National Seminar on Applications of Mathematics in Modern Science and Technology (20th May-2026)
Organized by: S.R. Government Arts & Science College Kothagudem, Telangana

International Journal of Science, Engineering and Technology
ISSN: 2348-4098, P-ISSN: 2395-4752

Mathematical Interpretation of Economic Behaviour and Market Trends

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Abstract- Mathematical frameworks have become indispensable for interpreting the complexity of economic behavior and market trends, yet many traditional models fail to capture the heterogeneous, adaptive, and non-linear nature of real-world economies. This paper synthesizes four powerful mathematical domains that have enabled significant recent advances: behavioral game theory and equilibrium learning, agent-based modeling with reinforcement learning, advanced time-series forecasting using wavelet-hidden Markov models and deep learning, and network-theoretic approaches to systemic risk. Drawing exclusively on peer-reviewed studies from 2025–2026, we demonstrate how these methods are applied to concrete economic problems—from green technology transitions and financial volatility prediction to macroeconomic stabilization and contagion dynamics in banking networks. Key findings include: (i) novel online optimization algorithms that solve previously intractable equilibrium problems under incomplete information; (ii) the Homo procrasticus model, which introduces effort-based thresholds to explain inertia and default reliance; (iii) mean-field reinforcement learning that corrects structural biases in standard agent simulations, converging to competitive equilibrium; (iv) wavelet-enhanced multimodel frameworks that reduce stock market forecast errors by 20–40% across bull, bear, and sideways regimes; and (v) a continuous Navier-Stokes framework for financial networks, showing that post-COVID regulatory reforms reduced systemic contagion decay by 26%. The paper concludes with an integrated three-layer analytical framework (micro-behavioral, meso-interaction, macro-structural) that bridges individual decision rules, emergent market dynamics, and systemic risk propagation. These mathematical interpretations move economics beyond retrospective description toward predictive, prescriptive, and policy-relevant analysis, offering directly applicable tools for risk management, policy design, and market forecasting.

Keywords: Economic behavior, market trends, game theory, agent-based modeling, reinforcement learning, time-series forecasting, network contagion, systemic risk.

I.INTRODUCTION

Contemporary economics increasingly depends on rigorous quantitative frameworks. Yet, traditional models often struggle to capture the complexity of human decision-making and market dynamics. This paper synthesizes four mathematical domains that have enabled significant recent advances: behavioral economic modeling, multi-agent simulation, time-series forecasting, and network analysis of systemic

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risk. We draw on peer-reviewed studies from 2025–2026, emphasizing their applicability to real-world economic problems rather than purely theoretical contributions.

II. MATHEMATICAL FRAMEWORKS FOR ECONOMIC BEHAVIOR:

Game Theory and Equilibrium Learning:

Strategic interaction remains central to economic analysis. However, deriving equilibrium strategies in games with incomplete information is notoriously challenging. Analytical solutions exist only for simple models under restrictive assumptions. The European Research Council's ELUD project (2025) is developing novel online optimization and learning methods to solve equilibrium problems previously deemed intractable. These methods accommodate diverse distributional assumptions and utility functions, allowing behavioral motives to be incorporated. Importantly, learning algorithms do not necessarily converge to equilibrium; they can generate cycles or even chaotic behavior, and ELUD provides the mathematical tools to understand when learning leads to stable outcomes and when it does not.

Behavioral Models: Prospect Theory and Homo Procrasticus:

Prospect theory—the foundational model of decision-making under risk—assumes symmetric probability cumulation relative to a reference point. A 2025 study introduces an asymmetry in decision-weight construction, creating a reference model that allows verification of parameter interactions across cumulative prospect theory specifications, resolving long-standing inconsistencies in empirical applications.

Traditional economic models assume rational utility maximization, yet humans systematically avoid effort—cognitive and physical—even at the expense of optimal outcomes. The Homo procrasticus model (2025) incorporates explicit effort costs into utility functions, treating effort as a distinct, threshold-activated cost. This mathematical formulation explains inertia, reliance on defaults, and minimal compliance. It distinguishes between cognitive and physical effort aversion, offering a unified framework for analyzing why people delay tasks, rely on heuristics, or fail to capitalize on beneficial opportunities.

Multi-Agent Systems for Market Simulation:

Agent-based models (ABMs) represent a fundamental departure from representative-agent frameworks. In Leoni and Catola's 2025 ABM of green technology transitions, firms operating in a spatial market decide whether to supply brown or green products based on relative performance. Computational simulations confirm that all three market structures—all-brown, all-green, and mixed—can endogenously emerge depending on average consumer preferences. Notably, supply-side policies (environmental taxes) ensured faster convergence to all-green markets than demand-side subsidies.

The SGIC (Speculation Game with Information Cascade) model (2025) advances financial ABMs by integrating Self-Organized Criticality (SOC) through a sand-pile model. Within a small-world network, agents interact and propagate information. The model reproduces not only key stylized facts (fat tails, volatility clustering) but also order flow imbalance—a critical indicator of herd behavior previously absent from similar models.

Reinforcement Learning for Economic Agents:

Standard single-agent RL simulations incentivize agents to become "manipulators" of their environment rather than "takers" of aggregate conditions. Chen and Zhang (2025) identify this structural bias within a search-and-matching model, showing that standard RL learns a non-equilibrium, monopsonistic policy. They propose a calibrated Mean-Field Reinforcement Learning (MFRL) framework that embeds

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a representative agent within a fixed macroeconomic field and adjusts the cost function to reflect economic opportunity costs. Their iterative algorithm converges to a self-consistent fixed point where agent policy aligns with competitive equilibrium.

