The Crisis in Economic Theory

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presentation at ABM conference
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Where it went wrong—and how the crisis is changing it
Today’s Crisis

• We have been faced with a virtual collapse of the world’s financial system which has had dire consequences for the real economy.
• The system has just gone through another paroxysm
• Most of the explanations given involve networks of banks, trust and contagion at all levels
• These are not features of, nor characteristic of, economic models
• But they are typical of complex systems
• Such systems can undergo sudden major changes

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A shift in approach in other disciplines

• There has been a shift away from what Bob May called the comfortable consensus in ecology for example.
• The standard view was that large systems in nature were intrinsically stable if man did not interfere with them.
• Furthermore the state of these systems was the result of a long evolution towards optimality.
• Both of these views have been challenged in other disciplines.

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Should this cause us to fundamentally rethink our theory?
The structure of this talk

1. Who is responsible for the crisis?
2. How sound is our basic theory?
3. General Equilibrium
4. The efficient markets hypothesis
5. Alternative approaches ABM models
6. Two models
7. Fluctuating asset prices
8. Contagious information elimination
9. Conclusions

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Confidence in our theory

The “central problem of depression-prevention has been solved,”, Robert Lucas 2003 presidential address to the American Economic Association.

In 2004, Ben Bernanke, chairman of the Federal Reserve Board, celebrated the « Great Moderation » in economic performance over the previous two decades, which he attributed in part to improved economic policy making.
The responsibility of scientists

• This is a longstanding debate with which physicists are familiar
• It was brought into particular prominence by the development of nuclear weapons.
• But what about economists?
Which side should we come down on?

- My basic claim is that we have been building unsound models which were the basis for many policies and practices.
- This was not simply harmless academic research
- Too many people developed and acted according to a world view which was unjustified
- What are now referred to as « excesses » are an intrinsic part of the economic system.
- We were not guilty of not forecasting the onset of the crisis but we were guilty of building models in which it could not happen.

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Bourbaki

• Why do applications [of mathematics] ever succeed? Why is a certain amount of logical reasoning occasionally helpful in practical life? Why have some of the most intricate theories in mathematics become an indispensable tool to the modern physicist, to the engineer, and to the manufacturer of atom-bombs? Fortunately for us, the mathematician does not feel called upon to answer such questions.

• (Bourbaki Journal of Symbolic Logic 1949, 2)
The Governor of the European Central Bank

- When the crisis came, the serious limitations of existing economic and financial models immediately became apparent. Arbitrage broke down in many market segments, as markets froze and market participants were gripped by panic. Macro models failed to predict the crisis and seemed incapable of explaining what was happening to the economy in a convincing manner. As a policy-maker during the crisis, I found the available models of limited help. In fact, I would go further: in the face of the crisis, we felt abandoned by conventional tools. In the absence of clear guidance from existing analytical frameworks, policy-makers had to place particular reliance on our experience. Judgement and experience inevitably played a key role. Trichet (2010)
The View of those responsible in the U.K.

• « But there is also a strong belief, which I share, that bad or rather over-simplistic and overconfident economics helped create the crisis. There was a dominant conventional wisdom that markets were always rational and self-equilibrating, that market completion by itself could ensure economic efficiency and stability, and that financial innovation and increased trading activity were therefore axiomatically beneficial. »

Adair Turner, Head of the U.K. Financial Services Authority

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An economic model is not scientific if it does not have “Sound Micro-foundations”

- By this we mean that we have a model based on the rational optimising behaviour of the individuals in the market or economy. This has been widely criticised from Simon onwards.
- In standard market models and in particular in macro models we characterise aggregate behaviour as resulting from such an individual model.
- This is at the heart of the General Equilibrium Model.
- Yet much structure is lost under aggregation so this is not legitimate theory.
The scientific approach

« There is something fascinating about science. One gets such wholesale returns of conjecture out of such a trifling investment of fact »

Mark Twain, Life on the Mississippi (1883)
Rationality

• Why are we economists so attached to our rational individuals?
• Mathematical convenience or economic plausibility?
• The assumptions are not testable they come from introspection. (Pareto, Koopmans, Hicks…..)
• They do not allow for development of preferences over time
• They do not allow for the influence of others
The Easy Way Out

- Macroeconomists make the assumption that the aggregate economy or market acts like an individual.
- They use the « representative agent »
- This removes the problems raised by SMD since an economy with one agent has a unique and stable equilibrium
- But is this legitimate?
- ABM explicitly remove this assumption

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Explaining economic phenomena

• Everyone wants to know how the economy can suddenly go into a downturn like the current crisis.
• Do economists build models which can explain this or do they offer ad hoc explanations without really questioning their models, (DSGE for example)?
• In my view, we start with the wrong basis, we start from the isolated individual and build up to the aggregate without looking at the most important feature: the economy as a system of interacting agents.
• I believe, that we should view the economy as a « complex adaptive system » and that a very useful way of modelling such systems is provided by ABM.

