# Financial markets and complex systems

SFI complex systems summer school
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# What are prices for?

- Setting goals.
- Financial markets provide a self-organized method for directing the activities of individuals.
- Efficient method for information processing distributed decision making (parallel processing).
- Highly specialized and geographically concentrated, and increasingly automated.
- How well does it work?

# Market efficiency

- Three kinds of efficiency
  - informational efficiency: prices are unpredictable
  - arbitrage efficiency: can't make profits without taking risks (stronger: all strategies are equally good)
  - allocative efficiency: can't make anyone better off without making someone worse off

# Still dominant theory of economics

- Rational choice (neoclassical)
  - 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

# Rational choice => perfect efficiency

- All information is properly incorporated into current prices
- New information is by definition random
- Markets are perfectly efficient
  - Changes in future prices are random
  - Informational efficiency implies both arbitrage and allocative efficiency

# Efficiency paradox

- Information is incorporated into prices by arbitrageurs.
- If market is efficient arbitrageurs cannot make better profits than others.
- If arbitrageurs are rational, they should leave the market.
- If no arbitrageurs, market cannot be efficient.

# Prediction Company

## (cofounded in 1991 with Norman Packard)

- Manages money under exclusive relationship with United Bank of Switzerland (Warburg Dillon Reed)
- "Cerebellar" approach to market forecasting
  - ~ empirically searches for patterns in historical data
  - ~ keys are feature extraction, law of large numbers
  - ~ little understanding of origin of patterns
  - ~ relies on abundant past data, stationary conditions.
- Trading is fully automated (no human decisions)

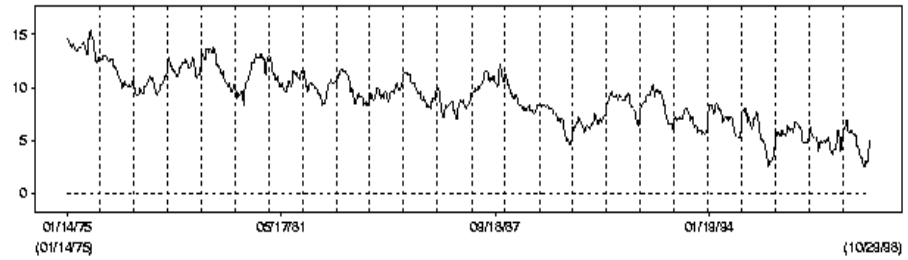
# Increasing automation of exchange, information processing and decision making

- Widely believed that most transactions in the LSE are initiated by machines.
- Ever-increasing trend in all markets.
- Machines are increasingly trading with other machines.
  - ~ mechanical trade execution, accounting
  - ~ information processing
  - ~ decision making

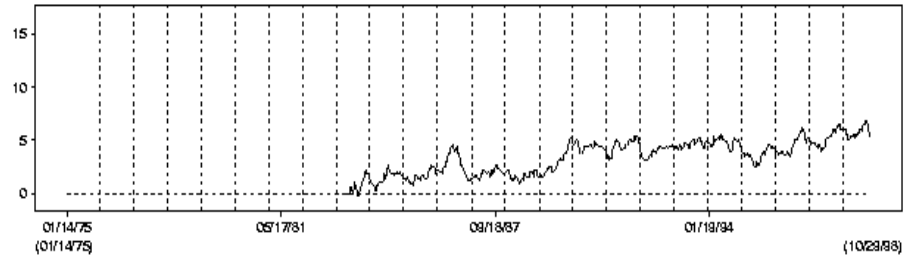
# Market efficiency?

