A CAUSAL DISCOVERY AND EVT-ENHANCED STOCHASTIC VOLATILITY FRAMEWORK FOR ROBUST FINANCIAL RISK FORECASTING

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ABSTRACT

This study proposes a novel data-driven machine learning (ML) framework for predictive modeling in financial time series, integrating state-of-the-art techniques from stochastic volatility modeling, causal discovery, and extreme value theory (EVT). Extending beyond conventional approaches that rely solely on Gaussian assumptions, our method incorporates fat-tailed distributions, dynamic volatility, and causal inference to achieve more robust forecasting performance under market uncertainty. We leverage advanced stochastic volatility models combined with reinforcement learning-based causal structure learning to identify root causes of market disturbances. Moreover, extreme value theory is employed to accurately capture tail risks, enhancing risk measurement and Value-at-Risk (VaR) estimation. We demonstrate the efficacy of our approach through empirical experiments on historical S&P 500 index returns, supplemented by simulated datasets. Our results confirm that integrating fat-tailed stochastic volatility models and causal discovery mechanisms outperforms traditional GARCH and baseline SV models in both in-sample fitting and out-of-sample predictive accuracy. Additionally, the EVT-based tail modeling significantly improves the stability and accuracy of VaR estimation, particularly under extreme market conditions. The proposed framework can be readily applied to various financial assets, enabling practitioners and researchers to better identify, predict, and manage financial risks.

Keywords: Stochastic Volatility, Extreme Value Theory, Reinforcement Learning, Causal Discovery, Value-at-Risk.