Finance and complex systems: Leverage as nonlinear feedback

SFI Complex Systems Summer School

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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)

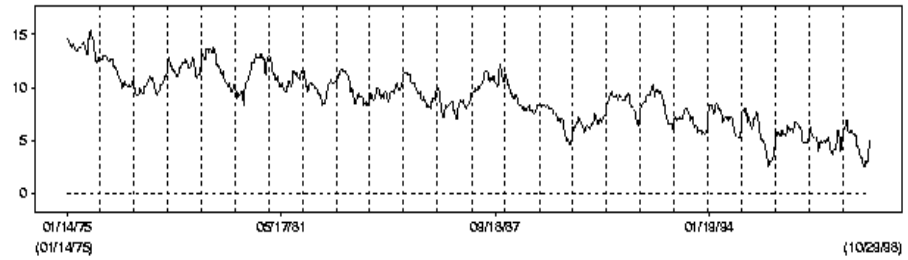
Advantages of financial markets as laboratory of study

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

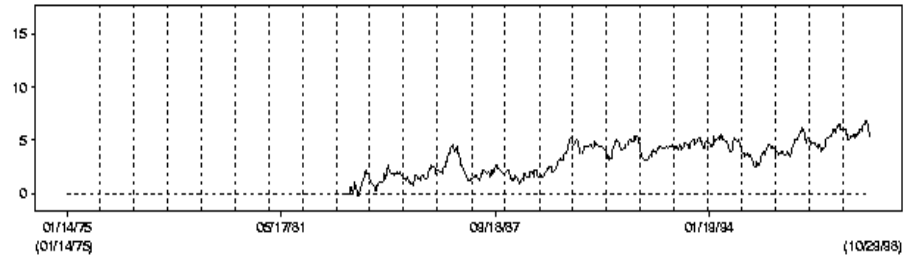
Market efficiency?

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.

Structure vs. strategy

- 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

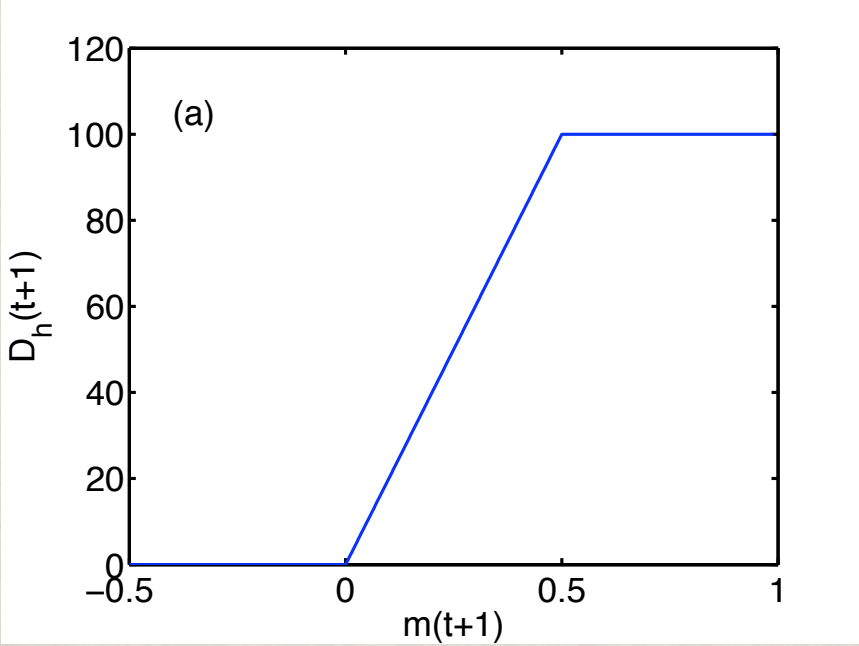
- Reducing risk by controlling the environment is a tried and true evolutionary strategy.
- Increasing complexity makes fitness increasingly endogenous (coevolution, niche construction)
- Makes optimization difficult
  - fitness determined by actors (self and others)
- Extrapolation rather than interpolation
- 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

