Modeling the Components Of An Economy As A Complex Adaptive System

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Problem Statement
• Simplifying assumptions of current economic theory disregard interrelated structure and feedback between components
• Conventional financial modeling relies on autoregressive integrate moving average (ARIMA) techniques to make forecasts. These depend on historical trends and correlations to make future predictions
• Complex systems science is used widely in natural sciences, few studies have applied it to economic behavior

Question
Can elements of the economy be modeled as a complex adaptive system?

Objective
Model stock market as a fully-connected, dynamic network using a system of differential equations and an exogenous influencing factor

1. Conjecture Model

2. Collect & Process Data

Sources
• U.S. Bureau of Economic Analysis
• U.S. Bureau of Labor Statistics
• Standard & Poor’s
• St. Louis Federal Reserve

Format
• Quarterly data to capture long-term trends in market
• 17 years of data (69 quarters)

3. Create Functional Form

Change in System State of S&P 500

Endogenous Factors

\[ \dot{S} = f(G, F, D, B, R, S) + g(F) \]

Euler’s Forward Method:

Change in current state

\[ \Delta s_i = \frac{\Delta s_i}{\Delta t} \]

4. Solve for Model Coefficients

Minimize

\[ f(x) = \sum_{i=1}^{n} \sum_{j=1}^{m} (y_{ij} - \hat{y}_{ij})^2 \]

subject to

\[ b_y \leq 1 \]

\[ b_y > 0 \]

\[ d_i \leq 0 \]

\[ a_{ij}, b_{ij}, d_i \in R \]

5. Analyze Results

Euler’s Forward Method projects system dynamics forward, using a single input and its own past predicted values to accurately forecast 17 years of stock market performance. Model satisfies mean-field theory, as reflected by normally-distributed residuals

Hypothesis testing fails to reject conclusion that Euler curves are statistically identical to actual data for five of six model components

5% Prediction Interval Baseline Overlap with Baseline?

GDP Per Capita

As Reported Earnings (Bill S)

Dividends (Bill S)

Buybacks (Bill S)

Retained Quarterly Earnings (Bill S)

S&P 500 Index (Price Level, $)

S&P 500

Model facilitates study of hypothetical “what if” scenarios, illustrating what would have happened had the Federal Reserve raised interest rates more quickly following the Great Recession. Prediction intervals evaluate alternative system end states compared baseline Euler curves

Findings
• Fitting to the data, rather than the slopes or secants, results in the most accurate portrayal of model behavior
• Euler curves can be used to accurately predict system performance over long time horizons
• Utility of model to predict system performance forward and study system components retroactively was established

Contributions
• Model is a proof of concept that financial markets can be modeled as complex adaptive systems
• A system of differential equations was used to simulate market behavior and predict turning points in the system
• Model demonstrates how financial markets can be forecasted over long time horizons with relative accuracy

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