Foundations of the future theory of economics

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Still dominant theory of economics

- Rational choice
  - All agents are omniscient
  - All agents are selfish, maximize highly unrealistic utility function
  - Markets clear
  - Price taking
  - Nash equilibrium
- 92.2 % of economists support this

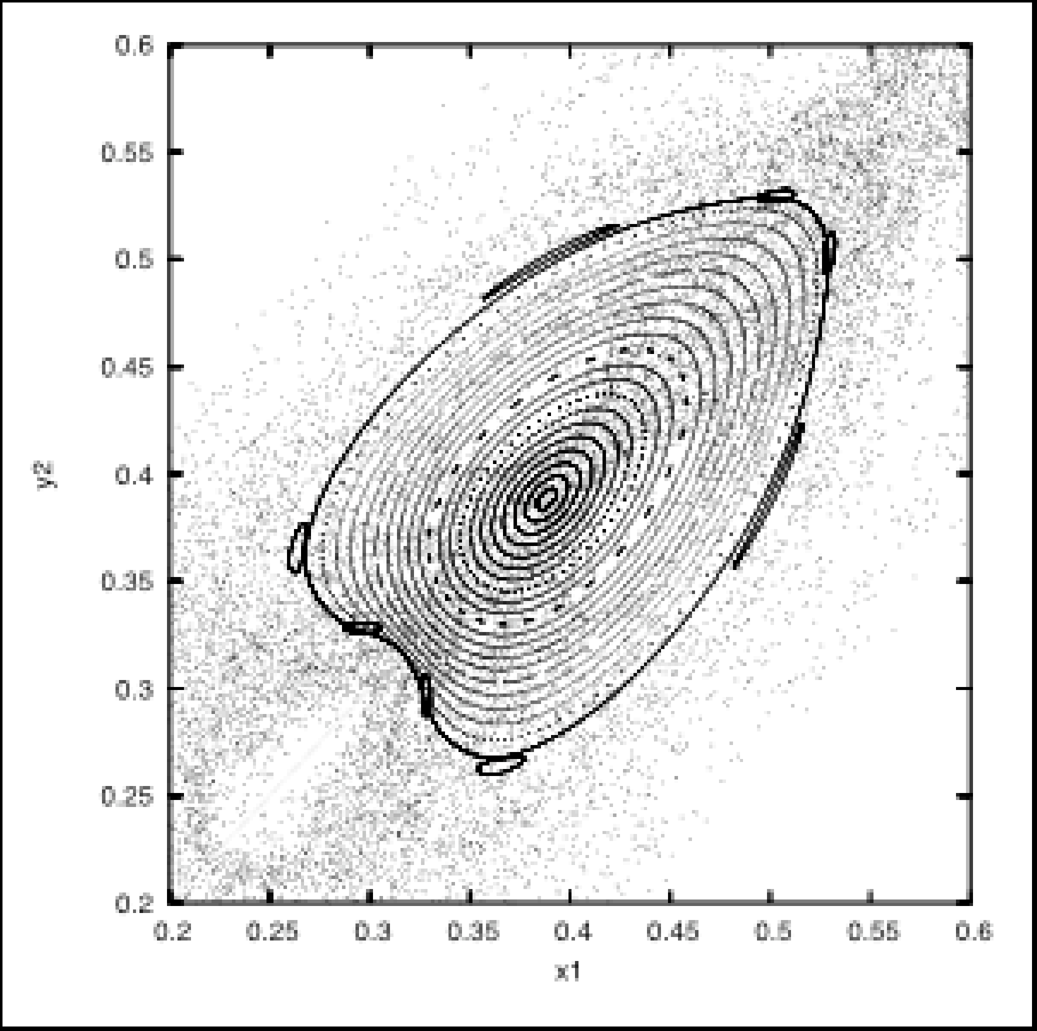
Modern economic research extends and perturbs the rational expectations paradigm (typ. modifying assumptions one at a time)

- Non-rational behavior
  - learning
  - behavioral anomalies
- Alternative utility functions
- Market imperfections
- Non-zero price impact of individual agents
- Evolutionary games

How to model agent behavior?

- Rational choice
- Econometrics
- Artificial intelligence and learning
- Behavioral economics (psychology, …)
- Experimental economics
- Zero intelligence
- Empirical behavioral

Learning to play rock, paper, scissors

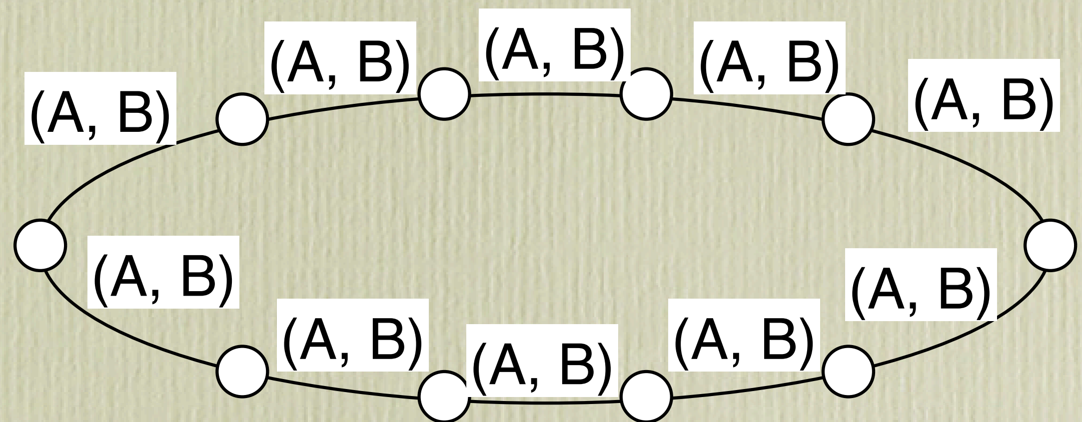


With Yuzuru Sato and Eizo Akiyama

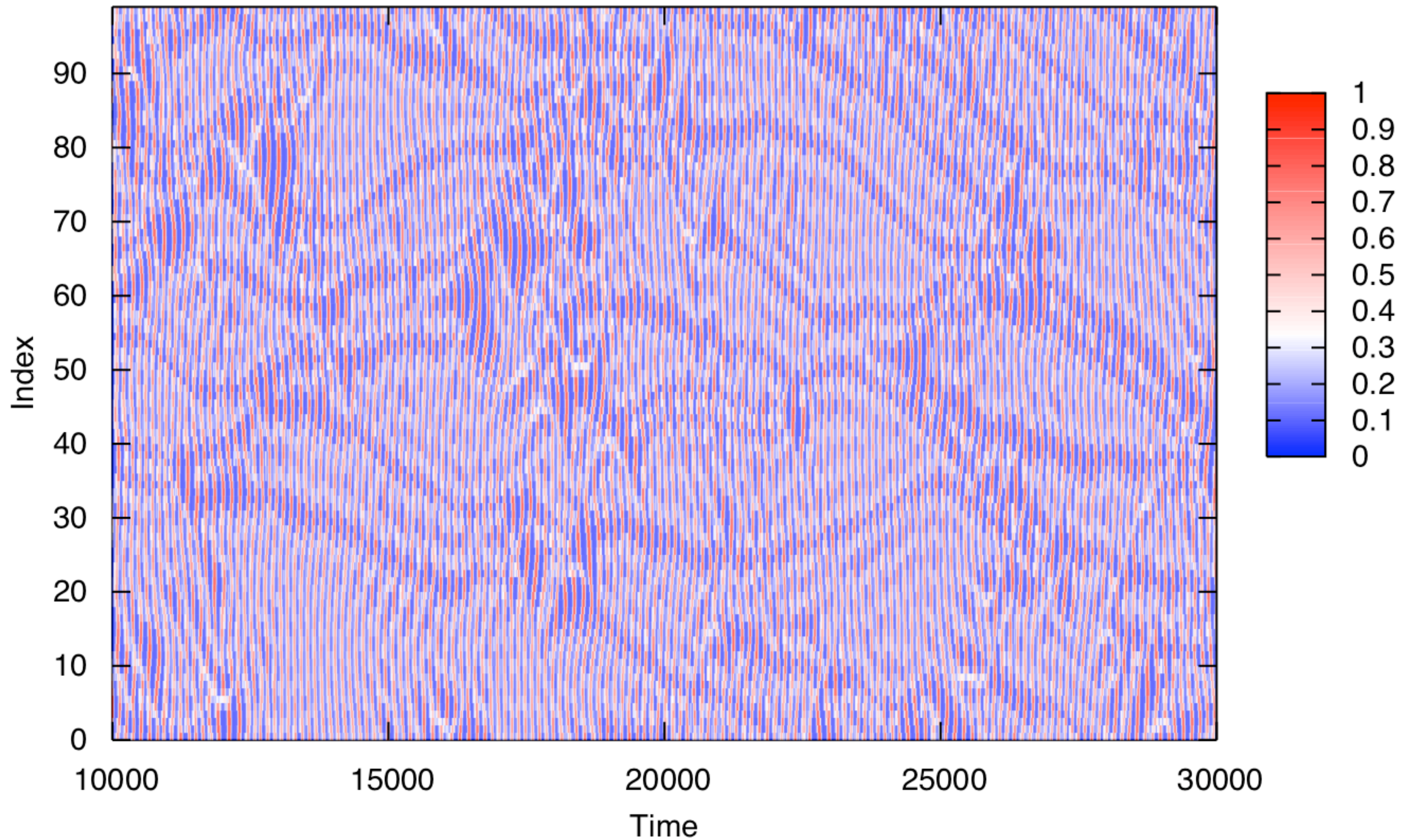
Ergodic hypothesis for games?