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Correspondence with Bob Solow April 1988

- « My view of the way economists actually do behave coincides with yours, and most especially about macroeconomists. I have become a sort of common scold on this subject.
- I wholeheartedly agree with the point that economics self-destructs in part because we insist on supposing that everywhere and always individuals maximize purely individualistic preferences subject only to technological, legal, and budget constraints.
Correspondence continued

• It is a transparently false assumption, and the brotherhood expends vast ingenuity trying to account for facts within that silly framework.
• There are at least two of us. »

Robert M Solow
The result of the insistence on « scientific » foundations

- Modern macro-economists have built more and more abstract and mathematically sophisticated models (Dynamic Stochastic General Equilibrium Models) but continue to base these on the same foundations.
- These models do not contain the possibility of a crisis
- They bear no perceptible relation to reality.
“Maybe there is in human nature a deep-seated perverse pleasure in adopting and defending a wholly counterintuitive doctrine that leaves the uninitiated peasant wondering what planet he or she is on.”

Robert M Solow 2009
Our basic assumptions Trichet again

- First, we have to think about how to characterise the homo economicus at the heart of any model. The **atomistic, optimising agents** underlying existing models do not capture behaviour during a crisis period. We need to deal better with **heterogeneity** across agents and the interaction among those heterogeneous agents. We need to entertain alternative motivations for economic choices. **Behavioural economics** draws on psychology to explain decisions made in crisis circumstances. **Agent-based modelling** dispenses with the optimisation assumption and allows for more **complex interactions** between agents. Such approaches are worthy of our attention.
Are there specific actors in the economy who are responsible?

• « In an avalanche no single snowflake feels itself responsible »

Voltaire

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Isaac Newton

« I can calculate the motion of heavenly bodies, but not the madness of people »

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Assumptions on Individuals

- If we have agents who are different we can make weaker assumptions on their behaviour, in particular on their preferences and choices.
- What looks at the aggregate level like the behaviour of a very sophisticated agent may be constructed from the aggregation of simple individuals, (Forni and Lippi).
- We can use this insight in building ABM.

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Les abeilles

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Coordination v. Efficiency

• **Efficiency** is the major concern of economists
• We focus on efficient allocations of resources, yet perhaps the problem of coordination is the most important
• How do collective outcomes emerge from the interaction between individuals each of whom has only a local vision of the situation?
• If we think of the economic system as **self organising**, will this result in a stable « equilibrium »?

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Different dynamics

• In the face of repeated, if infrequent crises should we not question our models where sudden changes are attributed to exogenous shocks? Rather than trying to return to our basic assumptions perhaps we should rethink the whole structure.

• Ben Bernanke « The brief market plunge was just an example of how complex and chaotic, in a formal sense, these systems have become… What happened in the stock market is just a little example of how things can cascade, or how technology can interact with market panic »

Interview with the IHT May 17th 2010

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A Remark

• We spent the twentieth century perfecting a model based on nineteenth century physics
• Maybe in the twenty first century we can make more use of twentieth century physics

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Self Organisation

• This idea that markets self organise was espoused by Hayek
• This has been used as a justification for not interfering with markets.
• Markets do clearly self organise but we have no reason to believe that this is a stable process.
• As the actors within them modify their rules new norms appear and these can gently lead the system to major “phase transitions”.

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The weakness of our foundations

All the economists here are aware of the difficulties with General Equilibrium Models, highlighted by Sonnenschein, Mantel and Debreu

But financial economics is built on equally shaky foundations.