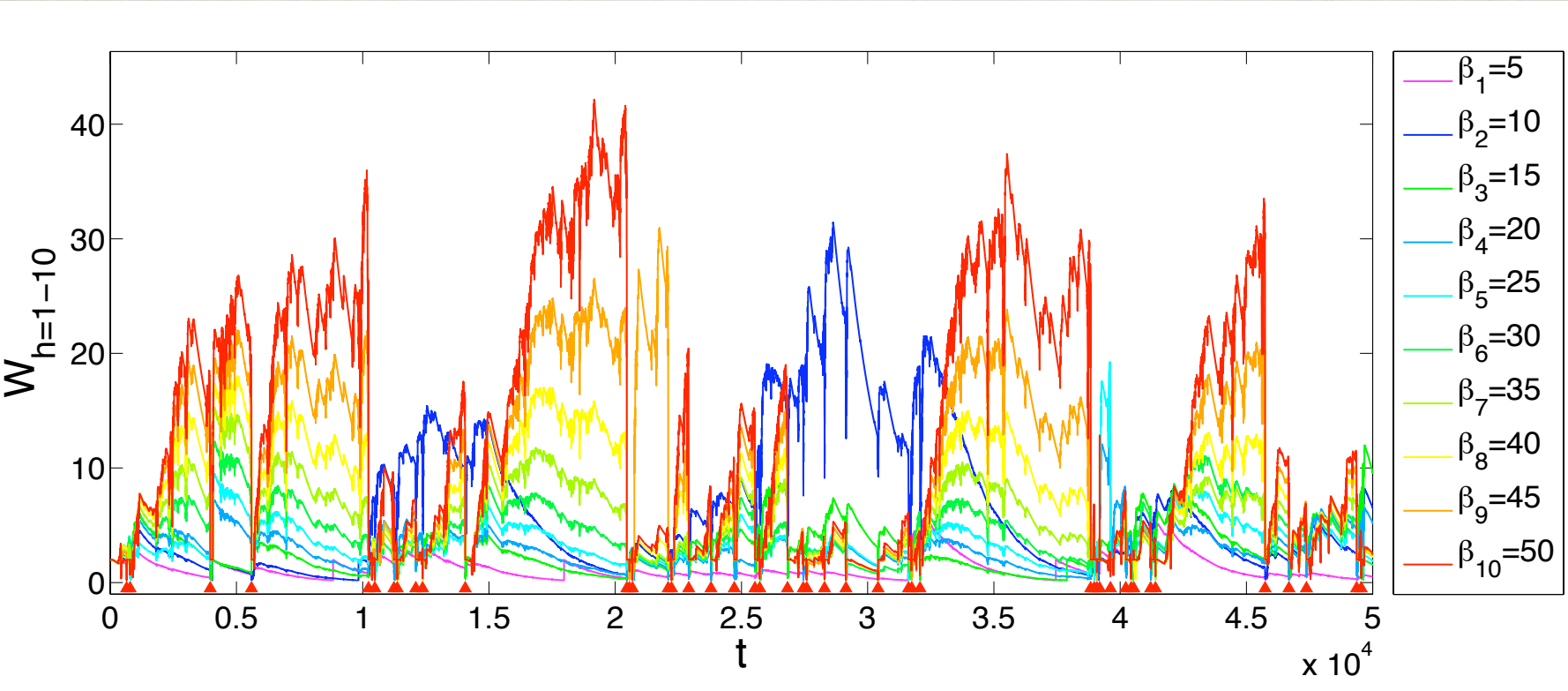
Hedge fund demand



mispricing

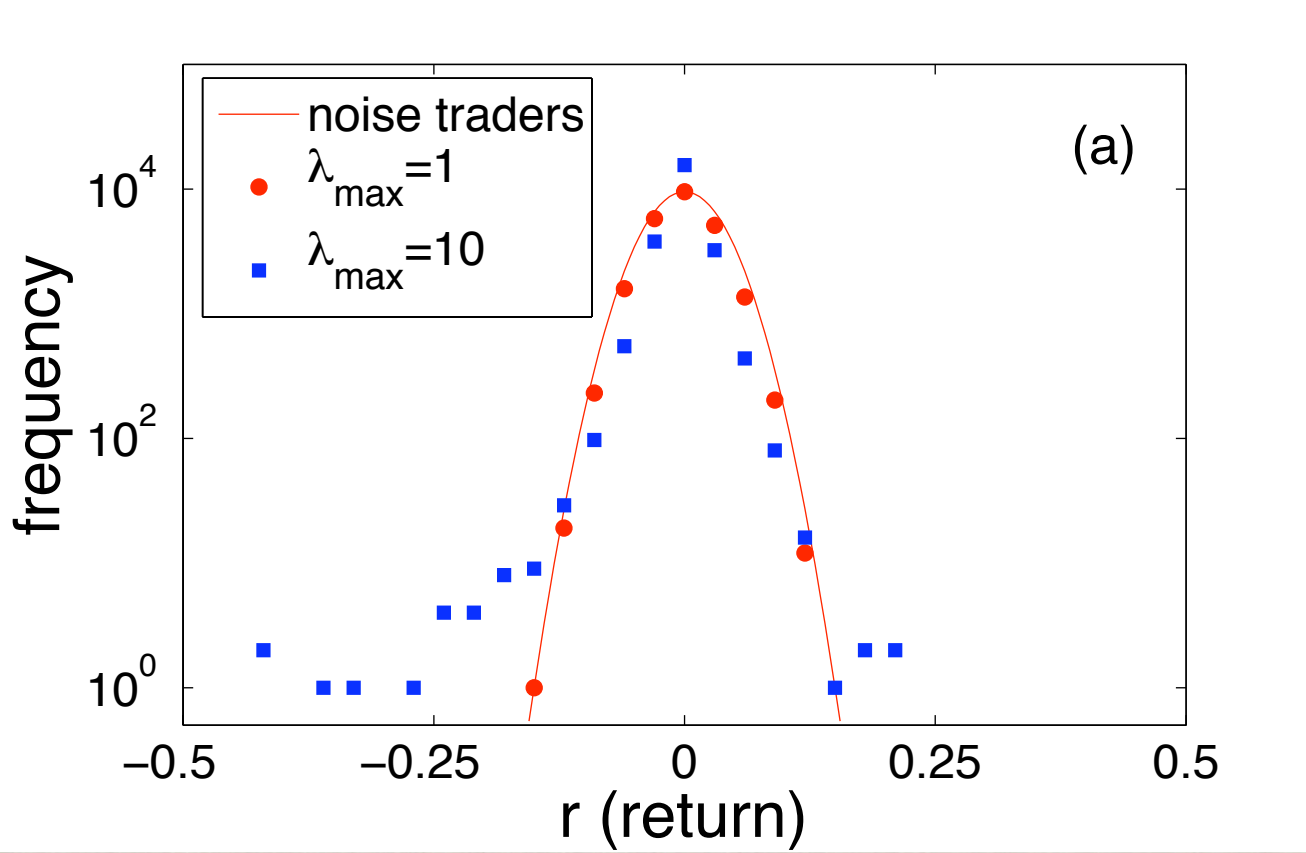
- Hedge funds can use *leverage*, defined as ratio of value of holdings to their wealth. Maximum leverage is key parameter
- Hedge funds differ in their aggression, i.e. how much they buy for a given mispricing (slope)

