



**School and Workshop on Market Microstructure: Design, Efficiency
and Statistical Regularities**

21 - 25 March 2011

Economic Theory in Crisis

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Presentation at the ICTP Workshop on Market
Microstructure: Trieste March 23rd 2011



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. An alternative approach
6. Two models
7. Fluctuating asset prices
8. Contagious information elimination
9. Conclusions



Two important questions

- To what extent should the economic crisis cause us to rethink economic theory?
- Do economists and their theories bear any responsibility for the crisis?



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) ⁴

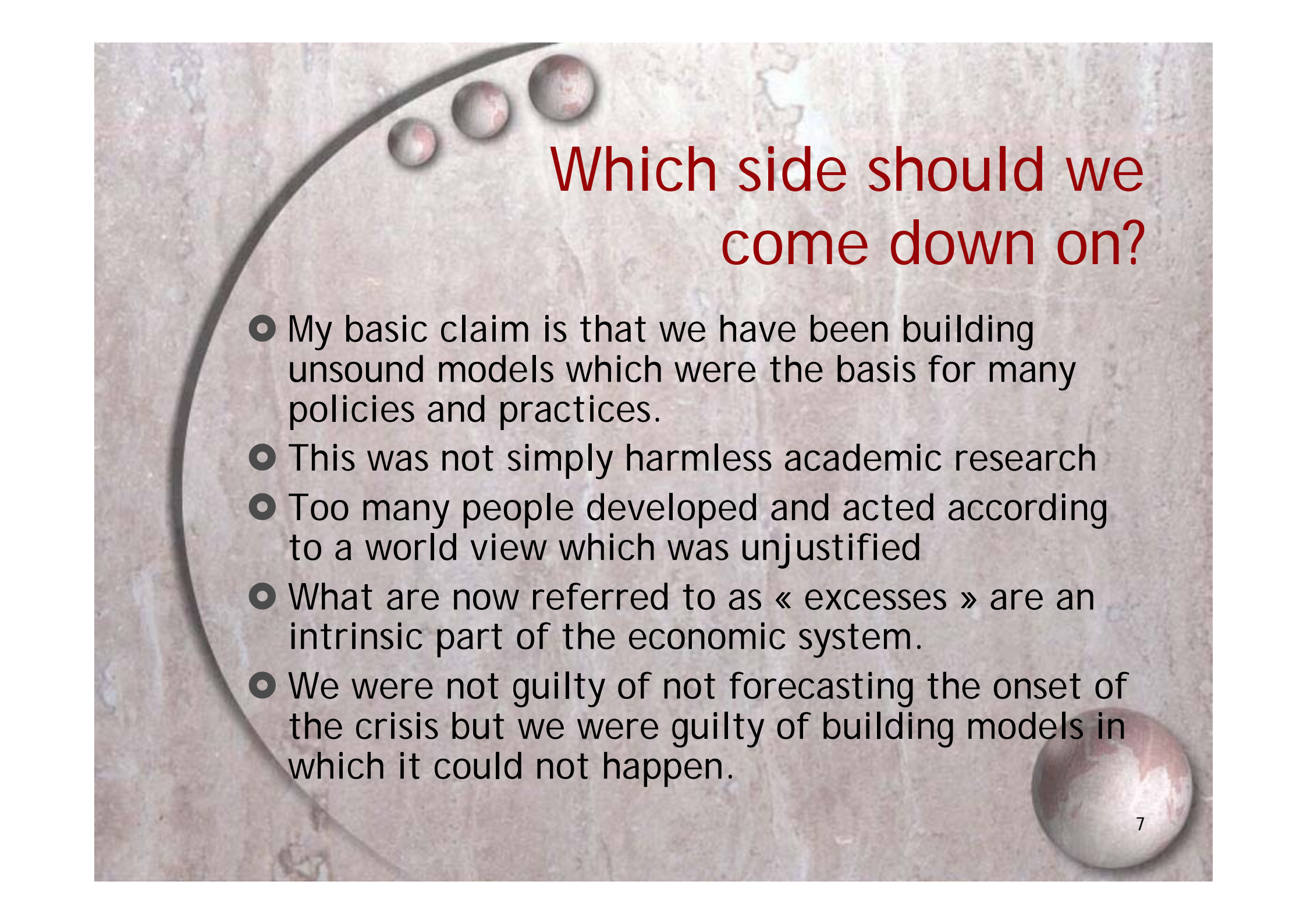
Paul De Grauwe: The crushing responsibility of economists