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A Link between financial and real models: Rational Expectations

• Originally a way of closing our models but has become an article of faith
• As several econometricians have pointed out it would be unreasonable for individuals to have « rational expectations » if the underlying DGP has structural breaks for example.
A more modest view

• Ben Bernanke again,
  « I just think it is not realistic to think that human beings can fully anticipate all possible interactions and complex developments. The best approach for dealing with this uncertainty is to make sure that the system is fundamentally resilient and that we have as many fail-safes and back-up arrangements as possible »

Interview with the IHT May 17th 2010

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An Important Example: Financial Market Models

• Models of financial markets share the same basic building blocks.
• Agents have a way of forecasting the future prices.
• This determines how much the agents’ wish to buy and this in turn determines the price of the assets.
• The prices will influence the forecasts.
The Efficient Markets Hypothesis

- This is very simple
- All relevant information is contained in prices therefore there is no need to look anywhere else: paradox
- This basic argument comes from the work of Bachelier but his thesis adviser said…

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Un avertissement

• Quand des hommes sont rapprochés, ils ne se décident plus au hasard et indépendamment les uns des autres ; ils réagissent les uns sur les autres. Des causes multiples entrent en action, et elles troublent les hommes, les entraînent à droite et à gauche, mais il y a une chose qu'elles ne peuvent détruire, ce sont leurs habitudes de moutons de Panurge. Et c'est cela qui se conserve

Henri Poincaré Report on Bachelier’s thesis 1900
But there were other clear warnings

• From the outset Poincaré and others argued that the underlying Gaussian assumption was flawed. The empirical evidence showed this
• Keynes questioned Bachelier’s assumptions, Mandelbrot spent most of his life arguing against the efficient markets hypothesis
• Yet, Markowitz developed his optimal portfolio theory on this basis
• Worse, Black-Scholes is based on the same assumption
The crucial role of information

Underlying the faith in the capacity of markets to self organise is the « efficient markets hypothesis » But as Greenspan observed,

« The whole intellectual edifice collapsed in the summer of last year »

Alan Greenspan, testimony to House of Representatives Committee on Government Oversight and Reform, October 23rd 2008
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Mencken cited by Krugman

• H. L. Mencken: “There is always an easy solution to every human problem — neat, plausible and wrong.”
Why then did we persist?

• Because if we drop the Gaussian assumption we can no longer use the central limit theorem and we lose the finite variance property
• So we continued to look where there was light
• But Fama (1965) himself, pointed out that diversification without the hypothesis is not justified!

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Inertia

• The finance profession like the economics profession exhibited an enormous amount of inertia
• Persist with a model you know how to analyse even if it does not correspond to anything you might observe
• In the economics case, even if major crises are not possible in the model.

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No Panic!

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Where does the efficient markets hypothesis go wrong?

• Remember Poincaré’s warning
• Individuals do not only look at their own information they also observe the actions of others and infer information from those actions.

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Where does the efficient markets hypothesis go wrong?

- The assumption is strongly related to that of « Rational Expectations » that is, individuals have a correct view of the distribution of probabilities of futures states of the world.
- As Trichet (2010) again said « we may need to consider a richer characterisation of expectation formation. Rational expectations theory has brought macroeconomic analysis a long way over the past four decades. But there is a clear need to re-examine this assumption. »
- Again recent work has shown that once individuals are aware of what other individuals forecast they tend to converge on a common forecast which is not as good as the median forecast (the wisdom of crowds) but in which they feel much more confident. (Lorenz et al. 2011)
Where does the efficient markets hypothesis go wrong?

• In a world with structural breaks in the underlying stochastic process the RE hypothesis is unjustified.
• As Hendry and Mizon (2010) point out
  « The mathematical derivations of dynamic stochastic general equilibrium (DSGE) models and new Keynesian Phillips curves (NKPCs), both of which incorporate ‘rational expectations’, fail to recognize that when there are unanticipated changes, conditional expectations are neither unbiased nor minimum mean-squared error (MMSE) predictors, and that better predictors can be provided by robust devices »

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Looking into the sky quickly gets passers-by to follow.

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Informational Cascades 1

• Here rational individuals, by their interaction, achieve an inefficient result
• The restaurant example
• Individuals have two signals about the quality of two restaurants A and B.
• The private signal is 90% reliable and the public signal is 55% reliable
Informational Cascades 2

• Suppose A is “objectively better”
• The public signal says B is better
• 90% of the private signals say A is better
• Everyone may wind up in B.
• Collective influence eliminates private information
• Contradiction with “efficient markets hypothesis”

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A week on the wild side

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What is the problem with the Efficient Markets Hypothesis empirically?

• What we have to explain is sudden large movements without the arrival of an exogenous shock or piece of news.
Equilibria in Financial Markets with Heterogeneous Agents
Equilibria in Financial Markets with Heterogeneous Agents
Where did the switch come from?