Wealth vs. time, 10 funds

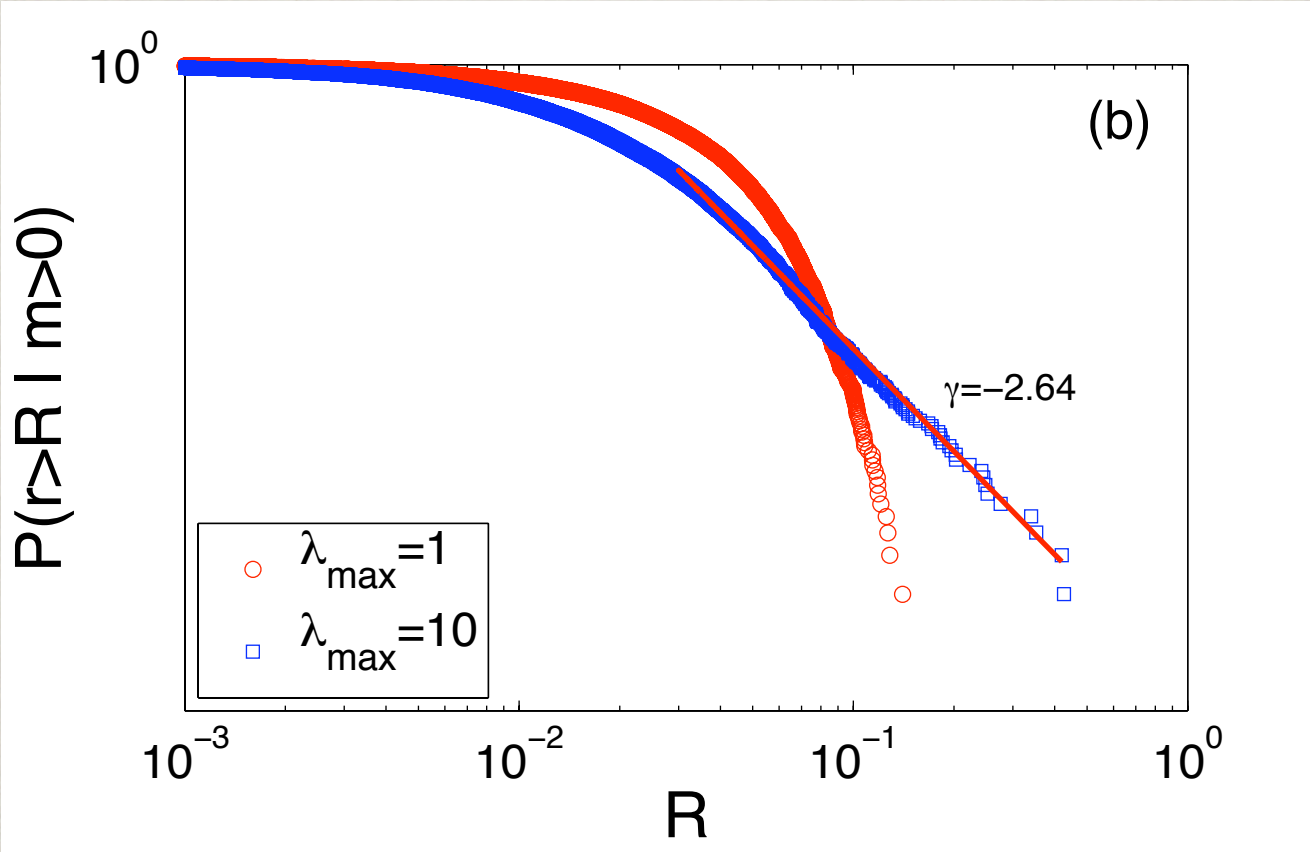


- Hedge fund wealth fluctuates
- There are crashes
- Evolutionary pressure favors more aggressive funds, but not exclusively