- « Clearly the financial crisis is not only due to the delusions of macroeconomists. The delusions were quite widespread among bankers, supervisors, media and policymakers. Yet society expects the community of scientists to be less prone to delusions than the rest. In that sense the responsibility of the economics profession is crushing ». Financial Times 2009

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.

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
- The explanations given involve **networks** of banks, **trust** and **contagion** at all levels
- These are not features of, nor characteristic of, economic models
- They are typical of **complex systems**

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.

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 »

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

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.

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?

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.

Bob Solow's View today

- 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

A simple example of a problem with rationality attention.

- One of the basic hypotheses of economics is that individuals maximise in circumstances of which they are fully aware and are capable of solving the problem with which they are faced.
- In particular they are able to concentrate their attention on that problem.
- Trichet (2010) yet again. « Very encouraging work is under way on new concepts, such as learning and rational inattention ».

How many passes?

- How many did you count?
- How many people saw something weird?

A Different Approach

- 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

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

Is complexity just a fad in economics?

- Complex systems are characterised by the following features:
- They are composed of interacting “agents”
- These agents may have simple behavioural rules
- The interaction among the agents means that aggregate phenomena are intrinsically different from individual behaviour.
- The network which governs the interaction is crucial
- Those who study market microstructure take this seriously

Coordination v. Efficiency

- **Efficiency** is the major concern of economists
- We focus on efficient mechanisms, such as auctions (an example).
- 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?



Why are Aggregates Different from Individuals?

Revolutions and Crowds

Who is responsible?

- « In a an avalanche no single snowflake feels itself responsible »

Voltaire



Isaac Newton

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

No Panic!



Presentation at the Workshop for
Chief Economists of Central Banks,
Bank of England May 2010



Why not treat the
aggregate like an
individual??

Where does the difficulty with the standard economic model come from?

- The economy is made up of individuals who interact directly.
- Such systems do not have aggregate behaviour which can be characterised as the average behaviour of the individuals

Direct interaction

- Economic agents interact with each other
- They exchange information
- They influence each other by modifying each others' expectations for example
- They mimic each other
- They trade



A Less Demanding View

- Think of a world in which agents use simple rules and interact with those around them
- They learn from and about those with those with whom they are linked
- If we take this view « externalities » are central and not an inconvenient imperfection.
- Once we accept this we have to specify the nature of interaction and how individuals take account of each others' actions and decisions The network of relations governs the evolution of the economy
- Understanding the structure and evolution of this network is crucial to understanding macroeconomic phenomena.

Ants

- Would you try to predict the behaviour of an ants' nest from the behaviour of the « representative ant »

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).



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 weakness of our foundations

Everybody here is aware of the difficulties with General Equilibrium Models, highlighted by Sonnenschein, Mantel and Debreu

But financial economics is built on equally shaky foundations.