• Derive a more complicated stochastic process
• Put it down to an exogenous shock, but then you must be able to identify the shock
• Find a micro model of interacting agents which generates this sort of shift
Ants

• Ants learn in an environment of which they have only very limited and local knowledge.
• Yet they produce quite sophisticated aggregate behaviour.
Ants learn to find the route to food

- Ants communicate with each other
- either through a pheromone trail
- or by tandem recruiting.
Ants learn to find the route to food

- Ants communicate with each other
- either through a pheromone trail
- or by tandem recruiting.
Ants learn to find a source of food

- Ants communicate with each other
- either through a pheromone trail
- or by tandem recruiting.
Acknowledgements for the ants

• © Guy Theraulaz, CNRS, CRCA, Toulouse (for the vidéos)

© Jacques Gautrais, CNRS, CRCA, Toulouse (for the simulations)

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How should we model this learning behaviour?

• Think of the number of ants taking a path at time $t$ as $k_t$ and suppose that one ant meets another and is recruited to the path of the other with probability $(1-\delta)$ and changes it path with probability $\varepsilon$.  

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The recruiting process

The dynamic evolution of the process is then given by

\[ \begin{align*}
  & k + 1 \text{ with probability } p_1 = P(k,k + 1) \\
  & \quad = \left( 1 - \frac{k}{N} \right) \left( \epsilon + (1 - \delta) \frac{k}{N - 1} \right) \\
  & k - 1 \text{ with probability } p_2 = P(k,k - 1) \\
  & \quad = \frac{k}{N} \left( \epsilon + (1 - \delta) \frac{N - k}{N - 1} \right).
\end{align*} \]
Limit distributions

Figure I
Equilibrium Distributions for the Model with State Space \([0, 1, \ldots, N]\) with Three Different Values of \(\epsilon\) and \(\delta\) and \(N = 100\)

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How might we use this idea to model financial markets?

• Think of several types of « gurus » or forecasting rules
• Two common examples are:
  • Fundamentalists who believe that prices will come back to some « fundamental » level
  • Chartists who extrapolate from previous prices.
• But one could add others or mixtures.
• Success of one rule reinforces the recruitment to that rule.
Models in this spirit

• With Hans Foellmer and Ulrich Horst, we have built models of financial markets to help understand where these sudden changes come from.
• These models incorporate the idea that people follow the behaviour of others particularly when that behaviour is successful.
• The behaviour is not irrational. Horizons.
• These models capture the contagion effects.
• There is structure in financial time series but no convergence to equilibrium in the standard sense.

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A Microstructure Model for Financial Markets

- Temporary equilibrium model for stock price dynamics.
- Heterogeneous agents: fundamentalists and chartists.
- Agents follow the recommendations of financial “gurus”.
- Propensities to follow individual gurus depend on the gurus’ performances → reinforcing learning effect.
- Stock prices are driven by the fluctuations in the gurus’ market shares and aggregate liquidity demand → feedback effects.
- Spontaneous herding generates temporary bubbles and crashes.
- Prices temporarily deviate, but inevitably return to fundamentals.

We study a financial market model where temporary bubbles occur, but where the overall behavior of the asset price process is ergodic.

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Stopping the process from exploding

• Bound the probability that an individual can become a chartist
• If we do not do this the process may simply explode
• We do not put arbitrary limits on the prices that can be attained however
Ergodicity of the Price Performance Process

• Theorem: Under certain regularity conditions on the probabilistic structure of the « gurus’ » recommendations the price performance process is ergodic.

• The presence of Chartists is clearly revealed by the nature of the limit distribution.

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A New Idea of Equilibrium

- The distribution of the time averages of prices converges.

- If the probability of becoming a chartist is not too high.
The Distribution of Stock Prices

Figure 1: Empirical stationary distribution of asset prices in a model with (red) and without (green) chartists.
Bubbles and Crashes

Figure 2: A bubble and the corresponding fraction of chartists.
Systemic Risk and the Role of the financial network

• As Haldane has pointed out the structure of the financial network, the links between countries or financial institution can play a major role in undermining the stability of the system.

• Increased connectivity is not enough to guarantee stability, other features are important.
The Bank of England’s View

When comparing the failure of Lehman bros and the epidemic of bird flu, Haldane says,

« These similarities are no coincidence. Both events were manifestations of the behaviour under stress of a complex, adaptive network. Complex because these networks were a cat’s-cradle of interconnections, financial and non-financial. Adaptive because behaviour in these networks was driven by interactions between optimising, but confused, agents. Seizures in the electricity grid, degradation of ecosystems, the spread of epidemics and the disintegration of the financial system – each is essentially a different branch of the same network family tree. »

Andy Haldane, Director of the Bank of England responsible for financial stability.