- Under some conditions it becomes impossible for any reasonable agent to find the Nash equilibrium of a game. Factors that contribute to this:
  - game is complicated
  - many players
  - payoffs are highly context dependent
  - players have inadequate information
- In this case trajectories become high dimensionally chaotic, and players resort to statistical rules of thumb.

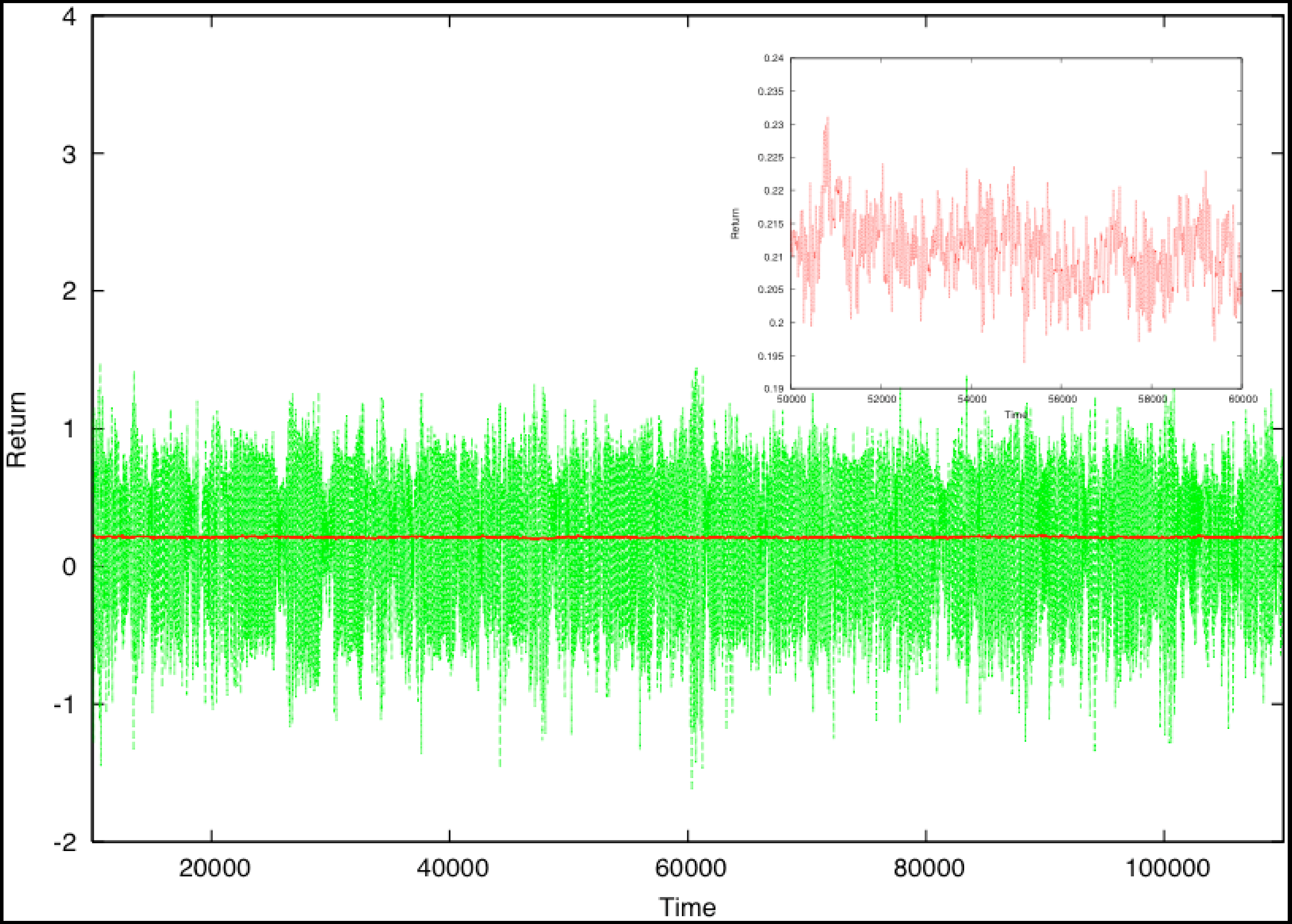
Rock-paper-scissors on a circle



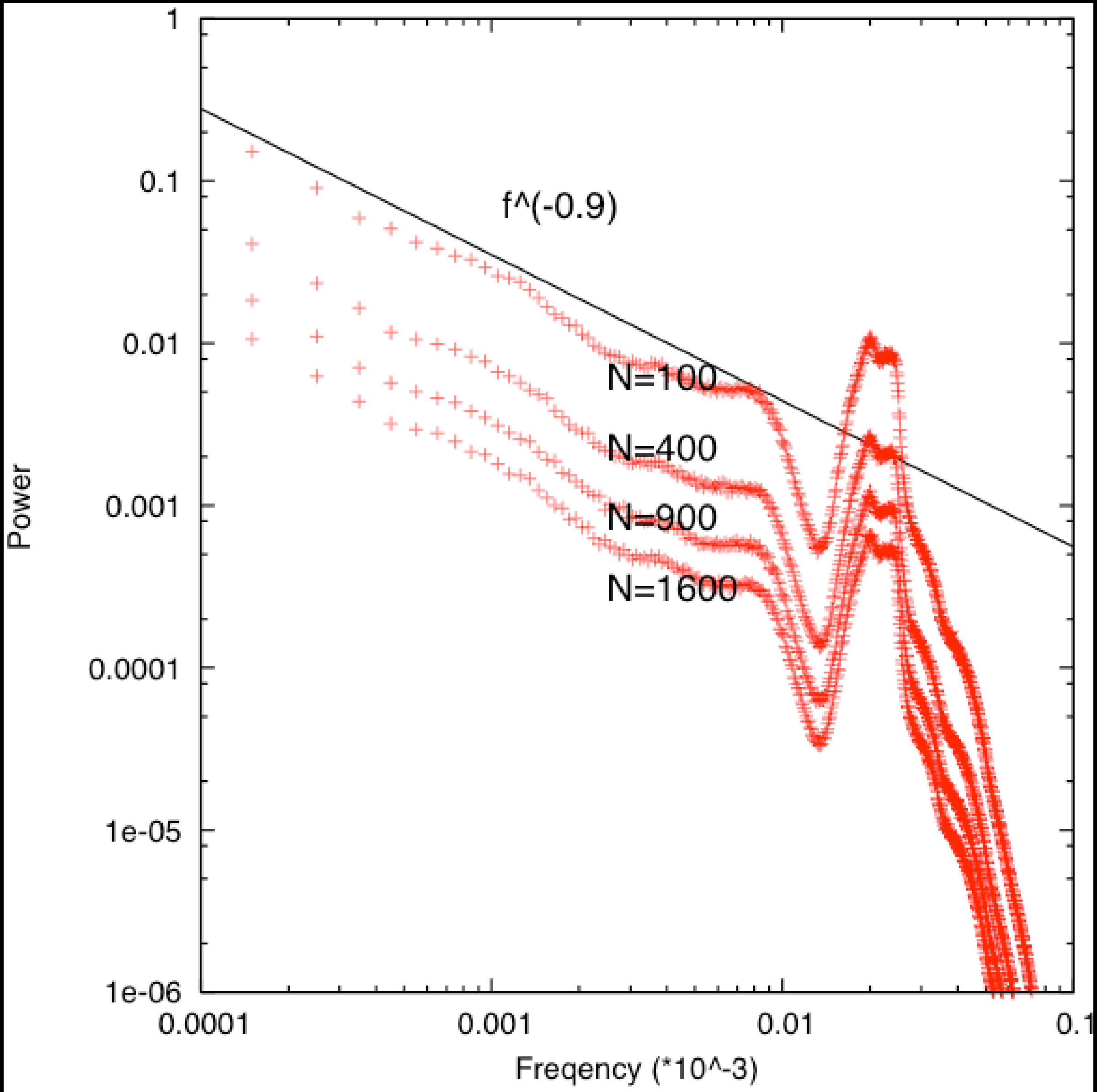
with Yuzuru Sato



Index
Time
0
10
20
30
40
50
60
70
80
90
10000
15000
20000
25000
30000
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0



Return
Time
4
3
2
1
0
-1
-2
20000
40000
60000
80000
100000
0.24
0.235
0.23
0.225
0.22
0.215
0.21
0.205
0.2
0.195
0.19
50000
52000
54000
56000
58000
60000



1
0.1
0.01
0.001
0.0001
1e-05
1e-06
Power
0.0001
0.001
0.01
0.1
Freqency (*10^-3)
f^(-0.9)
N=100
N=400
N=900
N=1600

Economics theory of the future

- Physics-like theory of near equilibrium behavior.
  - When economic conditions are only slowly varying (near punctuated equilibrium)
- Biology-like theory of evolution
  - Due to changing conditions, innovation, ... , economic conditions are sometimes far from equilibrium, and may change progressively.
- Difficulties in separating the two?

Physics-like aspects of economics

- Equilibrium
- Efficiency
  - Allocative (Pareto) efficiency
  - Informational efficiency
- Under current theory, no method to measure deviations from perfection
- Such deviations must exist!
  - If market is efficient, there is no possibility for profit making opportunities. But if there are no investors exploiting profit-making opportunities, then market cannot be efficient.
- No widely accepted non-equilibrium theory of economics.

