The Financial Market as a Global Algorithmic Brain

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H. Waelbroeck

Portware LLC
A Monkey

- Makes funny faces...
- Eats bananas...
- Sometimes acts violently...
How Does a Brain Work?

A Brain

Electric signals drive muscles
Drugs control behavior
Serious ailments unresolved...
Planet Earth

Grows cities...
Burns fossil fuels...
Sometimes acts violently...
A Neuron

Market data feeds algo

Algorithms predict future returns…
… place Buy/Sell orders
Markets clear the orders…
… publish a price

data feeds

code base

FIX client

FIX server

NYSE/Euronext

AV servers

buy / sell orders
Architecture of the Financial Market

Data

Algorithms

Market

Business/investment decisions

Price history

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Generalizes Elman network to k lags:

Mankind’s Greatest Accomplishment?

The cost of building the Global Algorithmic Brain
• from French (70bps cost of price discovery): $511bn/yr
• from KCG revenues (0.5% of global share volume): $330bn/yr
• 10-years equivalent at current burn rate -> $3-$5tr cost

Computing Capacity of the Global Algorithmic Brain
• 1 Tflops / server ($10^{12}$ operations/second)
• 1 million servers operate for finance firms
• (total market is approx. 500,000 servers/year)
→ 1000 Pflops ($10^{18}$ operations/second)

In comparison:
K server in Kobe, Japan:
22032 blade servers
10 petaflops

Construction cost of Great Pyramid: $5.6bn (2006)
A Global Algorithmic Brain

Public Policy

Financial Market

Business Intelligence

Economic Activity

valuation

decision
A Global Algorithmic Brain

Electric signals drive investment
QE, taxes control behavior
Serious ailments unresolved...
Part II

– Evidence for Emerging Intelligence?

A System Driven by Trading

Predict future prices

↓

Trade (every time scale) ➔ Price is approximately a Martingale

Why?

1. Invest (provide security to retirees, etc.) ➔ Market impact, mean reversion

2. Supply financing ➔ Credit growth, bubbles and crashes
How Does it Work?

\( \tilde{r} \) the expected return conditioned on a Hypothesis, \( h \)

Trading drives price close to efficiency:

\[
p(h)\tilde{r} + (1 - p(h))r^- = 0
\]

1. *Excess supply or demand drives market impact*

Hypothesis \( h \): the order flow imbalance will continue…

\[
p(\text{continue})(\tilde{S}_{k+1} - \tilde{S}_k) + p(\text{stop})(\tilde{S}_{k+1} - \tilde{S}_k) = 0
\]
How Does it Work?

\[ \tilde{r} \text{ the expected return conditioned on a Hypothesis, } h \]

Trading drives price close to efficiency:

\[ p(h)\tilde{r} + (1 - p(h))r^- = 0 \]

2. Credit growth drives markets towards a self-organized critical state

CAPM model \((h)\):  
\[ \tilde{r} = \alpha + \beta r_m + \xi \]

Problem: to compensate for risk, investors expect \( \tilde{r} = 6 - 8\% \)

If Jesus Christ had invested $1 at a 2% return, he would own 1000x global GDP today. What gives?

Answer:  
\[ r^- = \frac{p(h)}{1 - p(h)} \tilde{r} >> \tilde{r} \]

(i.e., there are crashes)
Why Self-organized Criticality?

Credit Availability Improves

Leverage Boosts Return on Capital

Credit growth funds investment (directly or through buybacks)

Growing claims on future revenues; Vulnerability to drop in revenues

Revenue declines are contagious
Is Criticality Desirable?

Small crises lead to:

- Efficient use of capital: investment goes to most valuable projects
- Cleansing events release resources for new ventures (including human capital, with training and mobility)

Large crises need to be avoided… lessons from forest management:

- dry season restrictions
- preventive positioning of firefighting equipment
- fire breaks
- prescribed burns?

Sovereign debt crisis: a prescribed burn in a global dry season?
Is the Market “Intelligent”?

Architecture

Learning

Predict future prices

Trade (every time scale) → Price is approximately a Martingale

Evidence for self-organized criticality

Is the market “intelligent”?
Is the Market “Intelligent”?

• What is “intelligence”? 
  One answer: ability to discover laws of motion…
  Examples: Newton, Einstein are “intelligent” by this measure

• What are the laws of motion of financial markets? 
  Here, the creator is mankind; yet we don’t know the effective laws of motion: 
  we only created the microscopic laws, i.e. the double-auction market

Example: execution of a hidden order over time through an incremental 
“slice and dice” process

• What is the expected price change? 

Note: this is not Physics! Mankind created the market but not 
its effective dynamical laws…
Fair Pricing Theory

Basic assumptions

1. Efficiency: \[ p(\text{continue})(\tilde{S}_{k+1} - \tilde{S}_k) + p(\text{stop})(S_{k+1} - \tilde{S}_k) = 0 \]

2. “Fair pricing”: \[ S_k = \frac{\sum_{i=1}^{k} n_i \tilde{S}_i}{\sum_{i=1}^{k} n_i} \]

Solving the Theory

Combining the two sets of equations,

\[ \tilde{S}_{i+1} - \tilde{S}_i = \frac{p_i}{\sum_{i+1}} \left( \tilde{S}_i - \frac{1}{i} \sum_{k=1}^{i} \tilde{S}_k \right) \]

where \( \sum_{i} \stackrel{\text{def}}{=} = \sum_{k=0}^{\infty} p_{i+k} = p(N \geq i) \)

Solving by recursion,

\[ h_{i+1} = -\frac{1}{i p_1} \frac{\sum_1 \sum_2}{\sum_{i+1}} r_1^+ \]

If hidden order sizes are Pareto-distributed,

\[ p_i = \frac{1}{\zeta(\alpha + 1, 1) i^{\alpha+1}} \]

\[ k \gg 1 \]

\( \tilde{S}_k - S_k = r_1^+ k^{\alpha-1} \quad (\alpha > 1) \]

\( \tilde{S}_k - S_k = r_1^+ \ln(k) \quad (\alpha = 1) \)
Institutional Order Distribution

Transaction Size PDF

\[ 1 + \alpha = 2.5 \]

\( \alpha \approx 1.5 \rightarrow \text{square root impact function} \)
Empirical Evidence for Fair Pricing

Dataset: 95 portfolio managers, 2008-2011, EU and US combined (135228 trades >1% daily volume)
Conclusion

The financial market has the architecture of a global algorithmic brain

There is evidence of self-organizing criticality
- Power-law tails in distributions of returns, magnitude of crises, etc
- Long-range correlations
- Control methods similar to forest management

There is evidence of self-organizing intelligence
- Pricing securities: news is followed by price adjustments in minutes
- The market has known laws of motion before we discovered them

Not infallible… this brain predicted a Romney victory…

It also suffers from chronic anxiety attacks, requiring injections of central bank assistance – as a non-linear system it is difficult to predict effects of policy on its behavior

*Who is the global psychiatrist?*