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US banks failed during the crisis

Failed banks: 0
Losses: 0.0 bns of $
The evolution of the international financial network 1985-2005
Chart 2: Global Financial Network: 1995

1995

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Chart 3: Global Financial Network: 2005

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The danger signs

1. The scale and interconnectivity of the international financial network has increased significantly over the past two decades.
2. Nodes have increased 14-fold and links have increased 6-fold.
3. The degree distribution has a long-tail. Measures of skew and kurtosis suggest significant asymmetry in the distribution. There is a small number of financial hubs with multiple spokes.
4. The average path length of the international financial network has shrunk over the past twenty years. Between the largest nation states, there are fewer than 1.4 degrees of separation.

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Result: Vulnerability

• Such systems are vulnerable to the transmission of problems, particularly those originating in one of the large nodes.
• But nobody planned that the system should develop in this way, it is the result of self organisation.

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Why is Greece of concern to the U.S.?

• U.S banks have very limited exposure to the Greek crisis. They hold very few Greek bonds and are not linked with Greek banks i.e. do not hold their bonds
• They are linked with German and French banks
• But the latter have extensive holdings of Greek assets.

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• Many people argue that derivatives reduce systemic problems, in that participants who can’t bear certain risks are able to transfer them to stronger hands. These people believe that derivatives act to stabilize the economy, facilitate trade, and eliminate bumps for individual participants. On a micro level, what they say is often true. I believe, however, that the macro picture is dangerous and getting more so. Large amounts of risk, particularly credit risk, have become concentrated in the hands of relatively few derivatives dealers, who in addition trade extensively with one other. The troubles of one could quickly infect the others. On top of that, these dealers are owed huge amounts by non-dealer counter-parties. Some of these counter-parties, are linked in ways that could cause them to run into a problem because of a single event, such as the implosion of the telecom industry. Linkage, when it suddenly surfaces, can trigger serious systemic problems.

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The derivatives genie is now well out of the bottle, and these instruments will almost certainly multiply in variety and number until some event makes their toxicity clear. Central banks and governments have so far found no effective way to control, or even monitor, the risks posed by these contracts. In my view, derivatives are financial weapons of mass destruction, carrying dangers that, while now latent, are potentially lethal.

Warren Buffet 2002
A Very Simple Example

• What we must do is to build models which capture the role of the interaction between individuals, their local rationality and the impact of this on the aggregate evolution of the market or economy.

• The idea of our example is to show how the gradual but rational adoption of rules at the individual level may lead to radical change at the aggregate level.

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**Historical motivation**

1. trading complex credit derivative products without really understanding what they’re worth

2. ... in the face of bad news accumulating ...

3. Crash!!!

Why so sharp?

The model: rule epidemics

- The rule:
  buy an ABS without checking whether it is “toxic” or not

- Strategy: follow the rule ($x_i=1$, $i=1,...,N$ labels agents)
  don’t, i.e. check before buying ($x_i=0$)
  Idea: checking is costly, if majority follows the rule, then I better follow it too

- $\text{Prob}[\text{ABS is toxic when checked}] = p$  (bad news: $p$ larger than expected)

- Agents connected in a network (OTC market):
  i trades with j drawn at random among his neighbors

- Payoffs: pay a price $p_0$ to seller
  - resell at $p_2 < p_0$ if buyer checks & ABS toxic
  - resell at $p_1 > p_0$ else
  - checking costs $-\chi$ (drawn from pdf $\Phi(\chi)$)

(reduce # params. by rescaling: $p_1-p_2=1$, $c=p_0-p_2$)

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<tr>
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<th>check &amp; toxic</th>
<th>no check</th>
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<tr>
<td>$z_i=0$</td>
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<td>$z_i=1$</td>
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\textbf{Analysis}

\begin{itemize}
  \item Expected payoffs:

  \[ u_i(z_i = 1) = E_j \left[ -p(1 - z_j)c + [1 - p(1 - z_j)](1 - c) \right] = 1 - p(1 - \bar{z}_i) - c \]

  \[ u_i(z_i = 0) = (1 - p)(1 - c) - \chi_i \quad \bar{z}_i = \frac{1}{|N_i|} \sum_{j \in N_i} z_j \]

  \item Best response:

  \[ z_i^* = \frac{\theta (u_1(1) - u_i(0))}{\theta (p(\bar{z}_i - c) + \chi_i)} = \frac{\theta (u_1(1) - u_i(0))}{\theta (p\bar{z}_i + \chi_i)} \]

