Revealing The Fragility Beneath: Engineering Dynamic Multi-Layer Financial Networks for Modeling Systemic Risk and Shock Propagation

Uffa, Nyel (School: Eden Prairie High School)

Modern financial markets are complex, interconnected systems where localized stress can amplify into system-wide instability. Traditional risk measures, such as volatility indices, quantify uncertainty at individual asset levels but often fail to capture the structural pathways of contagion. This limitation hinders the anticipation of systemic crises, such as the 2008 financial crisis and the COVID-19 market collapse. This research models financial markets as dynamic, multi-layer networks where assets are nodes and statistically significant dependencies form time-evolving edges. Using historical daily price data, rolling correlation-based networks were constructed with fixed window lengths to generate dynamic snapshots. Network-level metrics—including density, clustering, and centrality—quantified structural market fragility. To examine causal vulnerability, a shock propagation engine simulated localized disturbances and measured amplification, reach, and temporal persistence across network layers. Results demonstrate that market stress is characterized by increased network density and centralization, indicating heightened systemic fragility. Shock simulations reveal non-uniform propagation, with specific assets acting as disproportionate risk transmitters. Crucially, crisis regimes exhibited lower variability in shock persistence, suggesting more reliable contagion pathways. These network-derived indicators capture dimensions of instability invisible to traditional scalar measures. By integrating network science and applied mathematics, this research provides a novel, interpretable framework for analyzing instability. The methodology is generalizable to risk propagation in other complex systems, including epidemiology, infrastructure resilience, and systems engineering

Awards Won:

The Consortium for Mathematics and its Applications: Honorable Mention In-Kind

American Mathematical Society: Honorable Mention and One-Year Membership to AMS (for 5 projects with up to 3 team members per project)

Non-Trivial Ventures: Non-Trivial Fellowship Scholarship