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

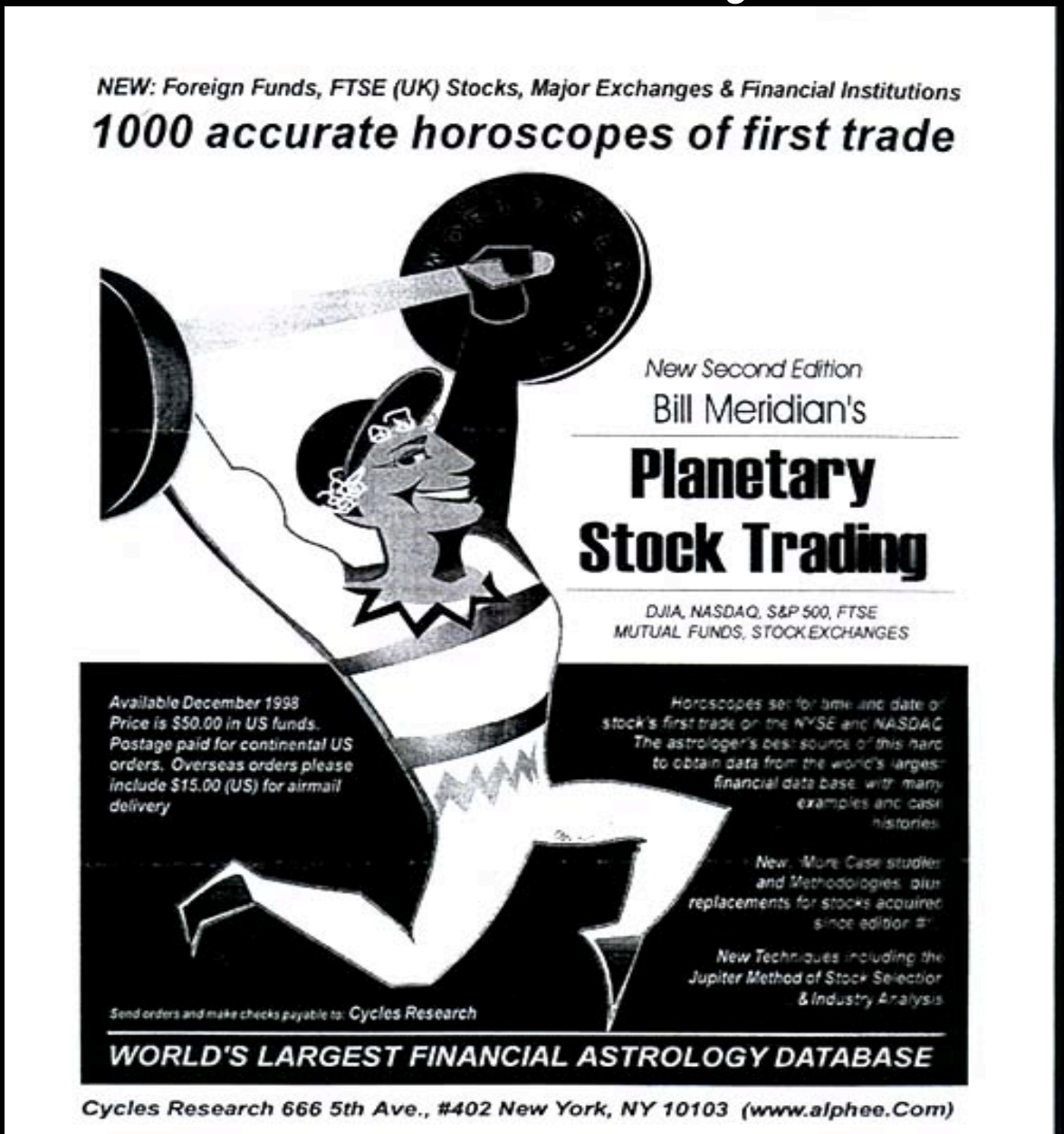
**Signal 1:**




**Signal 2:**



# Rationality?



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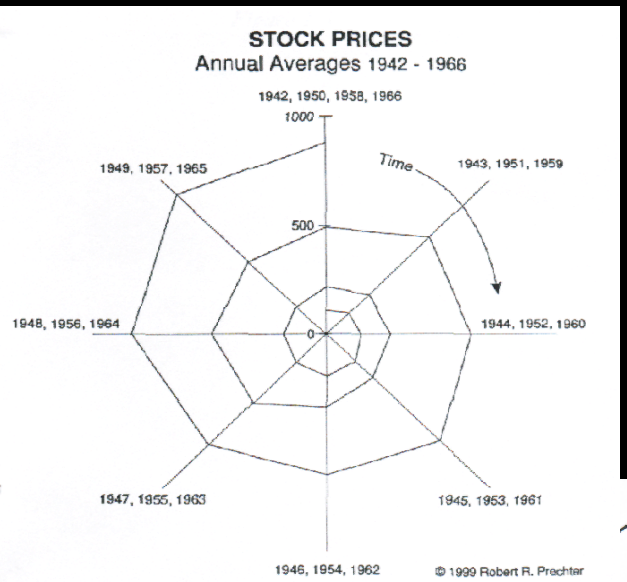
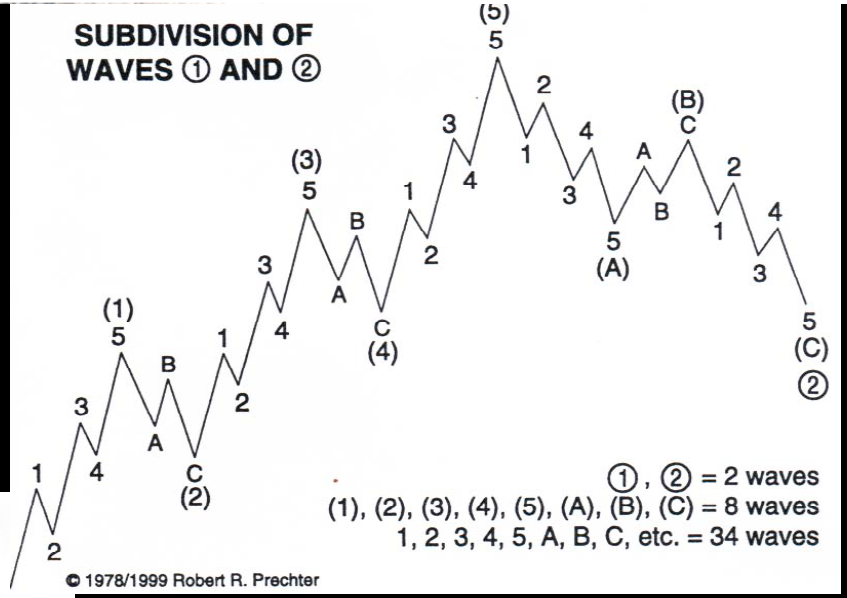
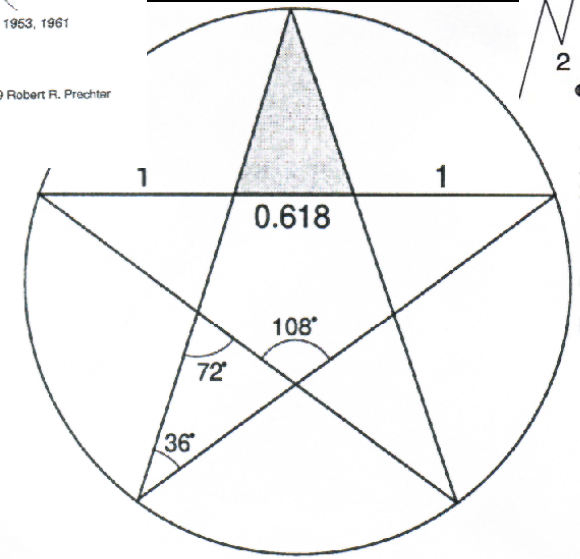