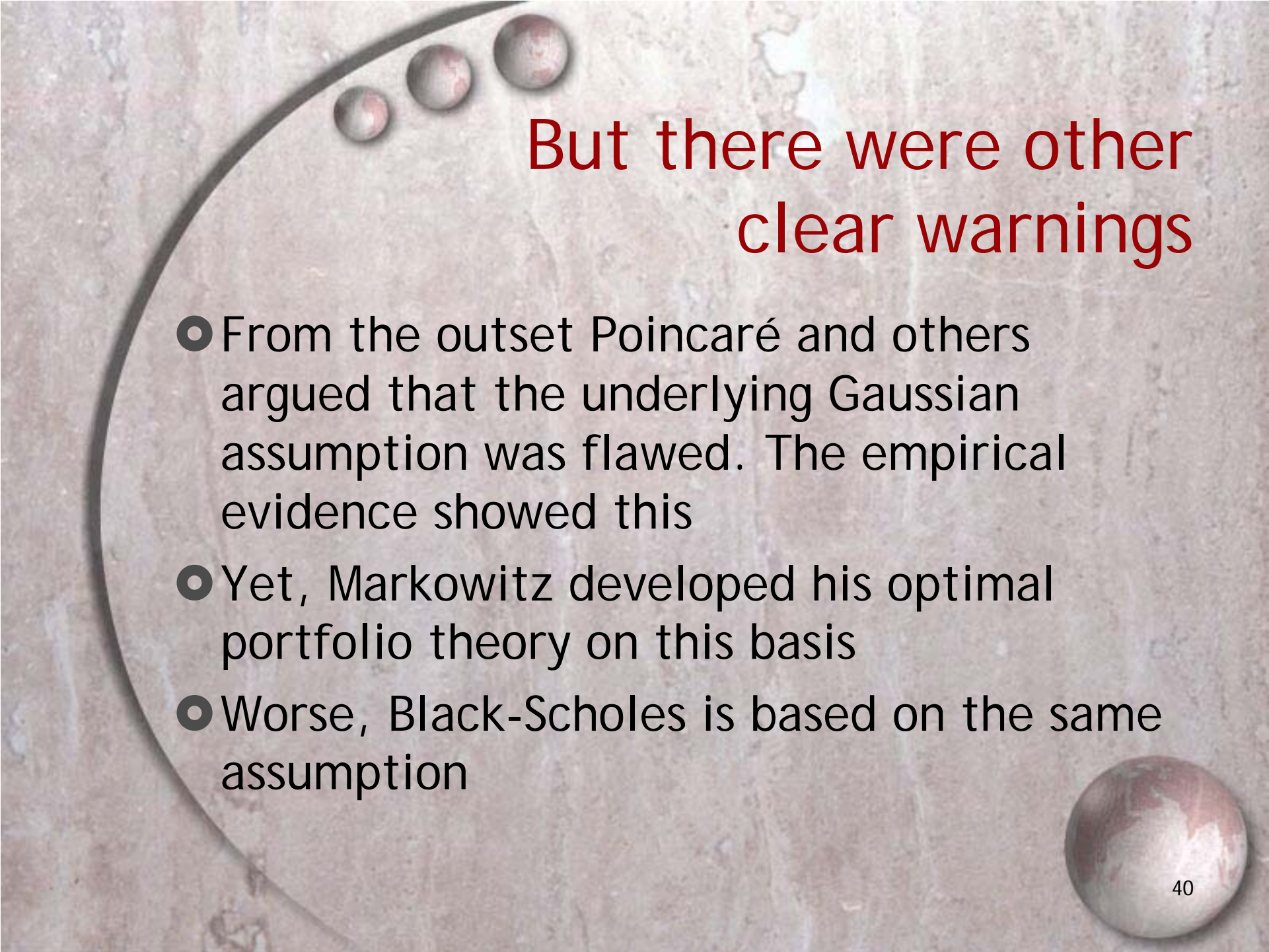
The Efficient Markets Hypothesis

- 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...

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 La Valeur de la Science 1908



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
- Yet, Markowitz developed his optimal portfolio theory on this basis
- Worse, Black-Scholes is based on the same assumption

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!

Warren Buffet's Warning

- « In our view, however, derivatives are financial weapons of mass destruction, carrying dangers that, while now latent, are potentially lethal. »

*Chairman's letter to the shareholders of
Berkshire Hathaway Inc. February 2003*

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.

Mencken cited by Krugman

- H. L. Mencken: “There is always an easy solution to every human problem – neat, plausible and wrong.”



And!

Speaking of the « efficient markets hypothesis »
« 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

Where does the efficient markets hypothesis go wrong (1)?

- 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. »

Where does the efficient markets hypothesis go wrong (1)?

- 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 »

Where does the efficient markets hypothesis go wrong (2)?

- 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.