Leverage causes extreme stock price movements

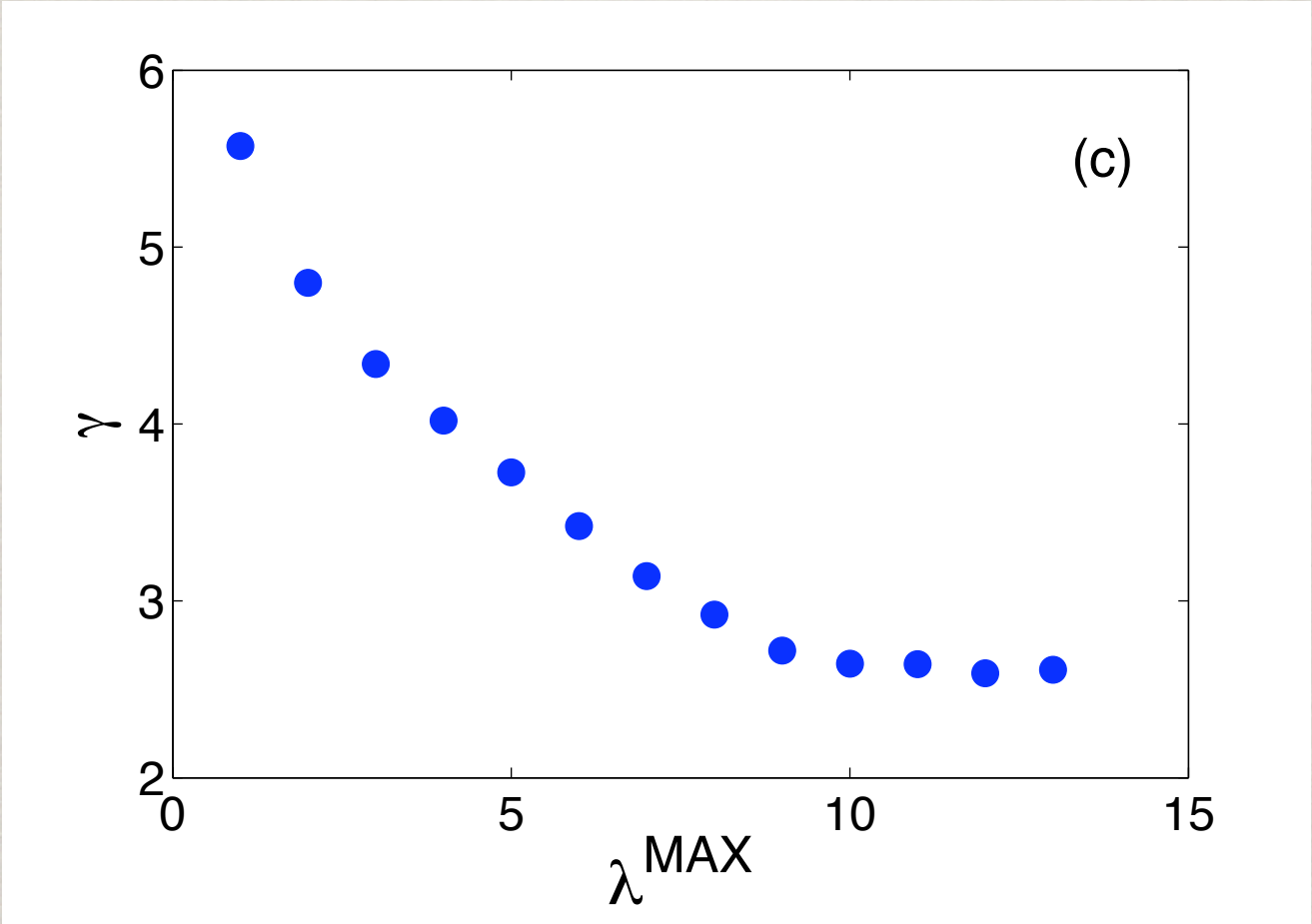


Leverage causes power law tail for stock returns



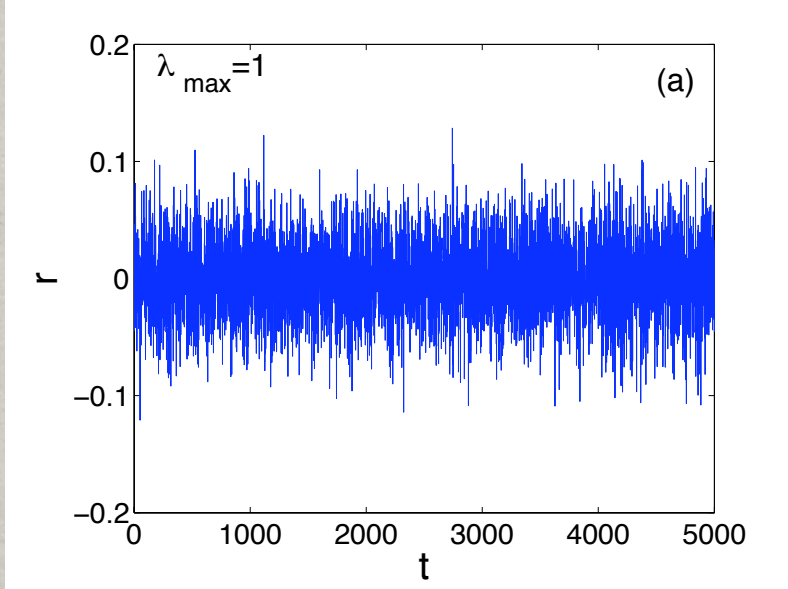
$$P(r > R) \sim R^{-\gamma}$$

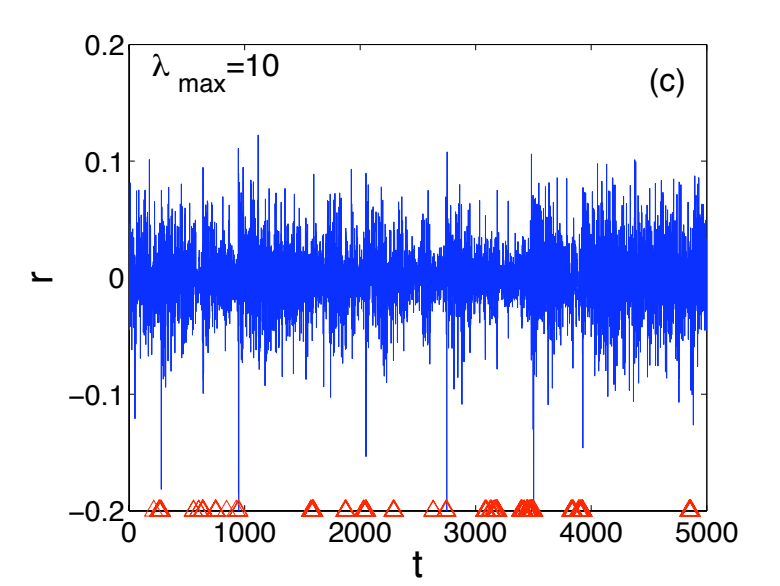
Extreme risk increases with leverage



