being greatly influenced by Environmental, Social and Governance (ESG) rating firms such as Morgan Stanley Capital International (MSCI), Sustainalytics and Carbon Disclosure Project (CDP). The FinTech industry is driven in continuous manner, greatly by a rapid shift to digital economy, a very successful example of which is the Unified Payments Interface (UPI), particularly in the paradigm of its wide adoption at an individual consumer level.

High-Frequency Trading

As the markets mature, one expects that it becomes more and more difficult for the portfolio performance to surpass the market performance. Fund management in such markets, consequently tend to be more passive in nature. An alternative to achieving improved portfolio performance came by the way of Hedge Funds, which managed funds comprising of a variety of instruments and strategies including derivatives, leveraging and short selling. Hedge Funds offered better returns than traditional mutual funds and Exchange Traded Funds (ETFs), while "hedging" the returns against risk factors.

The shift of the market mechanism from the open outcry system to electronic markets, ushered in an era of algorithmic trading, in general and high-frequency trading, in particular. Algorithmic trading is a trading strategy involving automated programming-based execution of trades making use of various market parameters and often relying on tools from mathematical finance. Some commonly adopted strategies for algorithmic trading include pairs trading, delta-neutral portfolios, arbitrage and mean reversion.

High-frequency trading setups rely greatly on high-speed internet connectivity and high turnover rates, requiring strong fundamental understanding of market microstructure. These include Market Orders (MO), Limit Orders (LO) and Limit Order Book (LOB). Further, the structure of exchanges plays a key role in how the orders are processed. The narrative around high-frequency trading also is contingent on the degree of transparency that exchanges offer, thereby resulting in the distinction between lit and other electronic markets. In fact, the recent emergence of many electronic markets is often attributed to the rapid growth of high frequency trading activities and the jury is still out on the matter of impact of high frequency trading on practice of market making and greater liquidity.

Sustainable Finance

The sense of global urgency when it comes to climate change and its impact, obviously has a significant impact on the financial sector, leading to rapid evolution and developments in sustainable finance. One key milestone in this direction is the Principles of Responsible Investing, whose genesis lies in a gathering of 2005, at the initiative of the then Secretary General of UN, Kofi Annan. Consequently, there has been an exponential growth in sustainable finance driven Asset Under management (AUM), which today runs into trillions of dollars. This has also been accompanied by a concurrent growth in terms of ESG regulations, globally.

ESG risk management practices is still in the process of evolution, with a variety of ESG rating entities providing their services. However, the specific ESG factors, as well as their weightage, still varies significantly amongst the providers of ESG scores, with the emphasis still being on corporate ESG data. ESG scoring relies on tree-based algorithms followed by normalization, so as to enable comparative interpretation of ESG scores across sectors. Today well-established engineering and data science methods, such as Shannon entropy, confusion matrix, Markov chain and transition matrix, have found their presence in the ESG rating practices.

Investment theory based on modern portfolio theory is being revisited now, in the paradigm of sustainable finance. These include refining well-established notions of efficient frontier, Capital Market Line (CML), CAPM and Sharpe Ratio, through the lens of sustainable investment requirements. A huge interest is being generated in green instruments, such as green bonds, sustainability bonds and transition bonds. Investment linked risk management strategies are increasingly coming into the mainstream risk management practices, relying on physical environmental parameters, making it imperative that risk measures and capital requirements become a part of the Basel framework, at the earliest. There is a highly diverse set of thought process being engaged in now, when it comes to determination of a universally accepted risk measure, including carbon intensity, dynamic risk measures and measure of greenness. Finally, the transition risk modeling needs examination to address questions pertaining to the effectiveness of carbon taxes and emission trading schemes.

FinTech

Financial Technology or FinTech is representative of the transition from traditional mechanism to technology driven methods in the delivery of financial services, relying increasingly on the usage of Data Science and Artificial Intelligence. In order to have insights into the world of FinTech, it would be prudent to delve into the structure of the global financial system and its pain points. The current financial structure is a result of legacy practices, especially when it concerns the notions of money, assets and liabilities.

One needs to examine, in particular, the characteristics of payments, both domestic, as well as cross border. In case of the former, the process of settlement is often cumbersome and consequently error prone. In case of cross border payments, the current system is hierarchal (which some may consider akin to bureaucracy), an unintended consequence of which is the existence of informal money transfer setups. A lot of these pain-points in the existing payment structure, has a potential solution in the adoption of blockchain technology, and a consequent transition from centralized to distributed ledgers. From a mathematical perspective, this area has adopted well-established cryptographic approaches, relying predominantly on abstract algebra (fields and rings) and number theory (including elliptic curves).

The most visible application of blockchain technologies, arguably, is cryptocurrencies (predominantly Bitcoin, Ethereum and Ripple). The charisma surrounding cryptocurrencies, especially when it comes to cross border transactions, acted as a catalyst in the development of Central Bank Digital Currencies (CBDCs) (used by central banks and narrow banks), as well as wide acceptance of wallets as a preferred and convenient form of day-to-day transactions. The emergence of digital currencies and wallets, notwithstanding the great interest generated, is still faced with several challenges, in terms of operability, privacy and (eventually) scalability aspects, questions which we hope would be addressed with clarity in the near future.

CONCLUDING REMARKS

The quant industry has arguably witnessed an expansion on a time-scale that is more accelerated, in comparison to other sectors of the economy, as well as other disciplines of learning. This itself bears testimony to the opportunities and also challenges this industry has to offer. The milestones, as noted in the section on "Developments" is more or less robust and well tested, thereby laying the foundation for the new innovations in the areas identified in the section on "Current Trends". In case of the former, namely the traditional well-established quantitative approaches, the educational setup (as it exists) provides for many learning resources, for individuals desirous of the joining the quant workforce. However, in case of the latter, in my opinion, three exists three main sources of challenges, namely, human resources, industry adoption and policy formulation (as well as implementation).

At this stage, the areas of high-frequency trading, sustainable finance and FinTech are still evolving, in terms of preparedness of human resources via existing educational setups. Industry adoption of these areas has resulted in challenges, due to existence of many pain points (in FinTech) and somewhat limited clarity (in Sustainable Finance), with the latter being focused on the urgency of development and adoption of universal industry practices. Finally, at the policy level, and consequent implementation, the global economic setup is working on the challenges towards realization of collective and equitable growth, especially when it comes to Sustainable Finance, within the broader scope of dialogues on climate risk mitigation.

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