Finance and complex systems: Leverage as nonlinear feedback

SFI Complex Systems Summer School

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J. Doyne Farmer
Santa Fe Institute
Financial markets provide a perfect laboratory in which to study social evolution

• Define “evolution” as any process with descent, variation, and selection.

• Social evolution differs in detail, but has the same three elements. But what is evolving?

• Of course, comparison should not be taken literally: Important to understand both similarities and differences.
What is biggest difference between social and biological evolution?

People can think.

• In this respect, biology is easier: Accurately modeling thinking humans is very difficult.
  – Innovation
  – Strategic anticipation

• Limiting cases (tractable but far-fetched):
  – Perfect rationality
  – Zero Intelligence

• ZI is like biology (if you define “ZI” so as to include rules of thumb).
Laws of markets?

- Are markets on other planets anything like those on earth?
- Prediction: They will have money, markets derivatives, ...
- They will obey many of same regularities as our markets do.
Market laws?

- Pareto’s Law for income, (exponential for body ?)
- Long-memory of supply and demand
- Power law for trading volume
- Relation between exponents of volume, S&D
- Anomalous scaling of firm size
- Laws of market impact
- Volatility = market impact = spread/2
- Power law for price fluctuations
- Equation of state of price statistics and order flow
- Distribution of mutual fund sizes
- Scaling of impact with market capitalization
- .... (another page or two)
Advantages of financial markets as laboratory of study

- Rapid timescale of evolution
- Huge data sets
- Highly constrained environment with accurately recorded record of human behavior.
Market efficiency?

Strength of two proprietary predictive signals (1975 - 1998), (measured as smoothed average % correlation between signal and future weekly return)

Signal 1:

Signal 2:
Statistical mechanics of human systems

Many human systems exhibit emergent phenomena generated by low level interactions of many individuals.

In constrained settings these exhibit consistent laws, like physical systems.

Challenge to make microscopic models of actors.

Two strategies:

- Find situations where institutional constraints dominate human choice.
- Find situations where we can use simple heuristics to characterize human reasoning.
Economics has stressed the importance of strategic interaction, often at the expense of fully modeling the institutions that modulate these interactions.
Risk under open-ended evolution

- Reducing risk by controlling the environment is a tried and true evolutionary strategy.
- Increasing complexity makes fitness increasingly endogenous (coevolution, niche construction)
- Makes optimization difficult
  - fitness determined by actors (self and others)
- Extrapolation rather than interpolation
- Effort to reduce risk can create risk
Hedge fund/leverage model

• With Stefan Thurner and John Geanakoplos

• Agents
  – hedge funds (long only value investors)
  – noise traders reverting to a fundamental value
  – investors choosing between hedge fund and cash; base decisions on trailing performance of funds
  – bank lending to hedge funds
Hedge funds can use **leverage**, defined as ratio of value of holdings to their wealth. Maximum leverage is key parameter.

Hedge funds differ in their aggression, i.e. how much they buy for a given mispricing (slope).
Hedge fund wealth fluctuates
There are crashes
Evolutionary pressure favors more aggressive funds, but not exclusively
Leverage causes extreme stock price movements.
Leverage causes power law tail for stock returns

\[ P(r > R) \sim R^{-\gamma} \]
Extreme risk increases with leverage.
Leverage and volatility

When mispricing is small, funds lower volatility.
At maximum leverage they amplify volatility.
Extreme events caused by attempt to control risk.
Other examples: stop-loss orders, call options, ...
In an immediate sense, the act of controlling risk amplifies the risk (recall of loan by bank amplifies volatility, generates heavy tails).
Risk-return tradeoff

- First order: Leverage increases returns and risks equally.
- Second order: Extreme risks increase
- This is due to impact of actions taken to control risk on prices (impact on environment)
Standard bank risk control policy is counterproductive

- When $k > 0$, banks lower maximum leverage when historical volatility is higher.
- Results in more defaults.
Evolutionary pressure for higher leverage
Need to regulate leverage

- Evolutionary pressure drives funds toward increasing leverage.
- Causes increased defaults, more extreme events.
- Goldilocks principle: What leverage is “just right”? 
  - Peters: Kelly criterion suggests $\mu / \sigma^2$

- Social experiments: Recent crisis demonstrates need for regulation.
Let the bank leverage too

Network of banks and hedge funds

Multiple assets, derivatives, stop-loss

Optimal control of risk by banks and hedge funds

Evolution of strategies
How do we reduce risks?

Two basic approaches

- Distribute risks: Decentralize, decouple
- Keynes: Manage the economy macroscopically
- Not mutually exclusive

Not just a question for economics
Need to treat the economy as an evolving complex system

- Remarkable fact: There is no agent based simulation model of the economy!
- Lucas critique, falsification of Phillips curve
- Need to model interacting institutions
  - obvious approach: agent-based model
- Need to explain macroeconomy from microeconomic arguments (Axtell)