Leverage and volatility

Stock returns vs. time

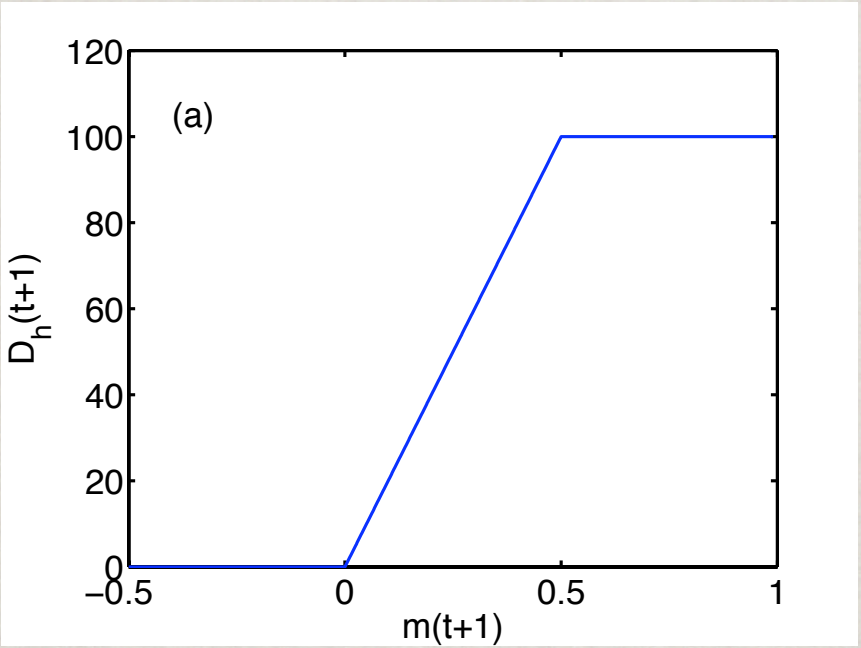




- When mispricing is small, funds lower volatility
- At maximum leverage they amplify volatility
- Extreme events caused by attempt to control risk.
- Other examples: stop-loss orders, call options, ...