Biology-like theory

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

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- 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.

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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).

In some respects finance is an easier forum to study evolution than biology

- Interactions are tightly constrained and more easily measurable.
  - Financial transactions vs. organism interactions
  - Money vs. energy
- Institutions that mediate financial interactions are simple and essentially mechanical.

Another possible advantage of finance as a medium to study

- Fitness may be easier to understand a priori
  - (e.g. fitness in engineering as given in design requirements is stated a priori)
  - Is there a notion of quality that can be defined without reference to reproductive success?
  - Does "survival of the fittest" make sense?

Not like biology -- need to cope with agent intelligence

Financial economics motivation for social evolutionary models

- Quantitatively resolve (numerous) failures of equilibrium theory
  - Fat tails, clustered volatility, disagreement of price and fundamental value, low influence of news, excess trading, diversity of financial strategies, rate of strategy evolution, …
- Huge practical/social importance: Design markets that minimize risk and transaction costs.
- Proof of principle: Blake Lebaron, “Calibrating an agent-based model”

Biology-like evolutionary theory

- Species -> agents with given strategies
- Population -> capital of agents
- Selection -> accumulation of capital
- Innovation -> creation of new strategies
- Environment -> factors driving price formation (which determines profits).
  - Lots of co-evolution and niche construction!

Market force, ecology, evolution

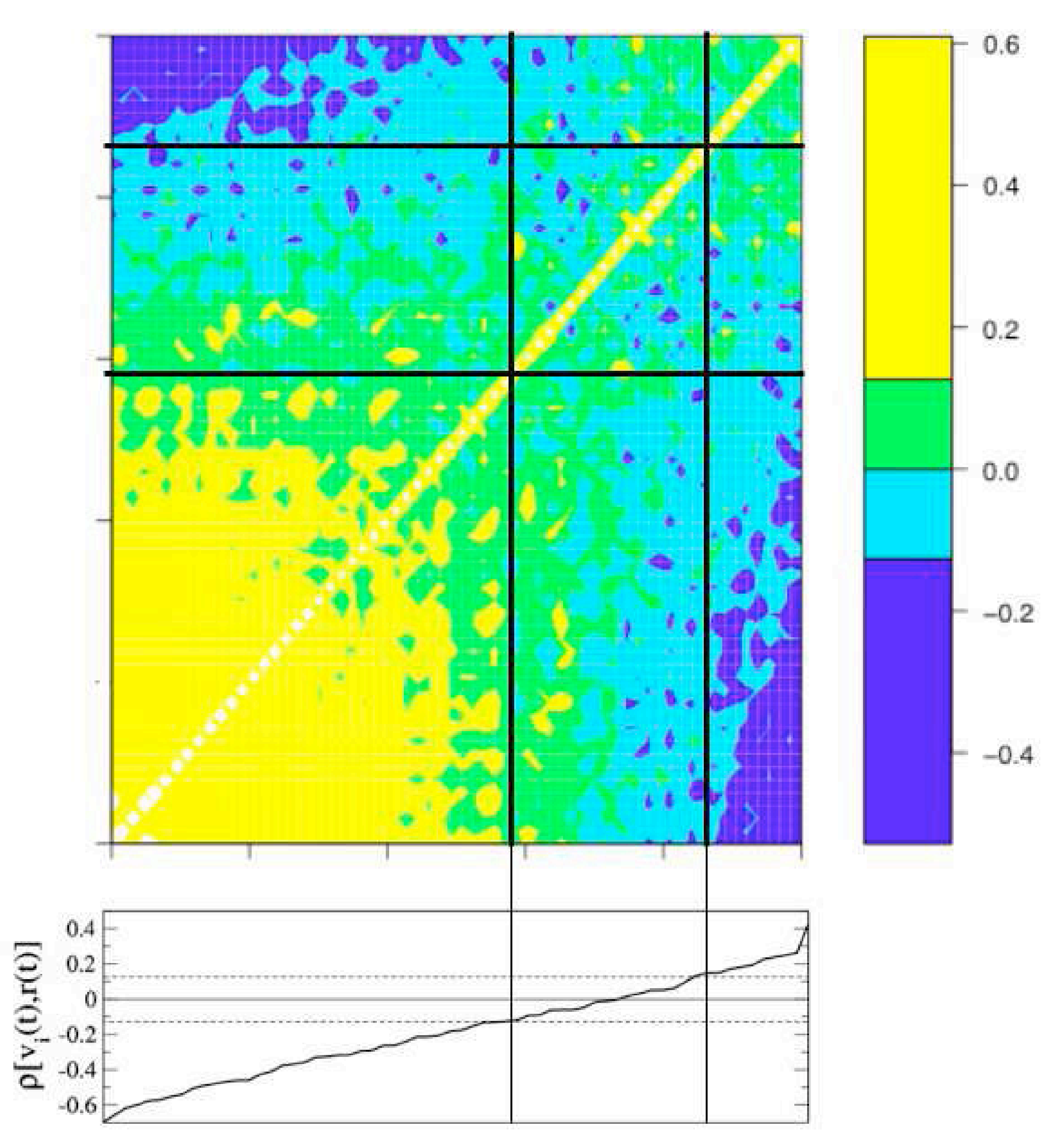
- Key principle is market impact.

$$\Delta p_t = \sum_i f_I(\Delta x_i(p_t, p_{t-1}, \ldots, I')) + n_t$$

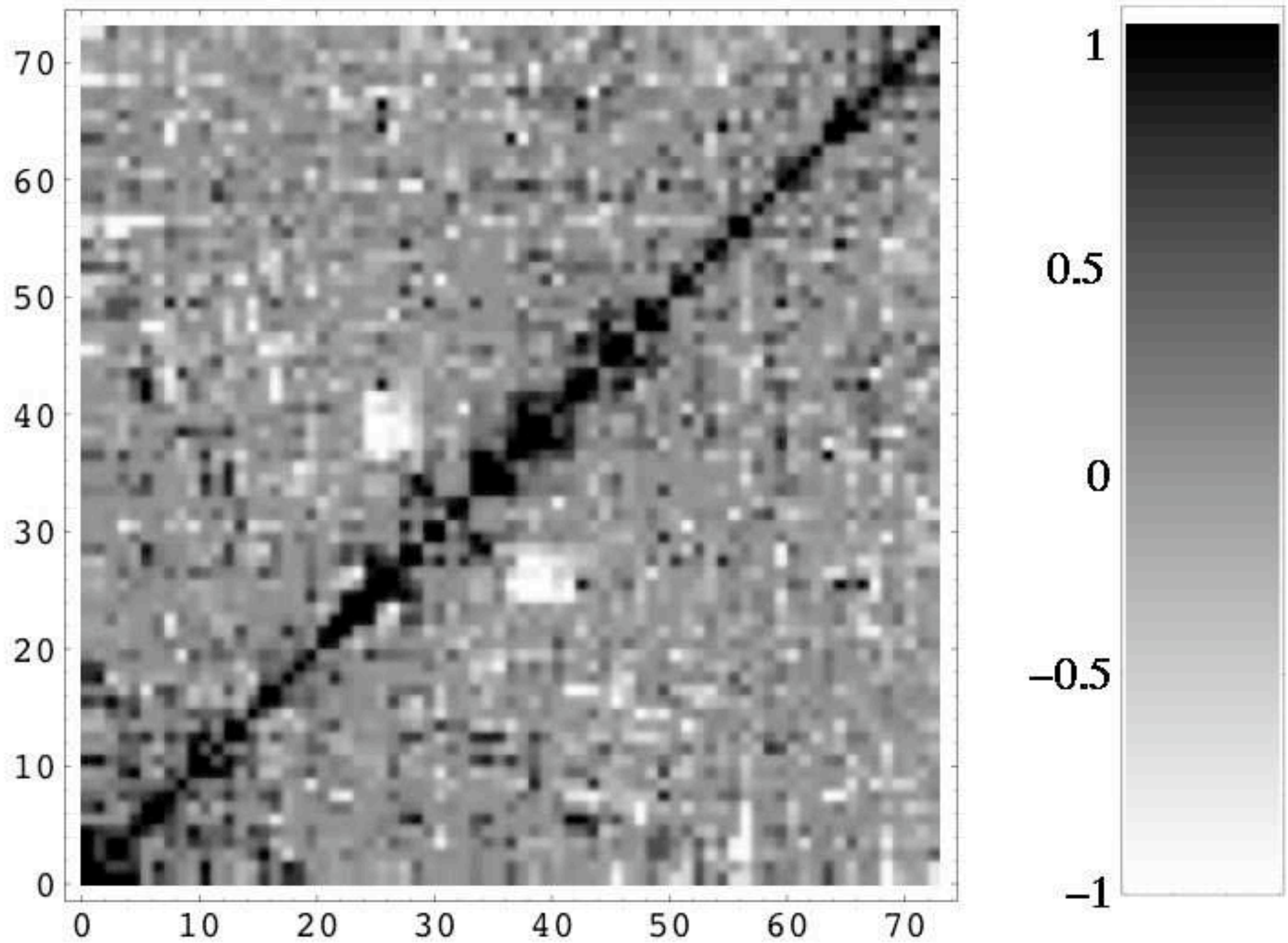
- Trading orders change the price.
- Agents observe price and place trading orders.
- Agents are specialized and form a diverse, evolving ecology.