Figure 3-22

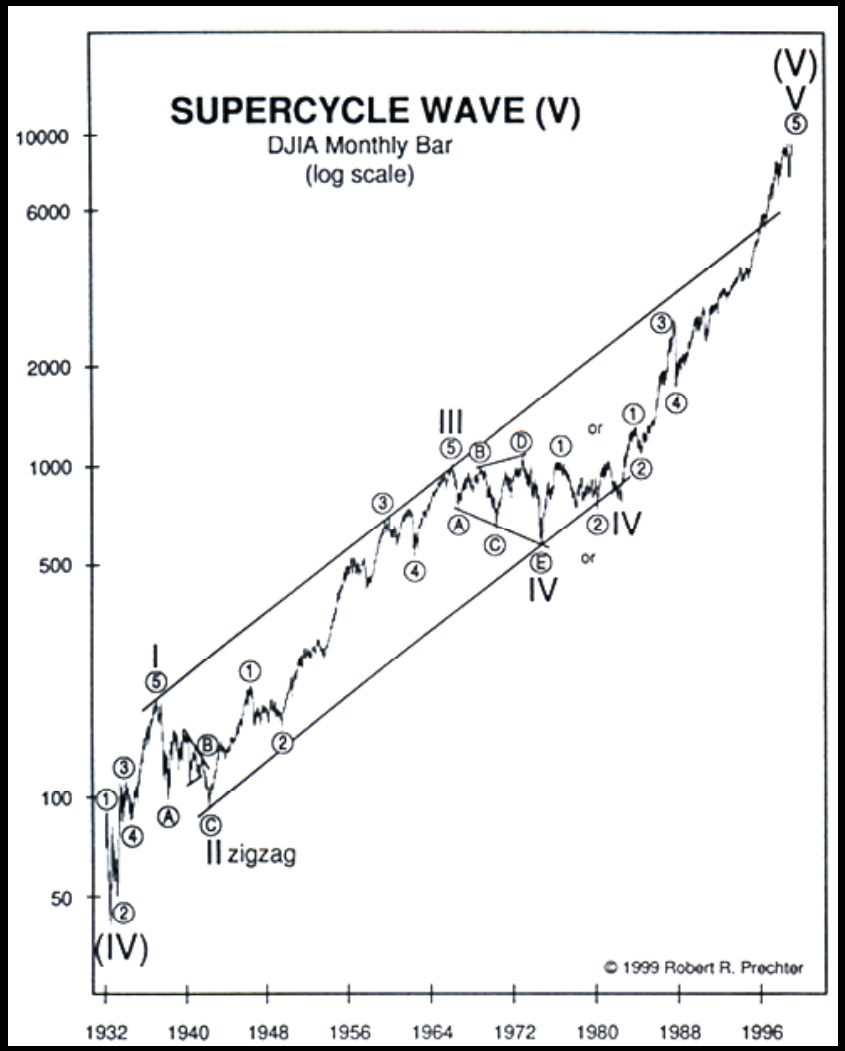


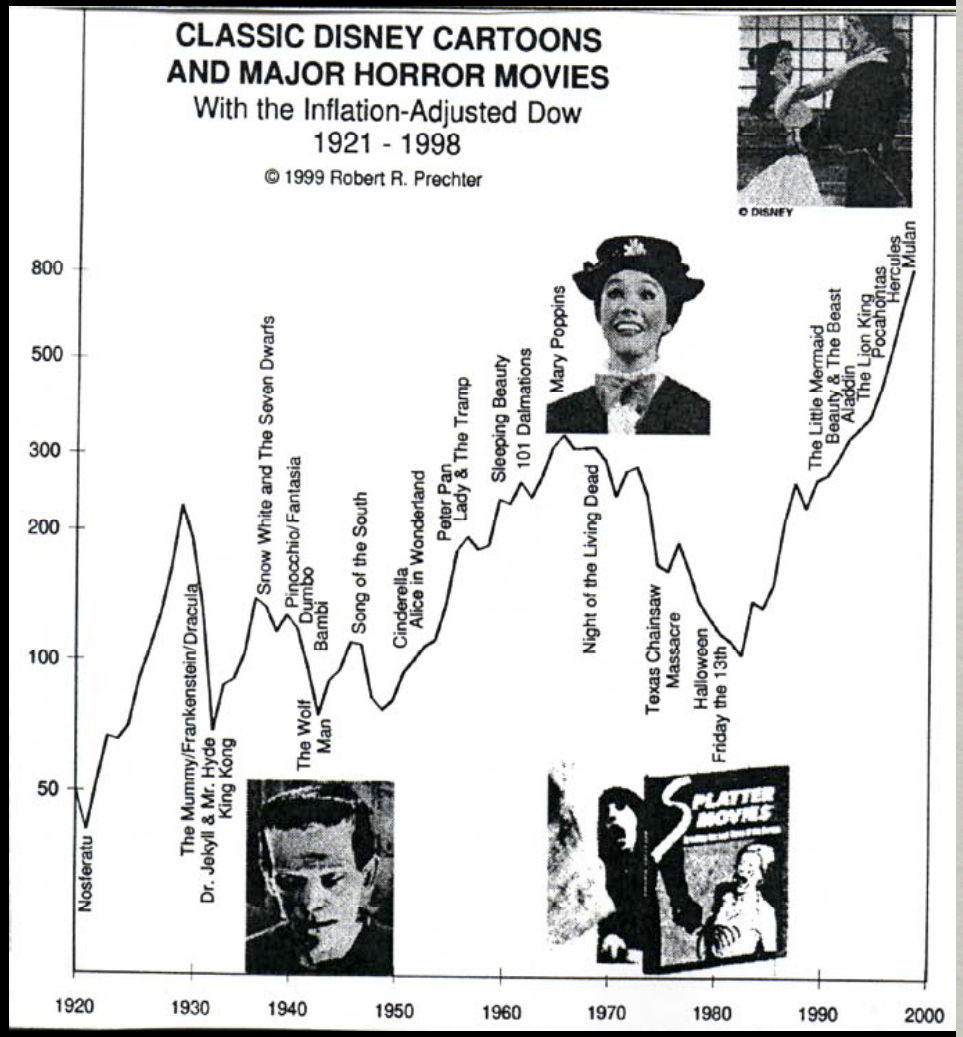




Fibonacci in the five-pointed star

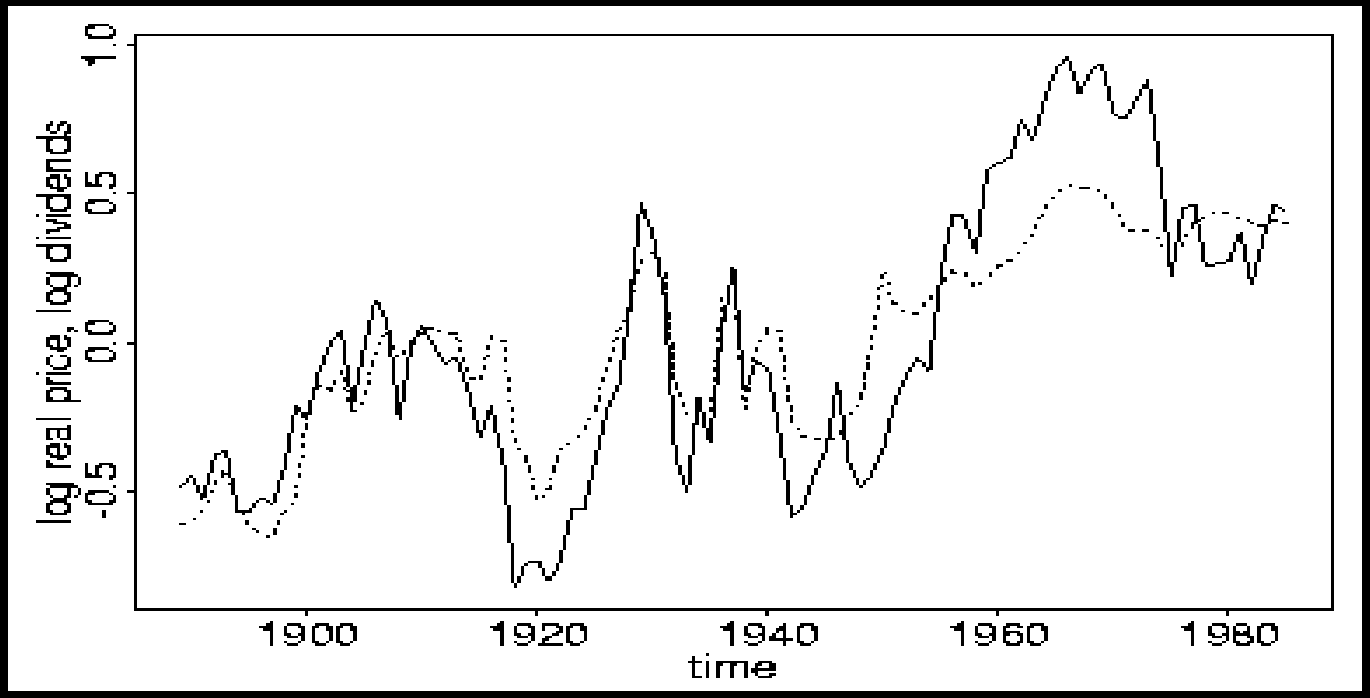
Figure 3-8

# Fibonnaci predicts social trends!



# Prices do not match fundamental values

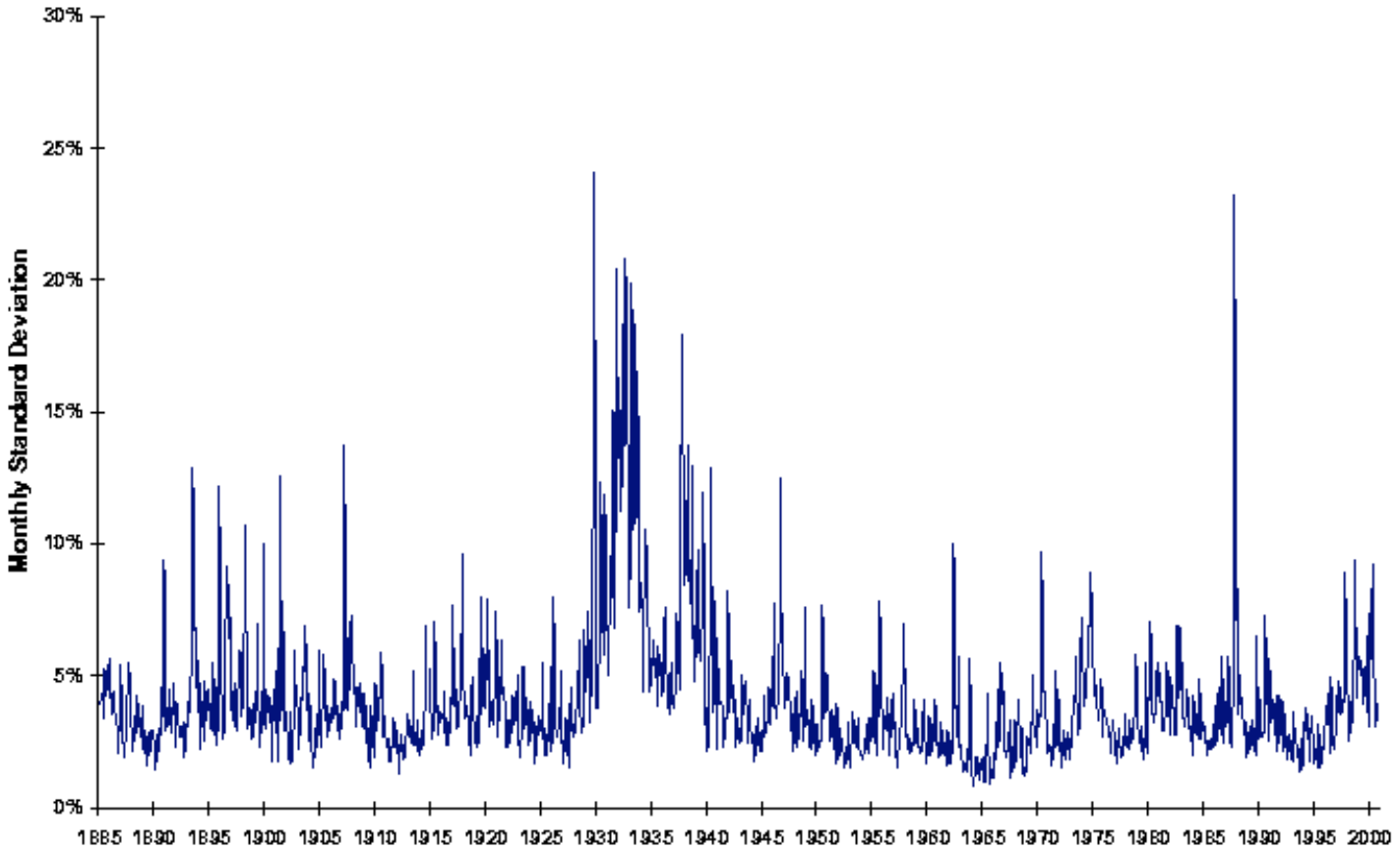


# Largest S&P index moves 1946-87

(Cutler, Poterba, Summers 1989)

| Rank | Date | % | NY Times explanation |
|---|---|---|---|
| 1 | Oct 19, 1987 | -20.5 | Worry over dollar decline and rate deficit<br>Fear of US not supporting dollar |
| 2 | Oct 21, 1987 | 9.1 | Interest rates continue to fall<br>Deficit talks in Washington<br>Bargain hunting |
| 3 | Oct 26, 1987 | -8.3 | Fear of budget deficits<br>Margins calls<br>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<br>Fear of higher interest rates<br>Tension with Iran |
| 11 | May 27, 1970 | 5.0 | Rumors of change in economic policy<br>"stock surge happened for no fundamental reasons" |
| 12 | Sep 11, 1986 | -4.8 | Foreign governments refuse to lower interest rates<br>Crackdown on triple witching announced |