  \item Nash equilibria?
\end{itemize}
Mean field analysis

- Regular random graph (\(|N_i| = k\) for all \(i\))

- \(\pi(\chi) \equiv P\{z_i^* = 1|\chi_i = \chi\}\)

  \[= \sum_{\ell > (c - \chi/p)k} \binom{k}{\ell} \frac{\bar{\pi}^\ell}{(1 - \bar{\pi})^{k - \ell}} \quad \bar{\pi} = E_{\chi}[\pi(\chi)]\]

- Taking expectation over \(\chi_i\) \(\Rightarrow\) self-consistent equation

  \[\bar{\pi} = E[\chi_i > p(c - \bar{z}_i)]\]

  \[= \sum_{\ell=0}^{k} \binom{k}{\ell} \frac{\bar{\pi}^\ell}{(1 - \bar{\pi})^{k - \ell}} P\{\chi > p(c - \ell/k)\}\]

  \[= F(\bar{\pi})\]
The function \( F(\pi) \)

- \( p = 0.1, 0.01, 0.005, 0.002, 0.0013, 0.001 \)
- \( \chi = 0.01 \) for 80% of agents, 20% informed minority (\( \chi=0 \))
- \( k=11 \) neighbors, \( c=0.8 \)

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Coexistence

$z_i = 1$ for all agents is always an equilibrium.

If $p$ is small enough it is the only equilibrium.

Exponential distribution of $\chi_i$ with $E[\chi_i] = 0.01, k=11$ neighbors, $c=0.9$

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Logit: \( P(z_i = 1) \propto e^{B[u_i(1) - u_i(0)]} \)

\( z_i=1 \) state unstable for large \( p \) if response too noisy (B small)

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Noisy best response

Logit: \( P\{z_i = 1\} \propto e^{B[u_i(1) - u_i(0)]} \)

\( z_i = 1 \) state unstable for large \( p \) if response too noisy (\( B \) small)

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Regulating this sort of system

• My main argument in this context is that the sort of complex system I have described is intrinsically difficult to control
• What we do not have in our model is an essential feature that as the actors find it profitable to make loans they will gradually lower their standards
• This will, in turn, lead to an increase in $p$

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Regulating this sort of system

• If we put in place a set of constraints and rules today they will have to be continually adapted as markets themselves adapt and self organise.

• Individuals act rationally given the limited and local information at their disposal but they may engender major changes in the aggregate

• We cannot simply design from scratch a « new regulatory framework » and then let things run.
How should we stabilise the system?

• The view that we can set up a new more sophisticated set of rules and then everything will be under control is illusory.

• It is based on the idea that there is a « correct » model and that, and if only we can find it we can establish the right rules and leave markets to sort things out.

• But, in reality there is no reason to believe that self organisation is a stable process and furthermore the economy is constantly evolving and and therefore so must the rules.

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Conclusion

• In a world where individuals interact with each other locally and with limited information, the collective behaviour of the system may undergo sudden and large changes without any « exogenous shock ». Asset markets, particularly derivative markets, are vulnerable to these. They are not the result of individual irrationality but of the intrinsic fragility of such systems.

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How long will it take?

« A new scientific truth does not triumph by convincing its opponents and making them see the light, but rather because its opponents eventually die, and a new generation grows up that is familiar with it »


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“You want to keep an open mind but you don’t want to open it so far that your brain falls out.”

Buz Brock
For those who wish to know more
Appendix

More details of the Foellmer, Horst Kirman model (2005)

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A Microstructure Model for Financial Markets

• Temporary equilibrium model for stock price dynamics.

• Heterogeneous agents: fundamentalists and chartists.

• Agents follow the recommendations of financial “gurus”.

• Propensities to follow individual gurus depend on the gurus’ Performances → reinforcing learning effect.

• Stock prices are driven by the fluctuations in the gurus’ market shares and aggregate liquidity demand → feedback effects.

• Spontaneous herding generates temporary bubbles and crashes.

• Prices temporarily deviate, but inevitably return to fundamentals.

We study a financial market model where temporary bubbles occur, But where the overall behavior of the asset price process is ergodic.

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Specifying Individual Behavior

There is a finite set $A$ of agents trading a single risky asset.

The demand function of the agent $a \in A$ takes the log-linear form

$$e_i^a(p, \omega) = c_i^a(\hat{S}_t^a(\omega) - \log p) + \eta_i^a(\omega)$$

where $\hat{S}_t^a$ and $\eta_i^a$ denote the agent's current reference level and liquidity demand, respectively.

