Understanding the complex dynamics of financial markets through microsimulation

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Summary

Financial markets are among the most complex systems in reality and many phenomena observed in real markets are still poorly understood. Specifically, prices of traded products often exhibit extraordinary changes or unexpected patterns seemingly not induced by external causes, instead arising endogenously. This seriously challenges neoclassical economics which depicts markets as efficient machines that automatically seek out an equilibrium state in which irregularities in prices are mainly caused by external factors.

We focused on two of the most active financial markets, which share many features with other types of markets. The dynamics of the financial assets in these markets is characterized by some 'stylized facts', which are counterintuitive and contrary to the expectations of traditional financial theories. In stock markets, high frequency returns follow a non-Gaussian heavy-tailed distribution. In addition, high and low absolute returns tend to group together, a phenomenon termed 'volatility clustering'.

In options markets, there is a phenomenon called 'volatility smile', which is intrinsically related to the well-known and widely used Black-Scholes model for options pricing. The only unobservable parameter of this Nobel Prize winning model is the volatility of the underlying asset which by nature should be independent of the strike of the option contract, i.e. the price at which the option can be exercised at expiry. However, the volatilities required to match option prices quoted in real markets, i.e. implied volatilities, exhibit a remarkable curvature against strikes and may change strongly over time. Understanding the origin of this phenomenon has eluded the financial world for more than two decades.

The ubiquity of the stylized facts has stimulated a great deal of academic work for developing models more consistent with empirical time series. For ex-

ample, ARCH and GARCH models have been developed to reflect the changes in volatility. Similarly, in the derivative finance literature, many new alternatives to the Black-Scholes model have been proposed, mainly through relaxing some of the restrictive assumptions of the Black-Scholes framework. However, although these models can reproduce the stylized facts to some extent, they do not explain the origin of the complex dynamics of financial markets.

During the last few decades, behavioral approaches and agent-based methods have been widely applied to the study of market dynamics. They can explain many phenomena in a more plausible way than traditional financial theories do. However, most of these theories or models either do not systematically examine the mechanisms underlying the phenomena or are too complicated to be helpful for clearly identifying the causal relations of the mechanisms. In addition, the majority of the existing agent-based models focus on stock markets, while very few center on derivatives markets.

In view of these facts, our general motivation was to apply a bottom-up approach for studying the mechanisms through which the complex market dynamics is generated. We studied a financial market by modeling its individual elements and their interactions. The macro-dynamics of the system would ultimately emerge from the micro-behavior. In particular, we aimed to develop microsimulation models with simple structures that can reproduce the extraordinary patterns observed in financial time series. In order to offer important insights into the complex dynamics, we adopted an approach of successive complexification of the basic models.

Our stock-market model can reproduce, in a simple and robust manner, the main characteristics observed in empirical financial time series. Heavy-tailed return distributions due to large price variations can be generated through agents' imitating behavior. Volatility clustering is related to the combined effect of a fast and a slow process: The evolution of the influence of external facts such as news and the evolution of agents' trading activity respectively. In a general sense, these explanations appear to be common among the most well-established microsimulation models which have confirmed the main characteristics of financial markets.

Our options-market model agrees with empirical studies in respect to the shape and dynamic properties of the volatility smile. It suggests that the smile phenomenon is a natural consequence of speculative and arbitrage trading behavior and the heterogeneity and variation of speculative traders' expectations about the future. Specifically, the variance of directional speculators' expected prices determines the level of the implied volatility curve and the corresponding mean controls the skewness. Other heterogeneous speculators such as spread traders and traders using the Black-Scholes model can alter the shape of the smile. However, our simulation results with regard to trading volumes suggest that these speculators are not the dominant traders in real markets. Overall, these results confirm that individual trading preferences indeed play a critical role in the formations of options prices.

The general insight we have obtained from this work is that the complex dynamics of financial markets can emerge naturally from market participants' simple and ordinary behavior and their interactions. Our results confirm that microsimulation is an indispensable method for deeply studying financial market complexity. The remaining challenge lies in applying our findings to the day-to-day practice of derivative valuation and financial risk management.