## Standard Deviation of Monthly Stock Returns from Daily Returns in the Month, 1885-2000

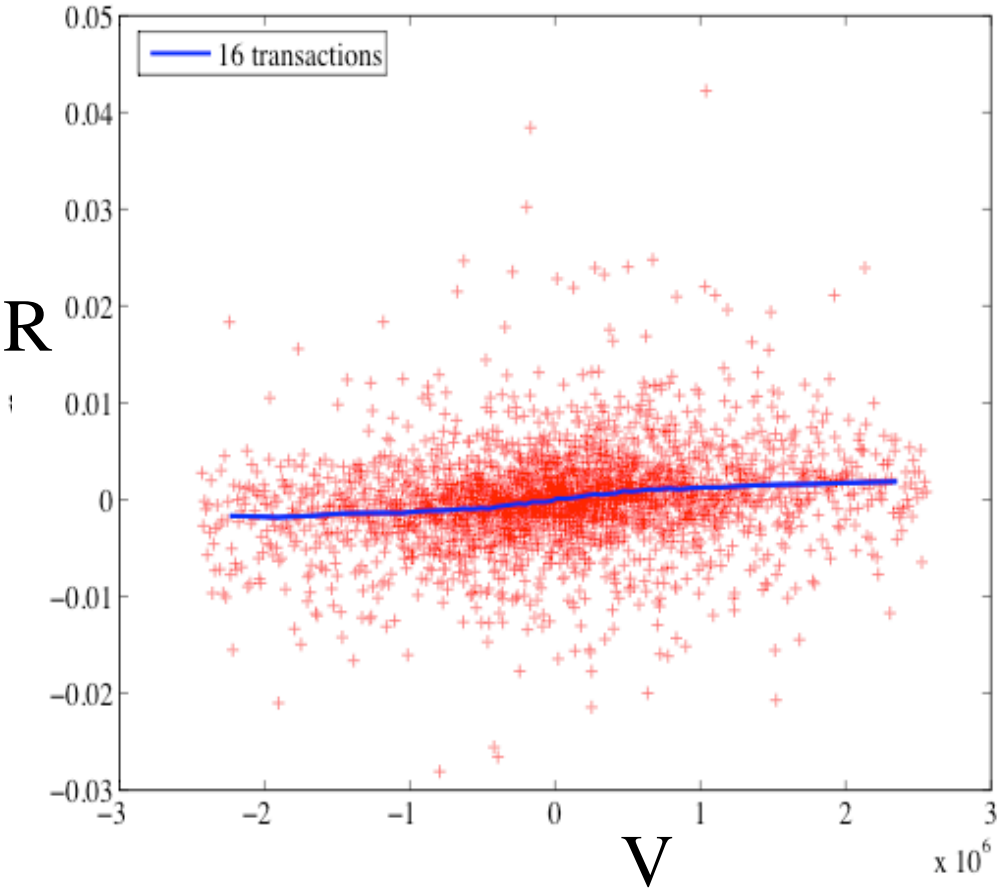


# Definitions

- Liquidity: Size of price change corresponding to trading a given quantity
  - Large price change -> low liquidity
  - Small price change -> high liquidity
  - Depends on availability of counterparties
- Market impact
  - price change v.s volume or time
  - liquidity is scale of market impact

# Liquidity

- Highly variable
- Variability is persistent
- Variability is much larger than average market impact
- Main driver of volatility
  - more important than volume
- Variable liquidity drives heavy tailed prices
  - important for risk control




$$
\begin{aligned}
R &= E[R_t|V,N] \\
r_i &= \log(p_i/p_{t-1}) \\
R_t &= \sum_{i=t+1}^{t+N} r_i \\
V_t &= \sum_{i=t+1}^{t+N} v_i
\end{aligned}
$$

- V: Net (signed) quantity traded in 16 successive transactions
- R: size of return in same 16 transactions

# Market design

- Liquidity is something we have control over by choosing market structure
  - how easily can counterparties find each other?
  - Fees for liquidity providers vs. liquidity takers
  - Information revelation
  - Interactions with price discovery
  - Can this change long-term volatility?
- How efficient are markets (how much room for improvement)

# Epistemological problems of economics

- Too much theory
  - Mathematics over common sense
- Lack of ambition in 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
- What are the right set of questions? Regularities?

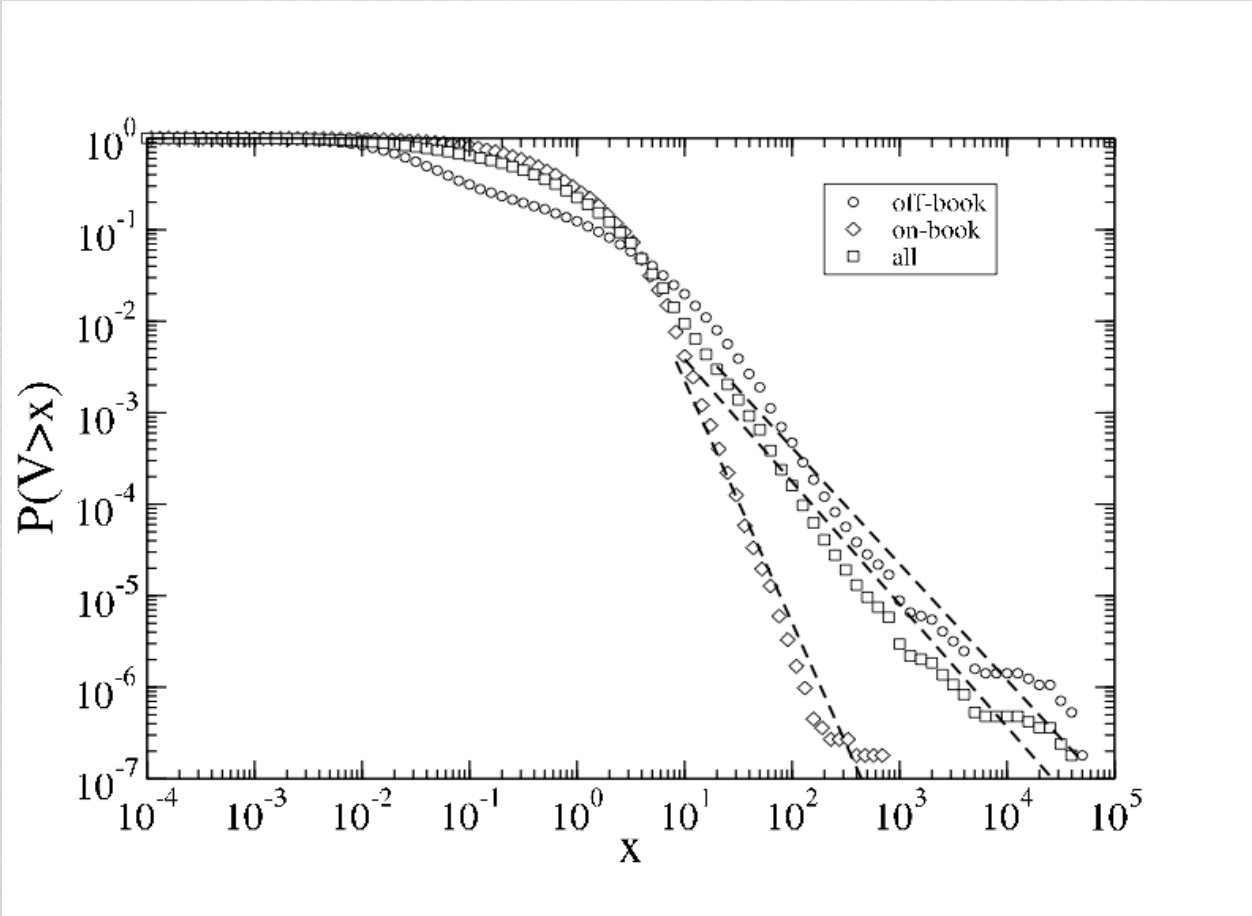
# Laws of markets?

