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Non-Extensive Statistical Mechanics and Heavy Tails in Financial Log-Returns: Stocks, FX, and Cryptocurrencies

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Non-extensive statistical mechanics, introduced by Tsallis, provides a robust theoretical framework for describing complex systems characterized by long-range correlations and extreme events. In the context of financial markets, the q-Gaussian distributions that emerge from this formalism constitute a natural generalization of Gaussian approaches, as they are capable of capturing the heavy tails that characterize empirical log-returns, which standard Gaussian models fail to reproduce. In this work, we present a comprehensive empirical validation of a hybrid model that integrates non-extensive statistical mechanics with a microscopic agent-based dynamics characterized by herding behavior. The simulated log-returns are compared with high-frequency data from stocks in developed and emerging markets, revealing that the q-Gaussian model reproduces the heavy tails of liquid markets with remarkable accuracy, whereas the Gaussian model better captures the statistical structure of assets such as oil and exchange rates, additionally exhibiting a surprising degree of temporal scale invariance. An additional finding is the identification of an intrinsic limit to the validity of the hybrid model, arising from its own dynamics without the need for externally imposed criteria. The analysis is further extended to high-frequency cryptocurrency and foreign exchange pairs, where the systematic variation of the parameter q enables the quantification of the degree of non-extensivity inherent to each market. The results indicate that the Tsallis formalism not only successfully captures the heavy tails of the assets considered, but also that the parameter q serves as a quantitative indicator of the degree of statistical complexity inherent in each asset class, raising the question of the potential universality of this approach across financial markets as diverse as digital and traditional ones.

Primary author: RUEDA MANTILLA, Juan Diego (Universidad Nacional de Colombia)

Co-author: QUIMBAY HERRERA, Carlos José (Universidad Nacional de Colombia)

Presenter: RUEDA MANTILLA, Juan Diego (Universidad Nacional de Colombia)

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