Hedge funds

Hedge fund demand



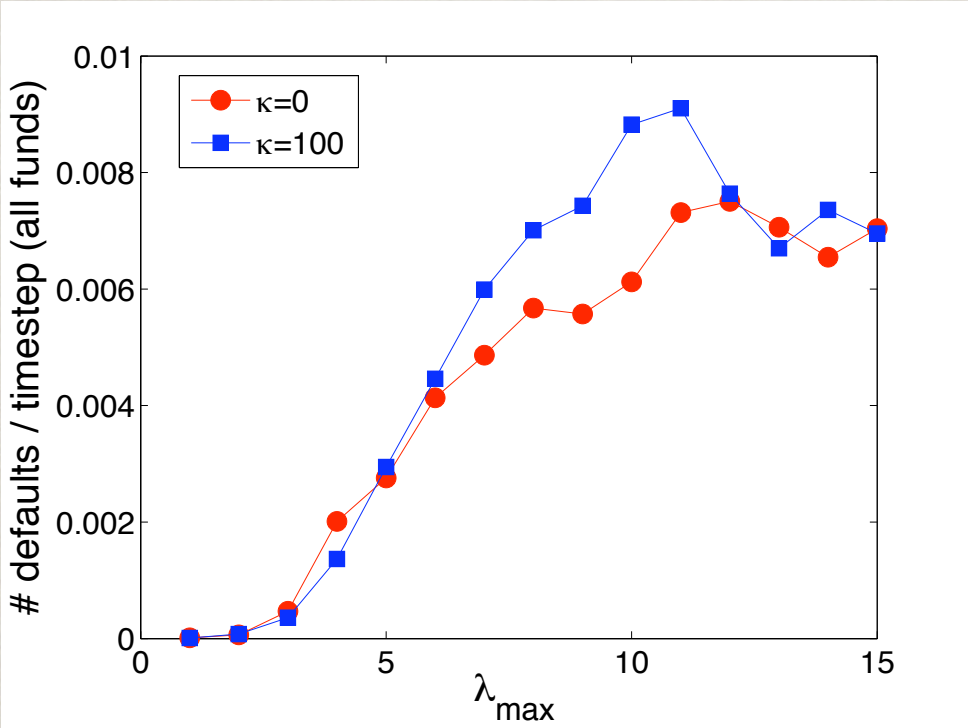
mispricing

- 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

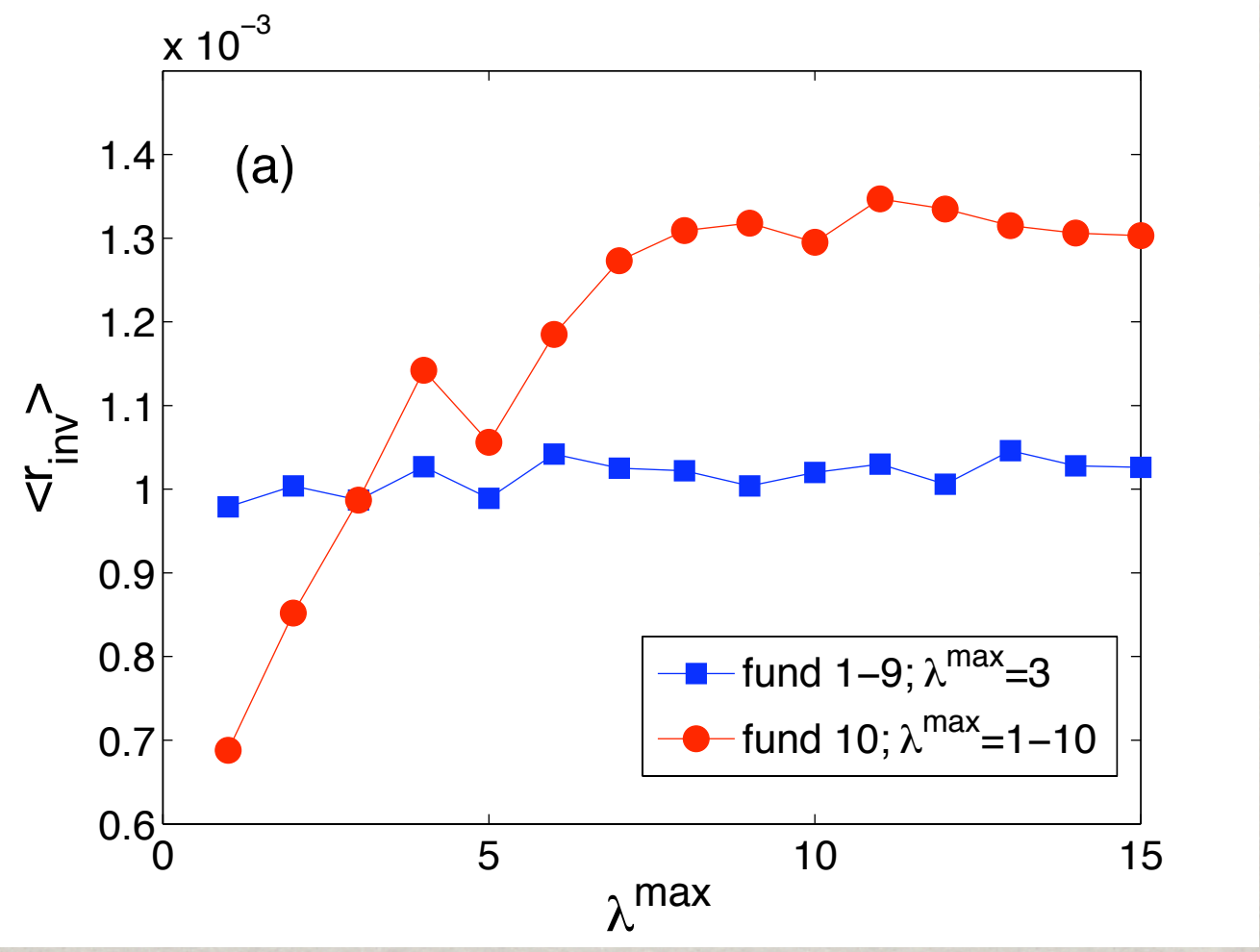
- First order: Leverage increases returns and risks equally.
- Second order: Extreme risks increase
- This is due to impact of actions taken to control risk on prices (impact on environment)

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 μ/σ^2
- Social experiments: Recent crisis demonstrates need for regulation.

Extensions

- 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

We are increasingly engaged in shaping our own environment

- 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)