- Are markets on alpha centauri anything like those on earth?
- E.g. do they have options? How are their prices related to the underlying?
- What about topics other than derivative pricing?

# Some possible laws?

- Long-memory of volatility
- Equivalence of bid-ask spread, market impact and volatility in transaction time (Bouchaud et al)
- Power law tail behavior of volume distribution (Gopikrishnan et al.)
- Long-memory of order flow
- Equation of state relating volatility to order flow

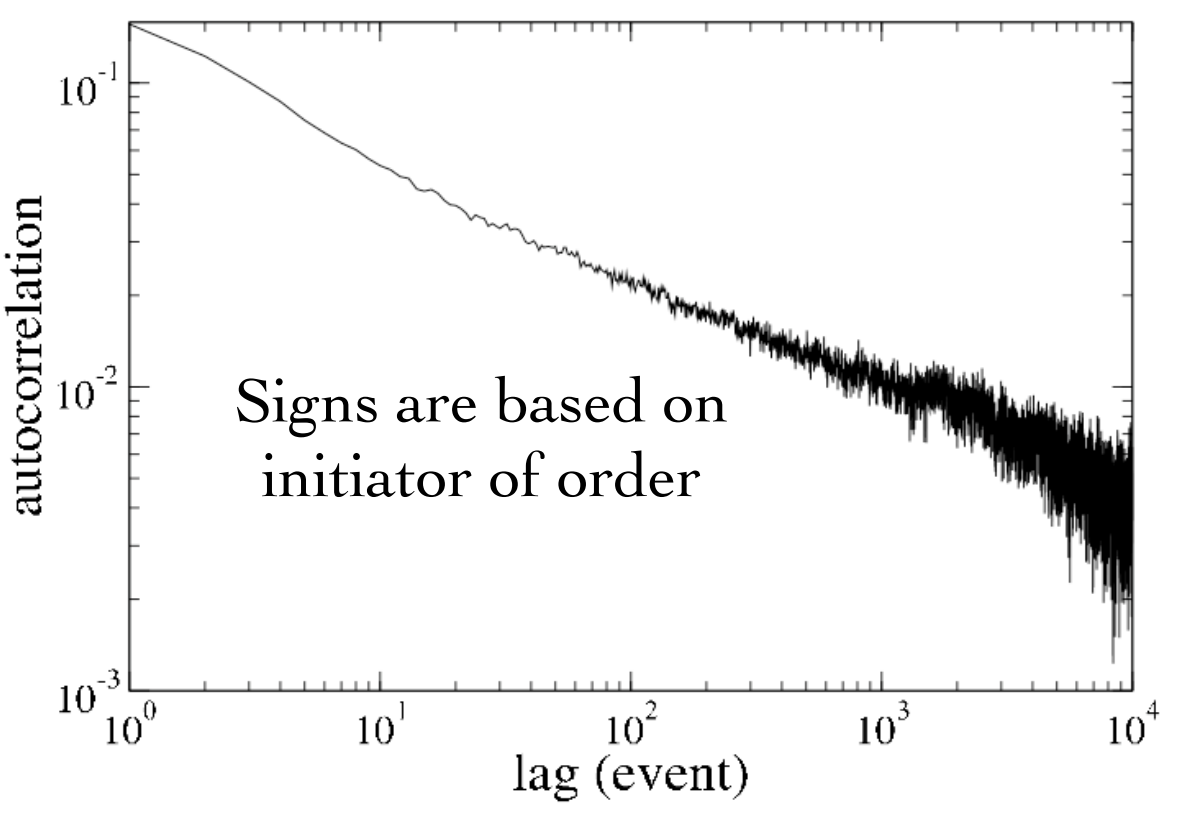
# Cumulative distribution of trading volume for LSE Stock Astrazeneca




Gopikrishnan, Gabaix, Plerou and Stanley (2000)
Lillo, Mike, Farmer (2005)

# Autocorrelation of order flow (long memory of supply and demand)

Autocorrelation of trade signs




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

# Autocorrelation

- Relation between the same variable x at two different times, t and t + s
- Depends on product of x(t) and x(t + s).
- C(s) = 1 if x(t) = x(t + s)
- C(s) = -1 if x(t) = -x(t + s)
- C(s) = 0 if they are randomly related

# Law relating volume distribution to long-memory of order flow

- Let a = slope of volume power law
- Let b = slope of order flow power law
- Conjectured law (derived by a theory)
- $a = b + 1$

# Market impact

- How does price movement correspond to amount traded? (related to net of supply and demand)
- Long-memory autocorrelation of order flow forms basis of theory for market impact
- Predicts functional forms
- Arguments are similar to Black-Scholes theory

# What is functional form of average market impact?

- Dependence on volume and time?
- Importance
  - Practical: Understanding and minimizing transaction cost (friction)
  - Allometry: Sets upper bound on size of funds
  - Interaction rule: Affects how much prices move, which affects how agents trade, which affects how much prices move, ...