Building a model from first principles: Market ecology

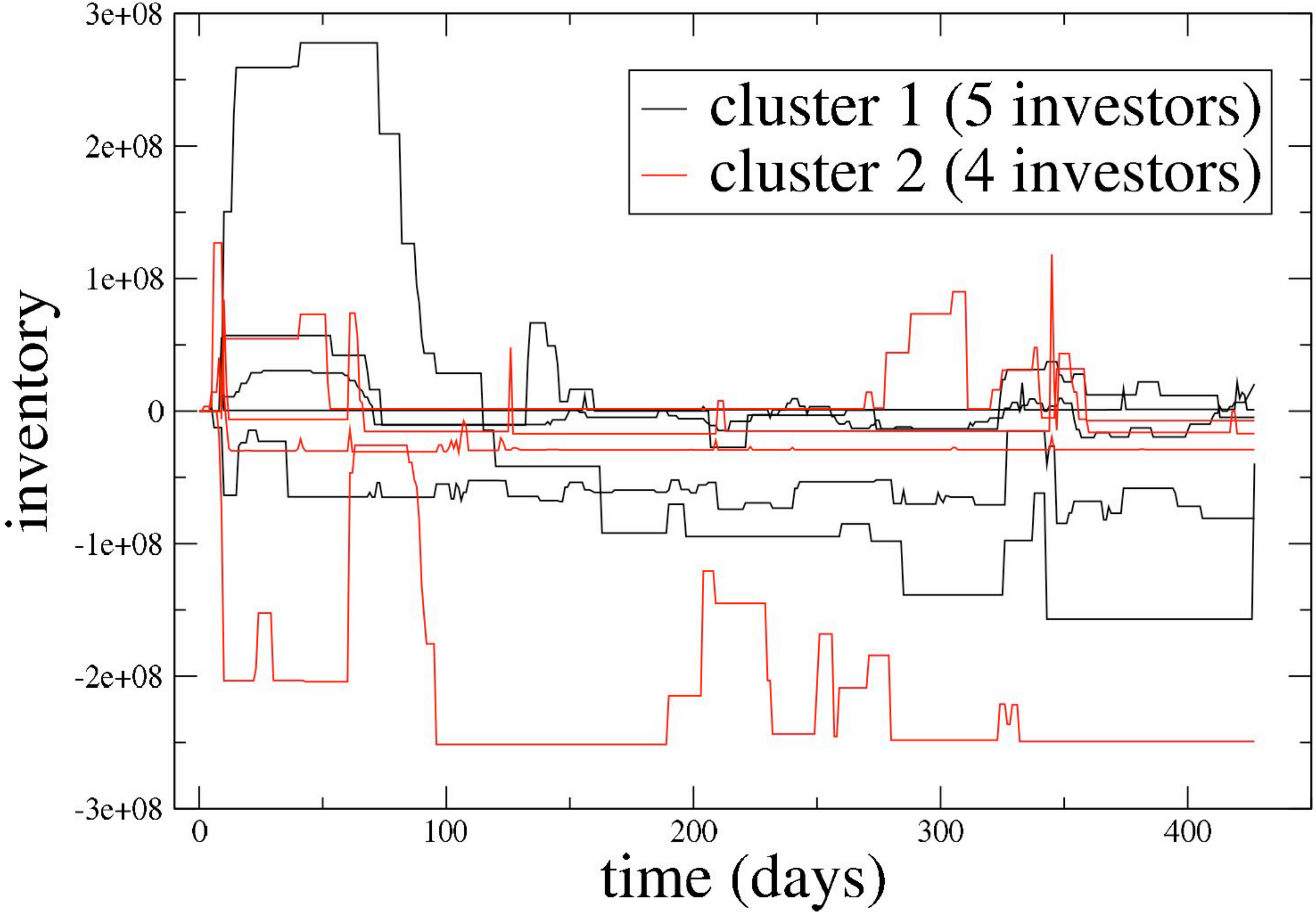
- Economic need is “food” for arbitrageurs.
- Agents in ecology (nice case study of specialization)
  - Market makers
  - Fundamentalists
  - Technical traders
  - …
- Agent construction
  - Hand constructed stylized models
  - Machine learning
  - Taxonomy via data analysis of real markets



Lillo, Moro, Mantegna (2006)



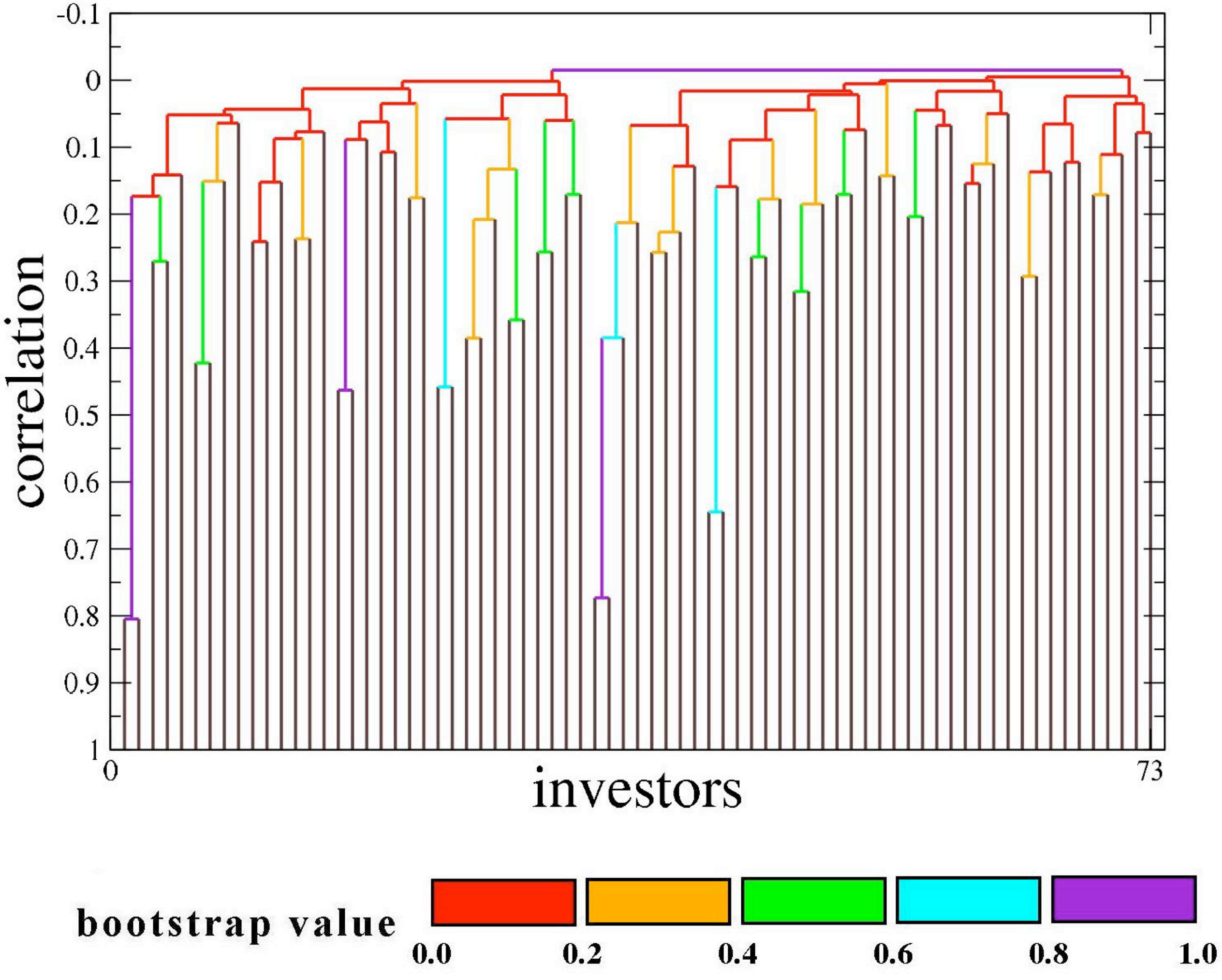
With Michele Tuminello and Neda Zamani



cluster 1 (5 investors)
cluster 2 (4 investors)
inventory
time (days)
3e+08
2e+08
1e+08
0
-1e+08
-2e+08
-3e+08
0
100
200
300
400