The logarithmic equilibrium price $S_t := \log P_t$ is defined through the market clearing condition of zero total excess demand:

$$S_t := \frac{1}{c_t \sum_{a \in A}} c_i^a \hat{S}_t^a(\omega) + \eta_t$$

Temporary equilibrium prices are given as a weighted average of individual price assessments and liquidity demand.
Choosing Individual Assessments

The choice of the reference level is based on the recommendations of some financial experts:

\[ \hat{S}_t^a \in \{ R_t^1, \ldots, R_t^m \} \]

The fraction of agents following guru \( i \) in period \( t \) is given by

\[ \pi_t^i := \frac{1}{c_t} \sum_{a \in A} c_t^a 1_{\{ \hat{S}_t^a = R_t^i \}} \]

The logarithmic equilibrium price for period \( t + 1 \) takes the form

\[ S_t = \sum_{i=1}^m \pi_t^i R_t^i + \eta_t \]

Temporary equilibrium prices are given as a weighted average of recommendations and liquidity demand.

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The Gurus’ Recommendations

The recommendation of guru $i \in \{1, \ldots, m\}$ is based on a subjective assessment $F_i$ of some fundamental value and a price trend:

$$R^i_t \equiv S_{t-1} + \alpha^i \left[ F^i - S_{t-1} \right] + \beta^i \left[ S_{t-1} - S_{t-2} \right]$$

The dynamics of stock prices is governed by the recursive relation

$$S_t = F(S_{t-1}, S_{t-2}, \tau_t) = \left[ 1 - \alpha(\pi_t) + \beta(\pi_t) \right] S_{t-1} - \beta(\pi_t)$$

in the random environment $\{\tau_t\} = \{\pi_t, \eta_t\}$

Unlike in Physics, the environment will be generated endogenously. The dynamics of stock prices is described by a linear recursive equation in a random environment of investor sentiment and liquidity demand.

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Fundamentalists

The recommendation of a fundamentalist conveys the idea that prices move closer to the fundamental value:

\[ R_t^i := S_{t-1} + \alpha_i^i \left[ P^i - S_{t-1} \right] \quad \alpha_i^i \in (0,1) \]

If only fundamentalists are active on the market

\[ S_t = \left[ 1 - \alpha(\pi_t) \right] S_{t-1} + \gamma(\pi_t, \eta_t) \sum_{i=1}^{m} \alpha_i \pi_i \]

and prices behave in a mean-reverting manner because \( \alpha_i^i \in (0,1) \)

The sequence of temporary price equilibria may be viewed as an Ornstein-Uhlenbeck process in a random environment. Fundamentalists have a stabilizing effect on the dynamics of stock prices.

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Chartists

A chartist bases his prediction of the future evolution of stock prices on past observations:

\[ R_t^i = S_{t-1} + \beta^i [S_{t-1} - S_{t-2}], \quad \beta^i \in (0,1) \]

If only chartists are active in the market

\[ S_t - S_{t-1} = \beta(\pi_t) [S_{t-1} - S_{t-2}] + \eta_t, \quad \beta(\pi_t) = \sum_{i=1}^{m} \beta^i \pi^i \]

Returns behave in a mean-reverting manner, but prices are highly transient. Chartists have a destabilizing effect on the dynamics of stock prices.

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The Interactive Effects of Chartists and Fundamentalists

If both chartists and fundamentalists are active

\[ S_t = [1 - \alpha(\pi_t) + \beta(\pi_t)]S_{t-1} - \beta(\pi_t)S_{t-2} + \gamma(\pi_t, \gamma_t), \]

Prices behave in a stable manner in periods where the impact of chartists is weak enough.
Prices behave in an unstable manner in periods where the impact of chartists becomes too strong.
Temporary bubbles and crashes occur, due to trend chasing.
The overall behavior of the price process turns out to be ergodic if, on average, the impact of chartists is not too strong.

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Performance Measures

How do the agents decide what guru to follow? The agents’ propensity to follow an individual guru depends on the guru’s performance.

We associate virtual profits with the gurus’ trading strategies:

\[ P_t^i = (R_t^i - S_{t-1}) (e^{S_t} - e^{S_{t-1}}) \]

The performance of the guru \( i \) in period \( t \) is given by

\[ U_t^i := \alpha U_{t-1}^i + P_t^i = \sum_{j=0}^{t} \alpha^{t-j} P_j^i \]

i.e., by a discounted sum of past profits.

