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A Robust Hybrid Semi-Analytical Analysis of Time-Fractional Black–Scholes European Option Pricing Model Emerging in Financial Markets

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Abstract

Fractional differential equations generalize the classical concept of integer-order derivatives, enabling the incorporation of memory effects and historical states into mathematical models. The ability of fractional-order models to more accurately represent time-dependent interactions and long-range dependencies observed in real-world systems has attracted considerable attention in recent years. These equations provide valuable tools for the mathematical analysis of phenomena that cannot be adequately described by classical differential equations, while offering greater flexibility in modeling complex systems [1]. One of the prominent applications of this approach is found in fractional option pricing models developed within the field of financial mathematics. Classical option pricing theory is fundamentally based on the assumptions of arbitrage-free markets and dynamic hedging strategies; however, it has been extended by various researchers through the introduction of fractional derivative concepts. In this context, the fractional Black–Scholes model for European option pricing allows for a more realistic evaluation of option values by incorporating memory effects and irregular price dynamics observed in financial markets. Such models have found widespread applications in risk management, derivative pricing, financial engineering, and investment strategy development, and continue to constitute an important area of research in modern financial theory [2, 3]. Analytical and semi-analytical techniques play a crucial role in solving fractional differential equations. Among these, integral transform methods have proven to be effective tools for reformulating differential problems into more tractable mathematical forms. The Kashuri Fundo Transform, introduced in recent years, together with the Homotopy Perturbation Method, which is widely employed for nonlinear problems, has been recognized as a powerful framework for obtaining highly accurate approximate solutions [4]. In this study, the applicability of these complementary techniques is investigated for a fractional-order financial model. The obtained results demonstrate that the proposed approach simplifies the solution procedure and facilitates the construction of convergent solutions. Therefore, it may provide an alternative and effective solution framework for fractional models encountered in financial mathematics.

***K*eywords** Black-Scholes European option pricing · Kashuri Fundo transform · homotopy perturbation method · fractional Black-Scholes model

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