Average Linkage Cluster Analysis

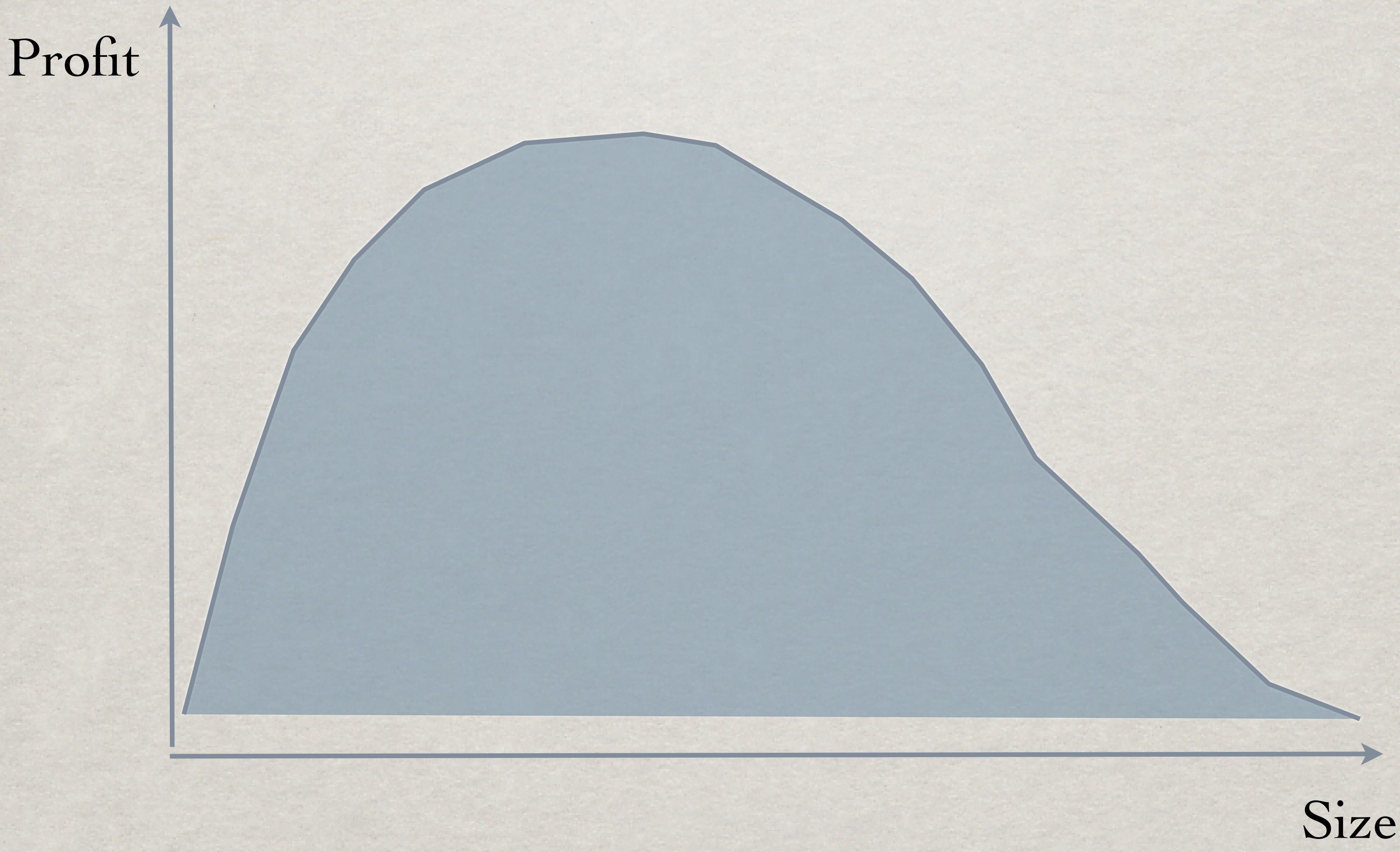
(73 investors; daily inventory variation)



MARKET FOOD CHAIN

- Market impact is interaction rule.
  - players made trades, trades alter prices, prices alter trades
- Profits of each player depend on interaction with others
  - If A gains capital, do B's profits go up or down? (competitive, predator-prey, mutualist)
- Profits influence capital -- link of short term and long term time scales. Evolutionary dynamics (e.g. Lotka-Volterra)
- Can use market impact to empirically map out ecology

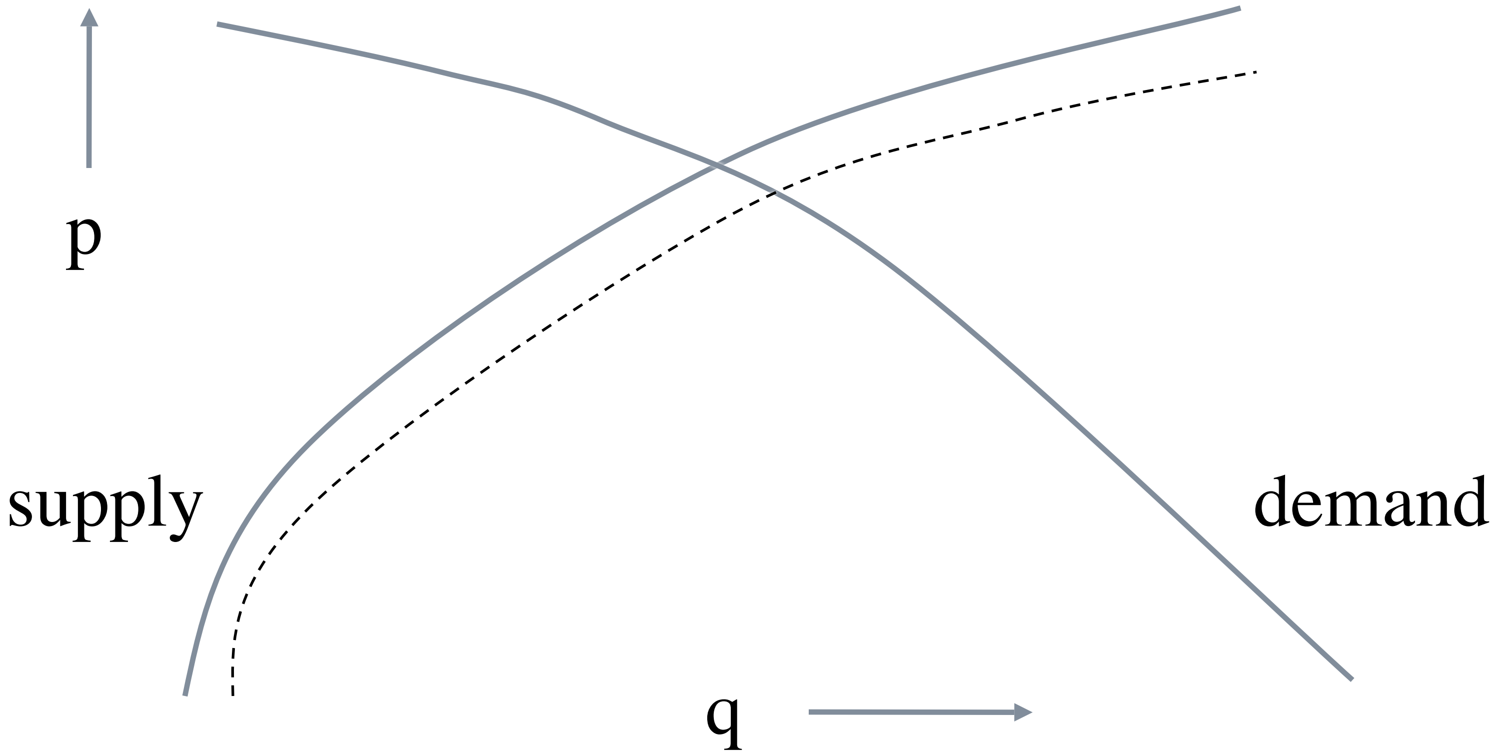
Market impact and size relations



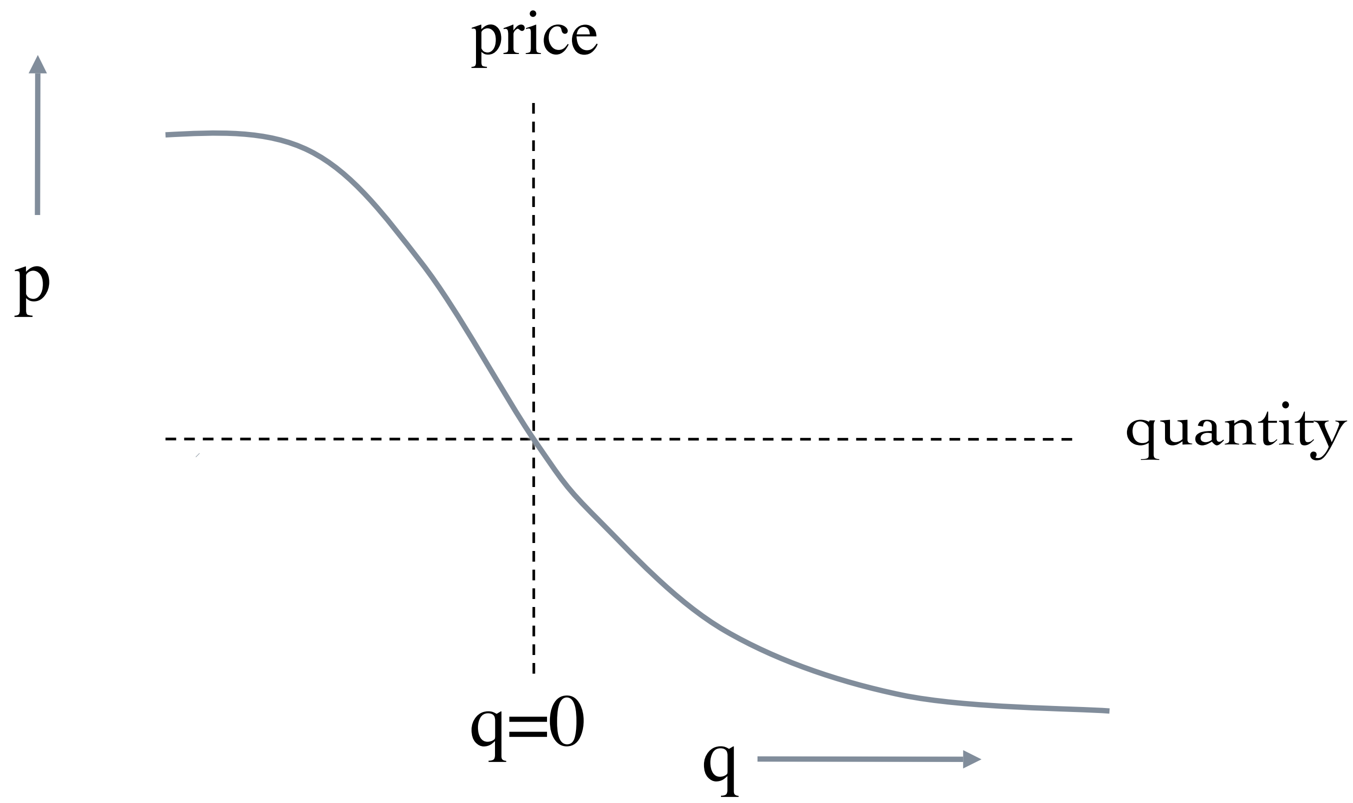
Achievements of theory

- Can predict how different types of strategies will affect price dynamics
- Can predict fitness of strategies in a given environment a priori
  - Which strategies can invade?
- Predictions are still only qualitative -- but new data sets offer hope to make it quantitative.