The agents adopt the gurus’ recommendations with probabilities related to their current performance.
Performance Measures

Propensities to follow individual gurus depend on performances:

\[ \pi_{t+1} \sim Q(U_{t};\cdot) \text{ where } U_t = (U_{t}^1, ..., U_{t}^m) \]

The better a guru’s performance, the more likely the agents follow his recommendations.

The more agents follow a guru’s recommendation, the stronger his impact on the dynamics of stock prices.

The stronger a guru’s impact on the dynamics of stock prices, the better his performance.

The dependence of individual choices on performances generates a self-reinforcing incentive to follow the currently most successful guru.

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Performance Measures and Feedback Effects

The dynamics of logarithmic stock prices are described by a linear stochastic difference equation

\[ S_t = [1 - \alpha(\pi_t) + \beta(\pi_t)]S_{t-1} - \beta(\pi_t)S_{t-2} + \gamma(\pi_t, \eta_t) \]

in a random environment \{\pi_t, \eta_t\}.

Aggregate liquidity demand is modelled by an exogenous process.

The dynamics of \{\pi_t\} is generated in an endogenous manner.

The distribution of \pi_t depends on all the prices up to time \(t-1\).

The dependence of individual choices on performances generates a feedback from past prices into the random environment.

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The Associated Markov Chain

Aggregate liquidity demand follows an iid dynamics. Stock prices are given by the first component of the Markov chain

\[ \xi_t = (S_t, S_{t-1}, U_t) \]

The dynamics of the process \( \{ \xi_t \} \) can be described by

\[ \xi_{t+1} = V(\xi_t, \tau_t) = \begin{cases} F(S_t, S_{t-1}, \tau_t) \\ S_t \\ \alpha U_t + P(S_t, S_{t-1}, \tau_t) \end{cases}, \tau_t \sim Z(U_t; \cdot). \]

The map \((S_t, S_{t-1}) \rightarrow P(S_t, S_{t-1}, \tau_t)\) is non-linear.

The dynamics of the price-performance process \( \{ \xi_t \} \) can be described by an iterated function system, but standard methods do not apply.

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Stopping the process from exploding

• Bound the probability that an individual can become a chartist
• If we do not do this the process may simply explode
• We do not put arbitrary limits on the prices that can be attained however
Bounding the Impact of Chartists

We need a mean contraction condition for the price process

\[ S_t = [1 - \alpha(\pi_t) + \beta(\pi_t)] S_{t-1} - \beta(\pi_t) S_{t-2} + \gamma(\pi_t, \eta_t) \]

To this end, we bound the impact of trend chasing assuming that

\[ \sup_u |1 - \alpha(u) + \beta(u)| + \sup_u |\beta(u)| < 1 \]

where \(\alpha(u)\) and \(\beta(u)\) denotes the conditional expected impact of fundamentalists and chartists given \(U_t = u\), respectively:

\[ \alpha(u) := E[\alpha_{t+1} | U_t = u] \quad \text{and} \quad \beta(u) := E[\beta_{t+1} | U_t = u] \]

This mean contraction condition can be translated into an assumption on the behavior of an individual agent.

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Existence of Stationary Distributions

**Theorem 1:** Under our mean-contraction condition, the Markov chain $\{\xi_t\}$ is tight, i.e.,

$$\limsup_{c \to \infty} P[|\xi_t| \geq c] = 0$$

The mean contraction condition prevents stock prices from exploding.

**Theorem 2:** Under our mean-contraction condition, the Markov chain $\{\xi_t\}$ has a unique stationary distribution $\mu$, and

$$\lim_{T \to \infty} \frac{1}{T} \sum_{t=1}^{T} f(\xi_t) = \int f(\xi) \mu(d\xi) \quad P_\mu - a.s.$$ 

i.e., time averages converge to their expected value under $\mu$.

If we bound the impact of trend chasing on stock price dynamics a unique equilibrium exists.

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Ergodicity of the Price Performance Process

• **Theorem:** Under certain regularity conditions on the probabilistic structure of the « gurus’ » recommendations the price performance process is ergodic.

• The presence of Chartists is clearly revealed by the nature of the limit distribution.

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A New Idea of Equilibrium

• The distribution of the time averages of prices converges.

• If the probability of becoming a chartist is not too high.
The Distribution of Stock Prices

Figure 1: Empirical stationary distribution of asset prices in a model with (red) and without (green) chartists.

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Bubbles and Crashes

Figure 2: A bubble and the corresponding fraction of chartists.

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