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

Informational Cascades 1

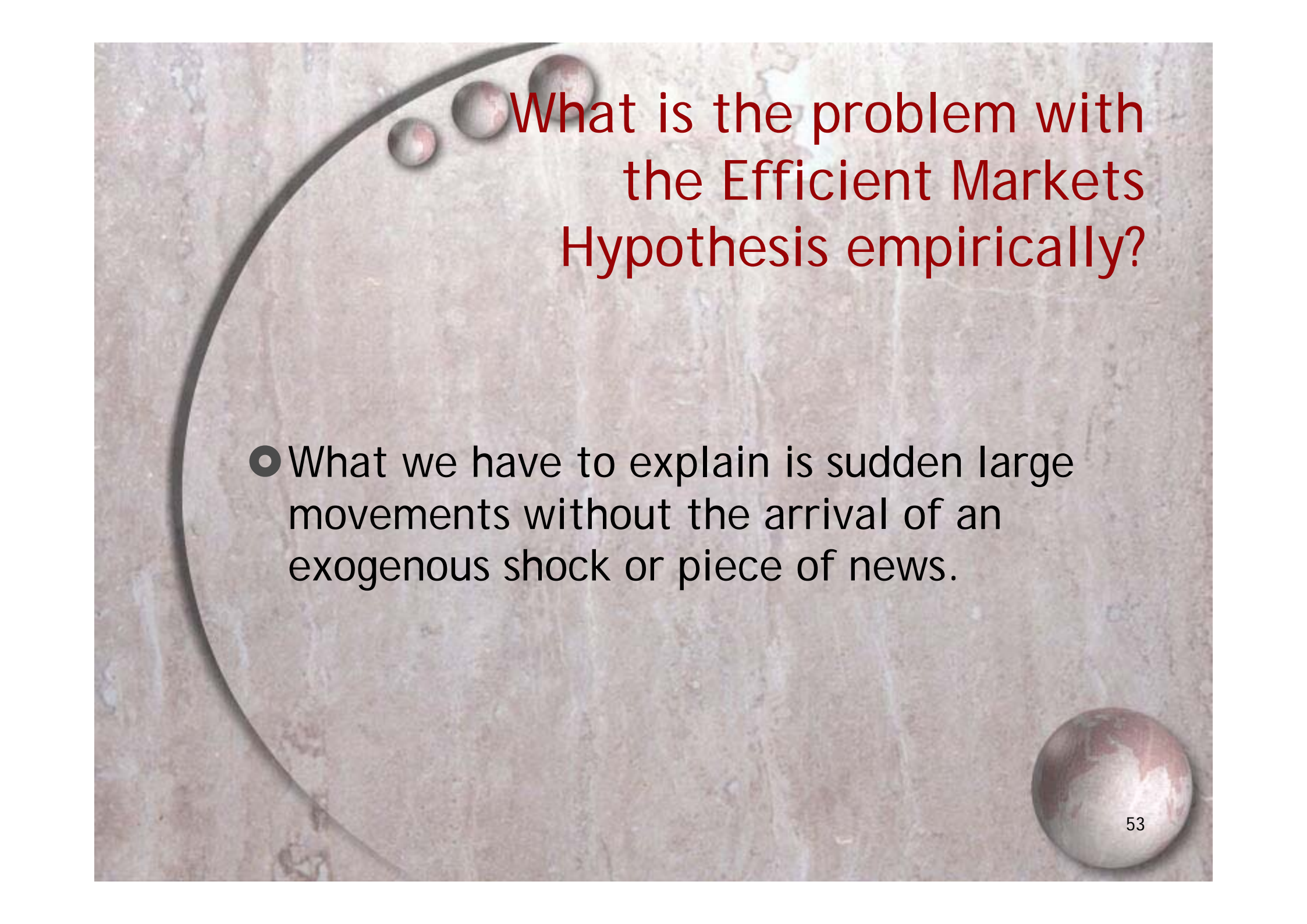
- Here rational individuals, by their interaction, achieve an inefficient result
- The restaurant example
- Individuals have two signals about the quality of two restaurants A and B.
- The private signal is 90% reliable and the public signal is 55% reliable

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”