Supply and demand



Excess demand = demand - supply



PRICE ELASTICITY
(NONDIMENSIONAL EXCESS DEMAND)

$$\frac{\Delta p/p}{\Delta q/q}$$

In financial markets it is more common to talk in terms of market impact (a.k.a market friction, price impact, ...), which is roughly proportional to price elasticity. I.e. average logarithmic return conditioned on signed trading volume.

$$market\ impact = E[R|V]$$

$$V = \sum_{i=1}^{N} v_i$$

$$v_i = \Delta q$$

$$R = \sum_{i=1}^{N} r_i$$

$$r_i = \log p_i - \log p_{i-1}$$

How do economists explain excess demand?

Neoclassical approach

- Assume a utility function
  - How desirable is wealth?
- Assume an agent cognition model
  - e.g. rationality with specified information set
- Assume all agents maximize utility under given cognition model

Structure vs. strategy

- Strategy: Interacting players that take strategies of other players into account.
- Structure: What is the framework for the interactions? What are the constraints? How do interactions aggregate? Are there emergent phenomena?
- Not mutually exclusive -- in general need both.
  - However, conservation of research effort implies one can't always do everything at once
  - Which dominates? (crowd behavior vs. tic-tac-toe)

Maximizing utility?

- Utility is a poor approximation of human preferences.
- Functional form of utility is not consistently reproducible in laboratory situations.
- Functional forms in theory are chosen for convenience
  - Parameters are fit on target data

Gabaix, Gopikrishnan, Plerou, Stanley

- Neoclassical model of market impact
- Assume first order risk aversion

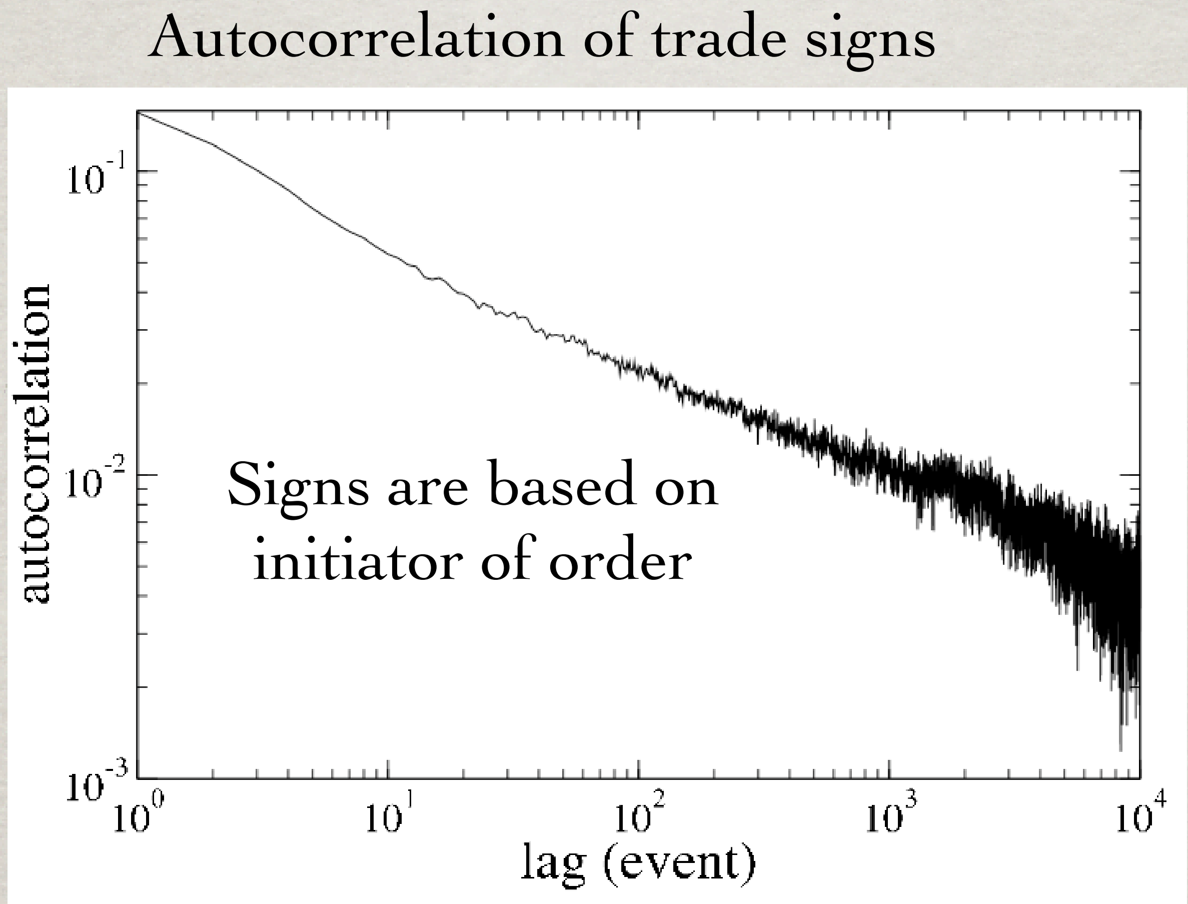
$$Utility \sim profit - (risk)^{\delta},\ \delta = 1$$

- Assume time to trade is proportional to trading size; risk then goes as $(size)^{1/2}$.
- Implies $market\ impact \sim (size)^{1/2}$

Alternative theory

- Make assumptions about flow of supply and demand.
- Enforce market efficiency at first order (assume people are profit seeking, enough time to reach approximate equilibrium).

Autocorrelation of volume signs (long memory of supply and demand)

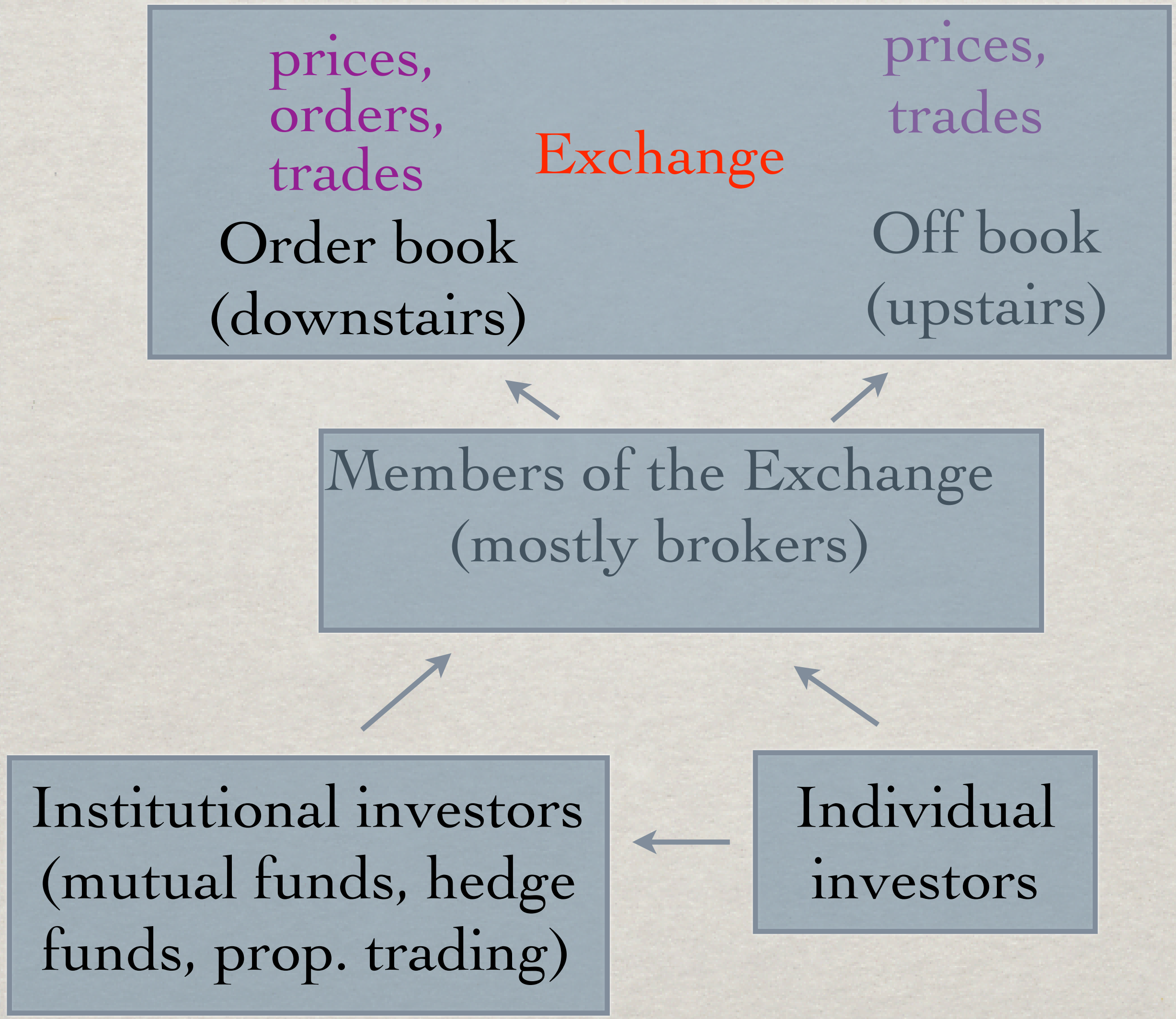


Bouchaud, Gefen, Potters, and Wyart (2004)
Lillo and Farmer (2004)

What causes long-memory of supply and demand fluctuations?