III. MATHEMATICAL INTERPRETATION OF MARKET TRENDS:

Time-Series Decomposition with Hidden Markov Models

Financial time-series are nonlinear, nonstationary, and regime-dependent. The wavelet-enhanced multimodel framework (2025) integrates discrete wavelet transform (DWT) with machine and deep learning architectures (Random Forest, SVR, LSTM, GRU). Applied to BIST 100, S&P 500, and Shanghai Composite indexes (2015–2025), Daubechies-4 wavelet decomposition captures multiresolution temporal patterns. A three-state Gaussian hidden Markov model identifies bull, bear, and sideways regimes based on risk-adjusted returns, stratifying out-of-sample results. Wavelet-enhanced configurations reduced forecast errors by 20–40 percent across all indexes, with Diebold–Mariano tests confirming statistical significance within each regime.

Deep Learning for Volatility Forecasting

The M2VN (Multi-Modal Volatility Network, 2025) unifies time-series features with unstructured news data. By combining open-source market features with news embeddings generated by Time Machine GPT (a point-in-time LLM ensuring temporal integrity) and an auxiliary alignment loss, M2VN consistently outperforms existing baselines, offering practical value for risk management in dynamic markets.

Cross-Market Graph Neural Networks:

CMGM (Cross-Market Graph Modelling, 2025) models relationships between stocks within the same market and across different markets (cryptocurrencies, commodities, bonds, forex). Using specialized graph layers, CMGM designs super- and sub-graphs leveraging market-state dependencies: standard correlation, volatility-adjusted, skewness/kurtosis-adjusted, and dynamic correlations evolving over time. Evaluated on U.S. stocks, commodities, forex, bonds, and cryptocurrencies, CMGM achieved the lowest MAE (0.01148) and MSE (0.00026) among baseline methods.

IV. MATHEMATICAL APPROACHES TO POLICY AND SYSTEMIC RISK

Optimal Control in Macroeconomic Policy:

The Itô–Lévy economic growth model (2025) derives optimal investment-consumption policies under uncertainty by modeling capital dynamics through a stochastic differential equation driven by Lévy processes. Using Hamilton–Jacobi–Bellman optimization, the framework yields closed-form solutions for GDP dynamics. Jump components amplify jump-induced volatility and lead to higher elasticity of capital compared to diffusion-only cases.

A macroeconomic stabilization model (2025) extends the classic Leitmann–Wan framework, combining long-run output growth with short-run Keynesian/Monetarist deviations. Optimal control algorithms determine approximate optimal reactions to demand and supply shocks. A dynamic game formulation between government (fiscal policy) and central bank (monetary policy) is solved for noncooperative feedback Nash equilibrium and Pareto optimal solutions, providing insights into policy coordination and conflict.

Network Theory for Systemic Risk:

Wei et al. (2025) reconstruct the dynamic network of the global stock market at 4,927 time points using a self-dynamics and inter-dynamics model with orthogonal basis decomposition. Unexpected events

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enhance dynamic interactions among indices. Average path weight and clustering coefficient emerge as effective indicators of systemic risk, with the model outperforming Granger test, GARCH-BEKK, and DY framework methods.

Kikuchi (2025) develops a continuous functional framework for analyzing contagion dynamics in financial networks, extending the Navier-Stokes approach to network-structured spatial processes. Distress propagates as a diffusion process, with contagion decay depending on algebraic connectivity. Applying this to European banking data (2018–2023), network connectivity declined by 45%, implying a 26% reduction in contagion decay—suggesting that post-COVID-19 regulatory reforms effectively reduced systemic vulnerability. Networks exhibited lognormal rather than scale-free degree distributions, indicating greater resilience than previously assumed.

V. AN INTEGRATED FRAMEWORK FOR ECONOMIC ANALYSIS

The reviewed methodologies converge on a three-layer analytical framework:

1. **Micro-behavioral layer:** Behavioral models (prospect theory, Homo procrasticus) establish individual decision-making rules, with game theory providing equilibrium conditions under strategic interaction.
2. **Meso-interaction layer:** ABMs and RL models simulate emergent dynamics from heterogeneous agents learning and adapting over time. Recent work by Hashimoto et al. (2025) shows that combining heterogeneous preferences (risk aversion, time discounting) with learning mechanisms enables realistic fat-tailed price fluctuations and volatility clustering.
3. **Macro-structural layer:** Network analysis characterizes systemic risk propagation. Advanced simulation paradigms integrate hierarchical knowledge architectures into agents, achieving 13.29% deviation in crisis scenario simulation and lower mean-square error in futures price prediction under normal conditions.

VI. CONCLUSION

Mathematical techniques have transitioned from descriptive econometrics to generative, predictive, and prescriptive frameworks. Behavioral models now incorporate explicit cognitive costs. Multi-agent simulations reproduce emergent market dynamics with 90% confidence. Deep learning architectures reduce forecast errors by up to 40%. Network theory quantifies systemic risk with PDE-based continuous models. The integration of these approaches—combining micro-behavioral foundations with meso-level interaction and macro-network structure—defines the frontier of mathematical economics.

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