A week on the wild side





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

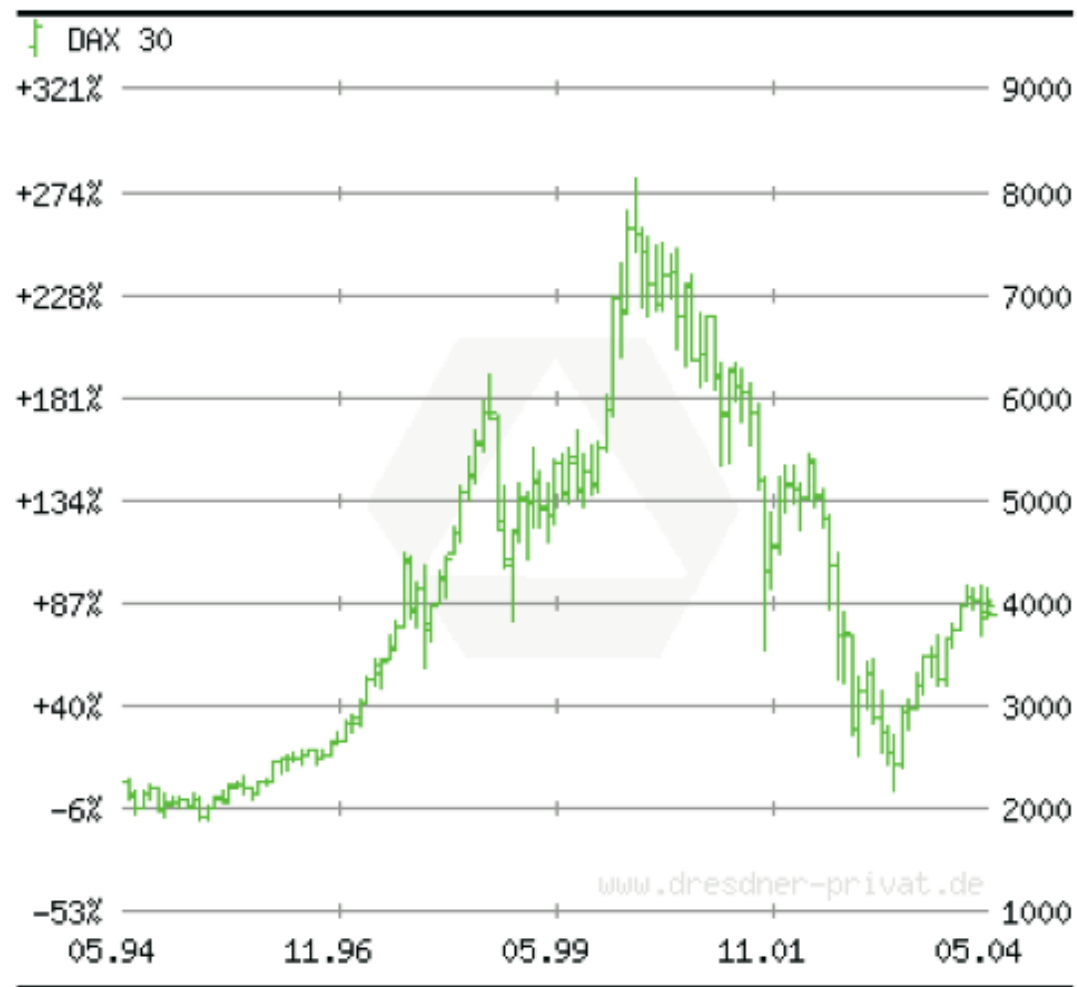


DFG Research Center: Mathematics for Key Technologies

Presentation at the Workshop for
Chief Economists of Central Banks,
Bank of England May 2010



Equilibria in Financial Markets with Heterogeneous Agents



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Where did the switch come from?