- E.g. herding
- Our theory: Strategic hiding of supply and demand (order splitting, i.e. trade packages)
  - To avoid revealing true intentions, large investors break their trades up into small pieces, and trade incrementally.
  - Converts heavy tail of volume distribution into long-memory in signs of realized trade series.

Market structure



Model of strategic order splitting
(Lillo, Mike, Farmer, 2005)

Assumptions:

- Hidden order (trade package) size is power law distributed.

$$P(V > v) \sim v^{-\alpha}$$

- Hidden order arrival is IID

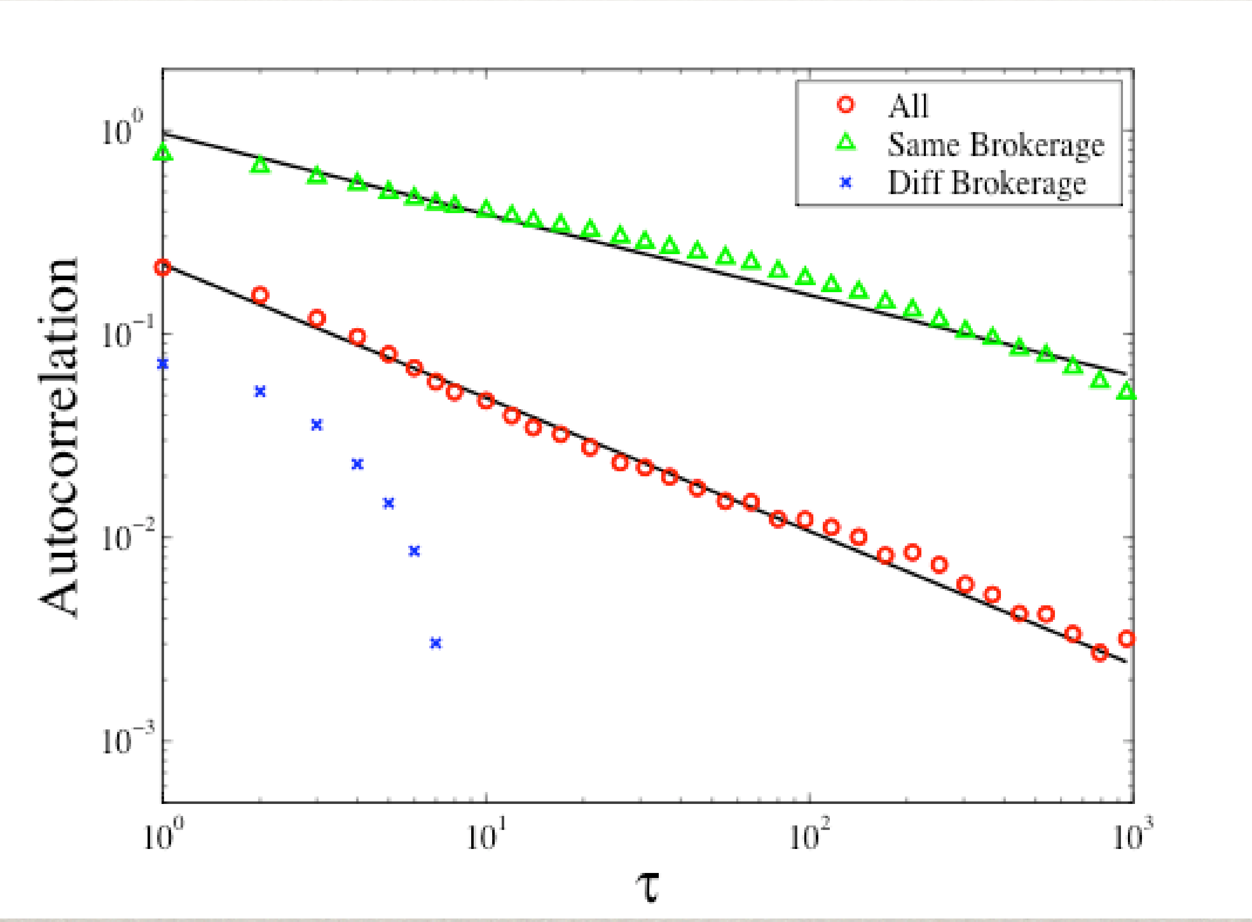
Implies $$C(\tau) \sim \tau^{-\gamma}$$ $$\gamma = \alpha - 1$$

- Execution rate is independent of hidden order size, i.e.

N ~ V

Autocorrelation of volume sign (vs. transaction number)

Autocorrelation of trade signs
for same vs. different broker codes



Long memory and market efficiency

- Supply and demand fluctuations have long-memory (autocor. function is non-integrable).
- Markets should be approximately efficient
  - Can't make easy money using obvious strategies
- Naively, long-memory + market impact => prices are predictable using linear model
- They aren't!

Theory for impact of hidden orders

(with Austin Gerig and Fabrizio Lillo)

Time series model of returns

$$r_t = \epsilon_t f(v_t) - \lambda_t + \eta_t$$

$r_t = return$

$\epsilon_t = order\ sign$

$v_t = signed\ volume$

$\eta_t = noise$

$\lambda_t = variable\ price\ response$

Two information sets

- Anonymous information set Ω: Past history of signed transactions, independent of who made them (time series model).
- Revealed information set Ω': Participants know
  - Distribution of hidden orders
  - Position *n* within each hidden order

Derivation of market impact

- In both cases: assume a hidden order of length N, traded on average every θ realized transactions, with each transaction of the same size v.
- Assume a power law with exponent alpha.
- Assume returns are efficient, i.e. $E[r_t] = 0$
- Taking predictability of order flow into account leads to two competing formulas for market impact:

Two formulas for market impact

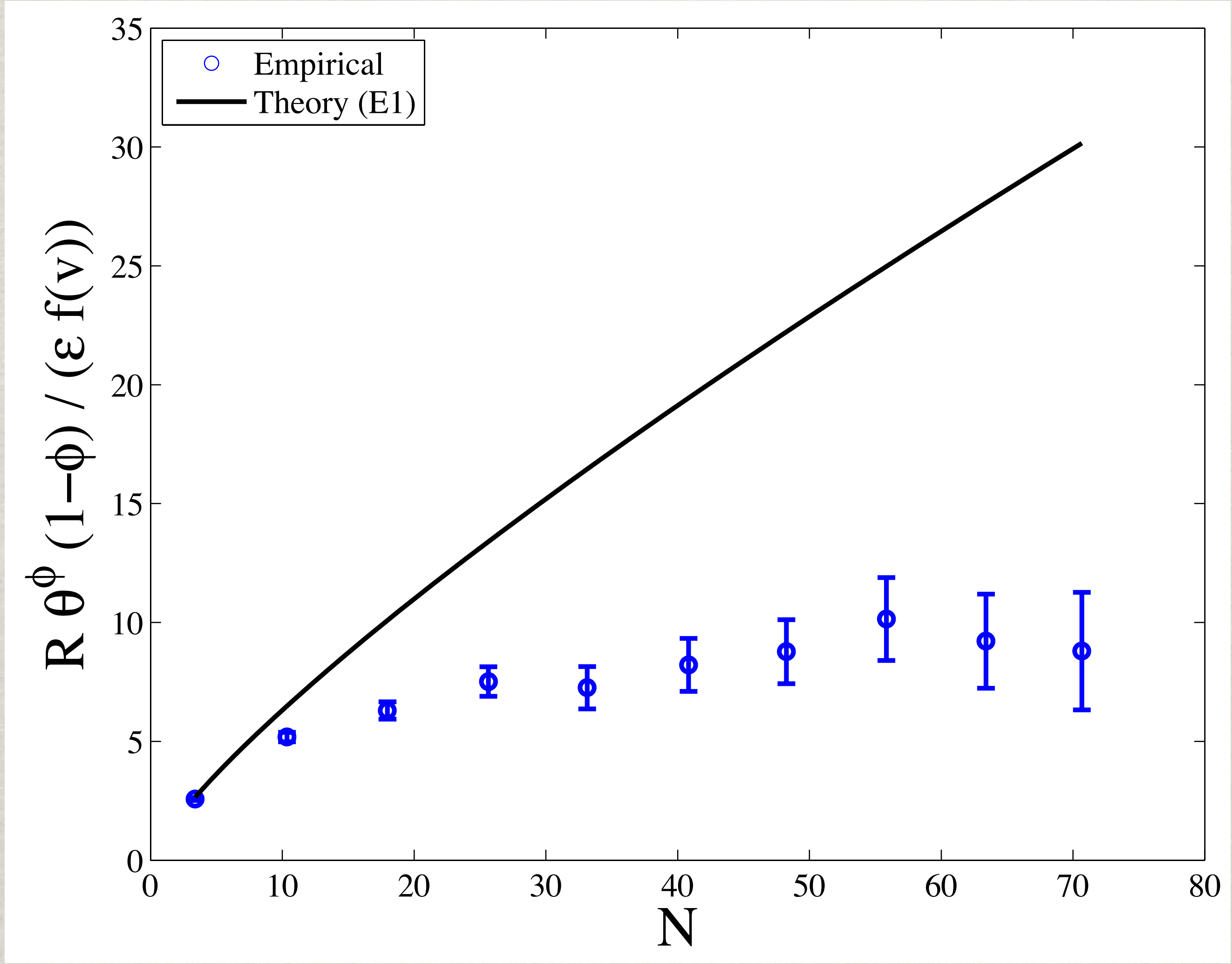
- Anonymous information set Ω:

$$E\left[R|\Omega\right] \approx \frac{\epsilon f(v)}{1-\phi}\ \theta^{-\phi} N^{1-\phi}$$

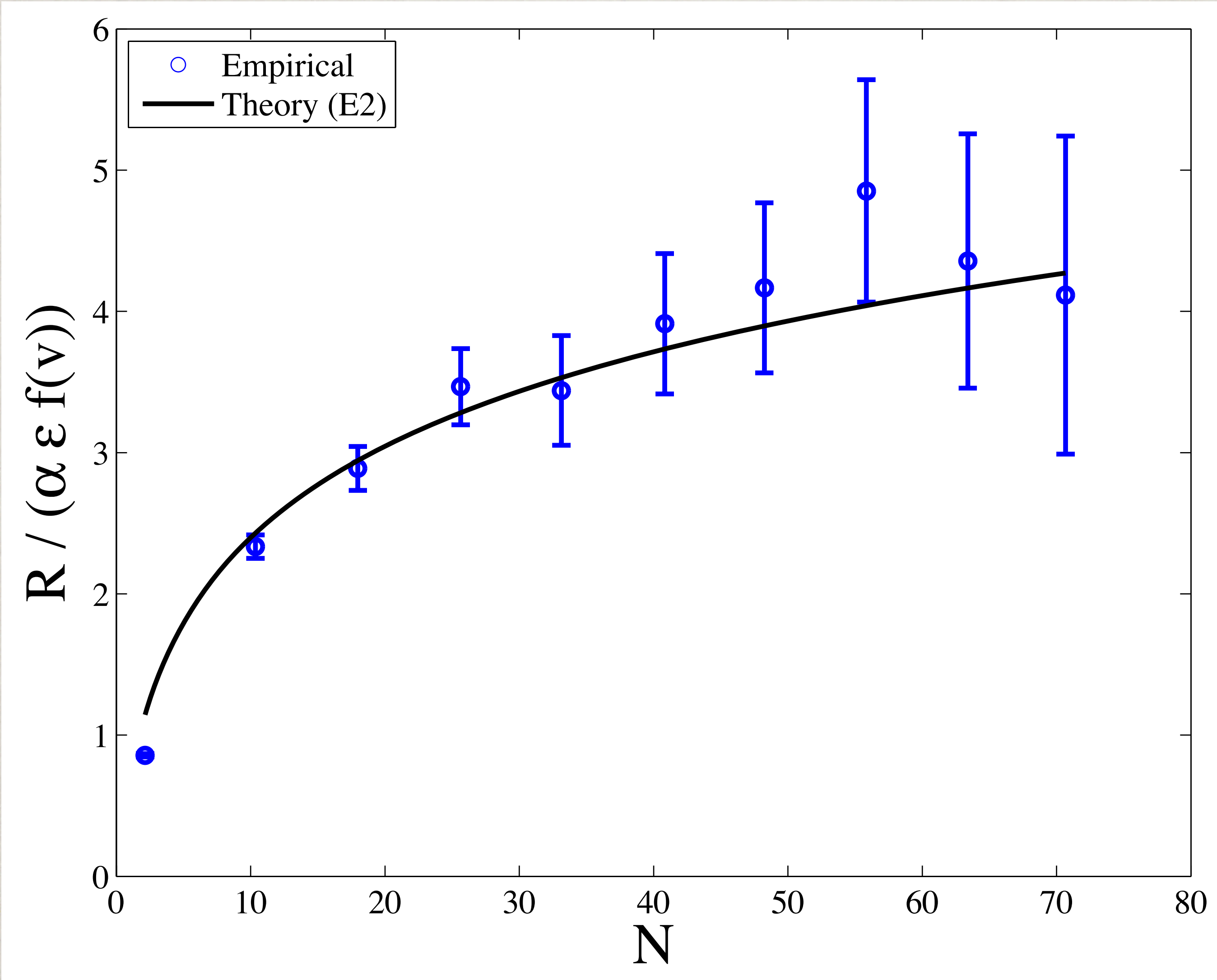
- Revealed information set Ω′:

$$E[R|\Omega'] = \alpha \epsilon f(v) \log(1+N)$$

Test of hidden order impact for anonymous information set model



Test of hiddden order impact for revealed information set model



Reductionism vs. synthesis

Healthy interplay between the two:

- Need to understand interaction rules of elementary components
- Then simulate interactions to understand emergent properties
- Often have to think about both at once!

Open questions in financial economics

- How accurately are prices set? I.e., to what extent are markets allocatively efficient?
- Do all market participants contribute to allocative efficiency? If not, who doesn't?
  - Why do financial professionals make so much money?
- What determines properties of market ecology?
- What drives instabilities in prices? Why do markets crash? Heavy tails, ...
- What causes volatility?
- How important are market institutions?
- How much regulation is optimal?
- Plus lots of financial engineering questions.

Largest S&P index moves 1946-87

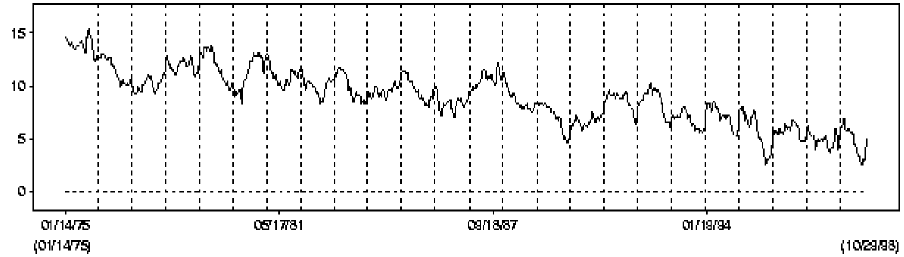
(Cutler, Poterba, Summers 1989)

Rank	Date	%	NY Times explanation
1	Oct 19, 1987	-20.5	Worry over dollar decline and rate deficit Fear of US not supporting dollar
2	Oct 21, 1987	9.1	Interest rates continue to fall Deficit talks in Washington Bargain hunting
3	Oct 26, 1987	-8.3	Fear of budget deficits Margins calls Reaction to falling foreign stocks
4	Sep 3, 1946	-6.7	"No basic reason for the assault on prices"
5	May 28, 1962	-6.7	Kennedy forces rollback of steel price hike
6	Sep 26, 1955	-6.6	Eisenhower suffers heart attack
7	Jun 26, 1950	-5.4	Outbreak of Korean War
8	Oct 20, 1987	5.3	Investors looking for quality stocks
9	Sep 9, 1946	-5.2	Labor unrest in maritime and trucking
10	Oct 16, 1987	-5.2	Fear of trade deficit Fear of higher interest rates Tension with Iran
11	May 27, 1970	5.0	Rumors of change in economic policy "stock surge happened for no fundamental reasons"
12	Sep 11, 1986	-4.8	Foreign governments refuse to lower interest rates Crackdown on triple witching announced

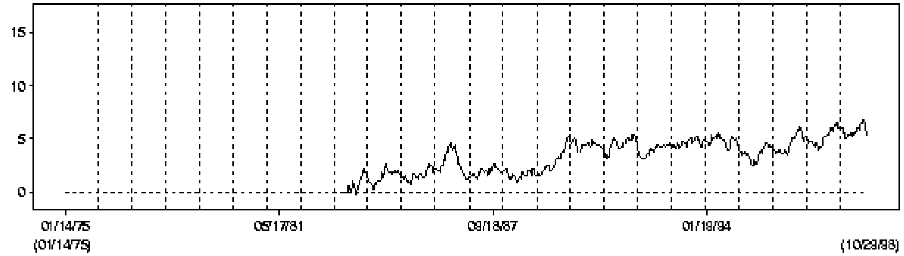
Market efficiency?

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

Signal 1:



Signal 2:



Epistemological problems of economics

- Too much theory
  - Mathematics over common sense
- Inattention to data gathering.
- Theory and data not well connected
  - good statistical testing, but models aren't crisply falsifiable, theories are not formulated in terms of measurable quantities
- Slavish adherence to neoclassical paradigm