# 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.

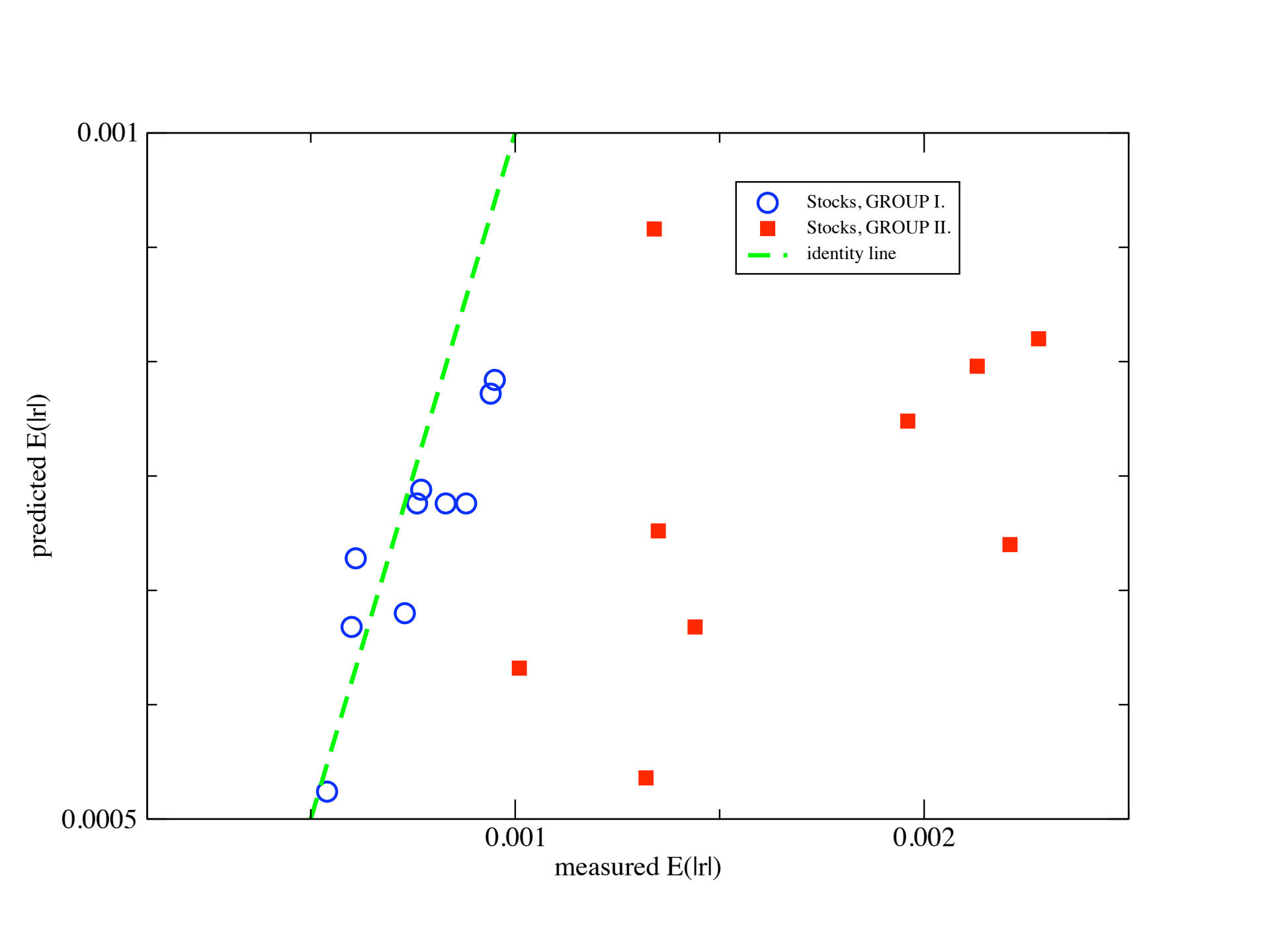
# What is biggest difference between social and biological evolution?

## 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).

# Equation of state connecting order flow to statistics of prices

- Zero intelligence model (Daniels, Farmer, Iori, Smith, 2003, Smith, Farmer, Gillemot, Krishnamurthy, 2003)
- Assumes order placement and cancellation are Poisson processes.
- Predicts equation of state relating order flow to spread and volatility.
- More realistic non-Poisson simulation model by Mike and Farmer (2008) reproduces heavy tails of prices.


0.001
0.0005
predicted E(|r|)
0.001
0.002
measured E(|r|)
Stocks, GROUP I.
Stocks, GROUP II.
identity line

# Conclusions

- Markets provide a good forum to study a complex system.
- Availability of data, constraints of market environment provide a good test bed to search for laws underlying a social system.
- Significant opportunities to improve social welfare through better market design
- Consilience:  Perhaps theories for markets can be much more similar to complex systems in other branches of science.