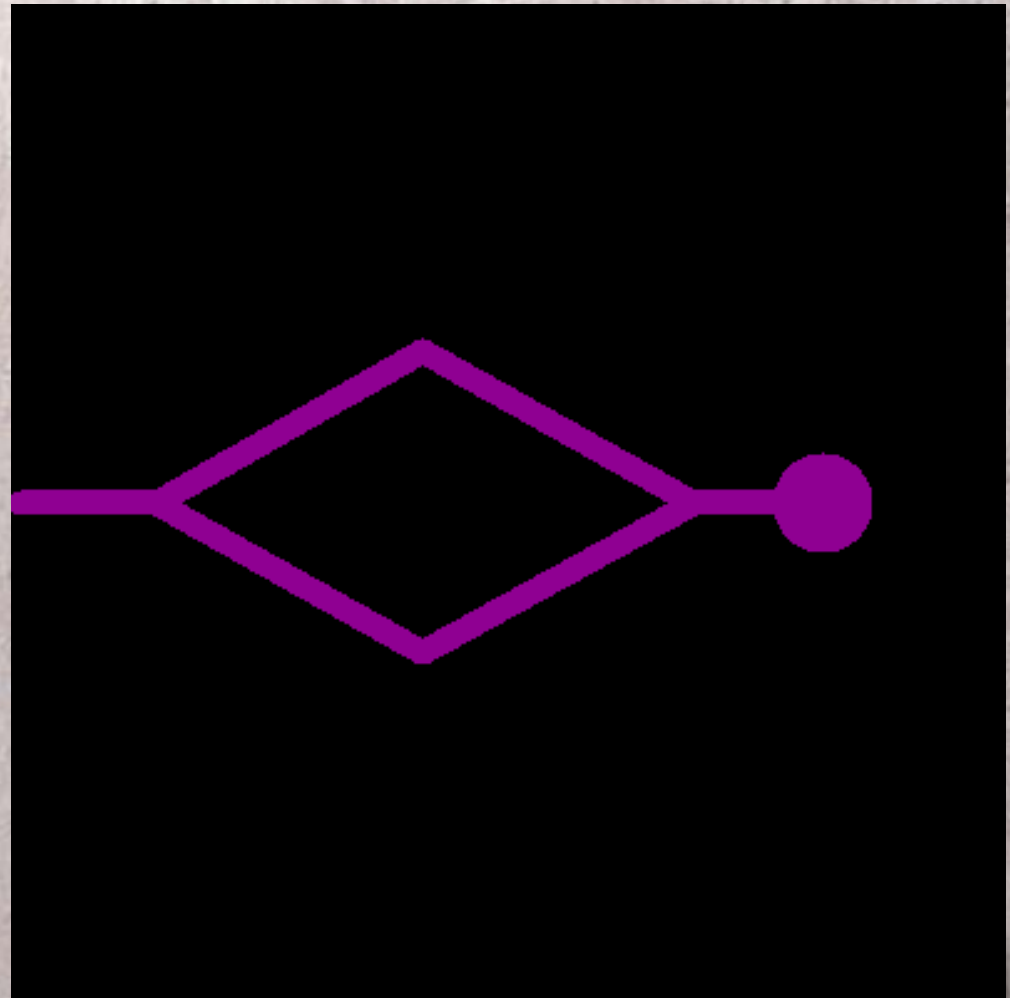
- Derive a more complicated stochastic process
- Put it down to an exogenous shock, but then you must be able to identify the shock
- Find a micro model of interacting agents which generates this sort of shift

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.



