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 1 graph]

Signal 2:

![Signal 2 graph]
Rationality?
5: Forecasting Pattern on the Basis of Pattern

**Figure 3-22**

**Figure 3-8**

**STOCK PRICES**
Annual Averages 1942 - 1966

- 1942, 1950, 1958, 1966
- 1000
- 500
- 1949, 1957, 1965
- 1942, 1961, 1969
- 1944, 1962, 1960
- 1947, 1955, 1963
- 1948, 1954, 1961

**SUBDIVISION OF WAVES ① AND ②**

①, ② = 2 waves
(1), (2), (3), (4), (5), (A), (B), (C) = 8 waves
1, 2, 3, 4, 5, A, B, C, etc. = 34 waves

- Fibonacci in the five-pointed star
Fibonacci predicts social trends!
Prices do not match fundamental values
## Largest S&P index moves 1946-87

(Cutler, Poterba, Summers 1989)

<table>
<thead>
<tr>
<th>Rank</th>
<th>Date</th>
<th>%</th>
<th>NY Times explanation</th>
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</table>
| 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 |
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
- **V**: Net (signed) quantity traded in 16 successive transactions

- **R**: size of return in same 16 transactions

\[
R = E[R_t | V, N]
\]

\[
r_i = \log(p_i / p_{t-1})
\]

\[
R_t = \sum_{i=t+1}^{t+N} r_i
\]

\[
V_t = \sum_{i=t+1}^{t+N} v_i
\]
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

Signs are based on initiator of order

Bouchaud, Gefen, Potters, and Wyart (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 $a = \text{slope of volume power law}$
- Let $b = \text{slope of order flow power law}$
- 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

- Assumes order placement and cancellation are Poisson processes.
- Predicts equation of state relating order flow to spread and volatility.
measured $E(|r|)$

predicted $E(|r|)$

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.