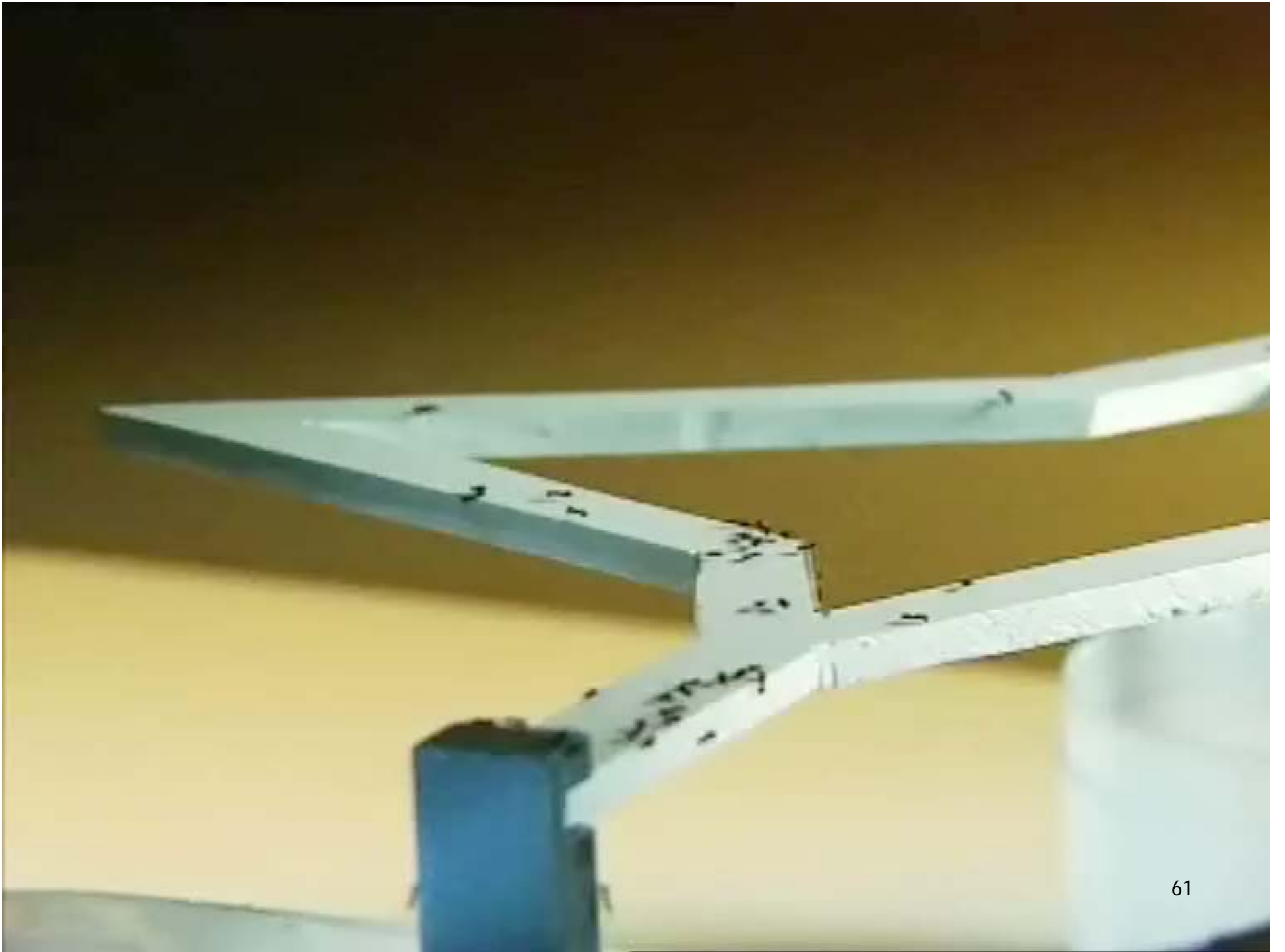
Ants learn to find the route to food

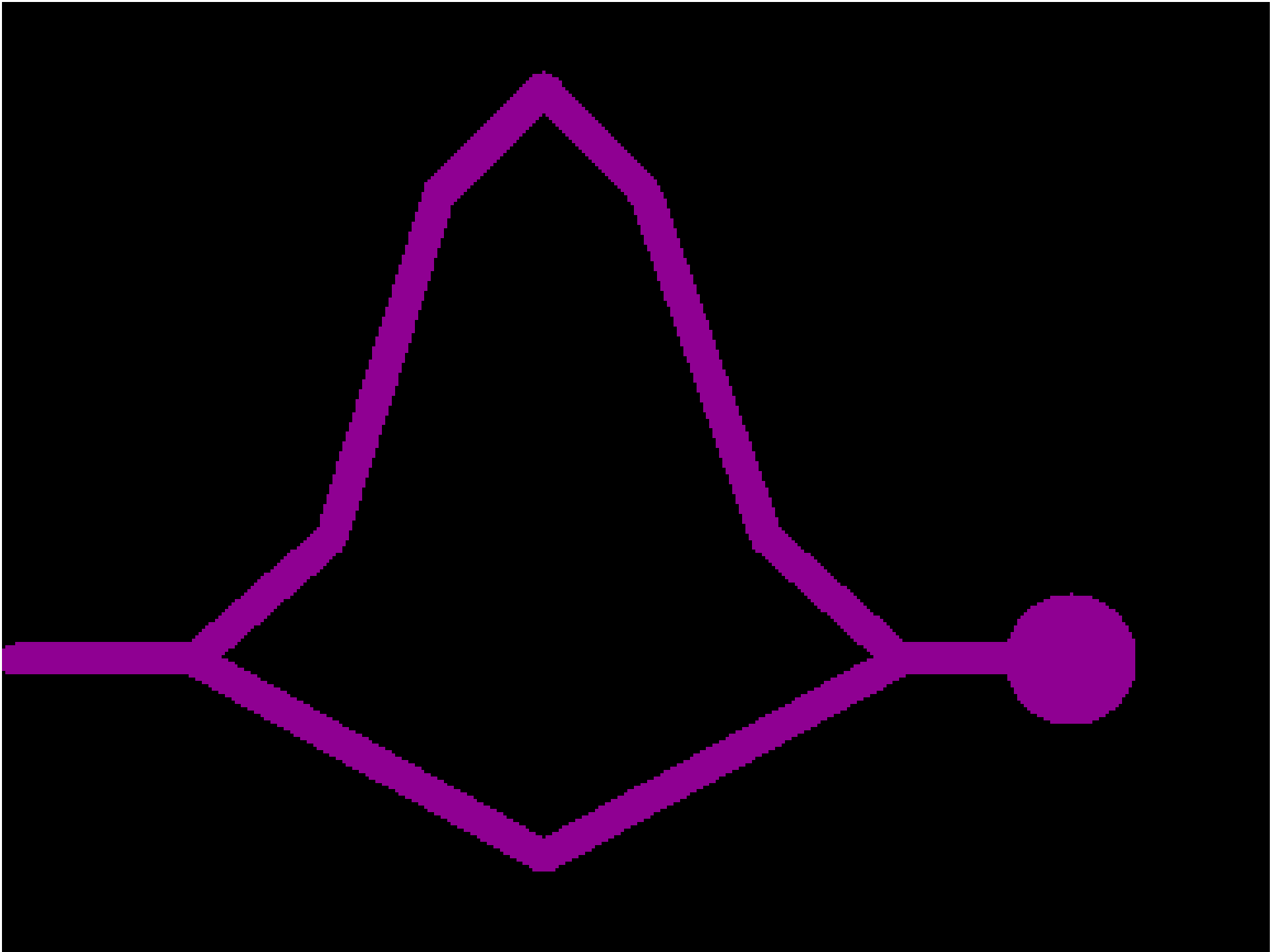
- Ants communicate with each other
- either through a pheromone trail
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Ants learn to find a source of food

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





How should we model this learning behaviour?

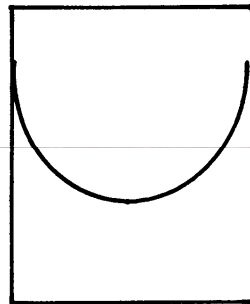
- Think of the number of ants taking a path at time t as k_t and suppose that one ant meets another and is recruited to the path of the other with probability $(1-\delta)$ and changes its path with probability ε .

The recruiting process

The dynamic evolution of the process is then given by

$$(1) \quad \begin{array}{l} \nearrow k + 1 \text{ with probability } p_1 = P(k, k + 1) \\ k \\ \searrow k - 1 \text{ with probability } p_2 = P(k, k - 1) \end{array}$$
$$= \left(1 - \frac{k}{N}\right) \left(\epsilon + (1 - \delta) \frac{k}{N - 1}\right)$$
$$= \frac{k}{N} \left(\epsilon + (1 - \delta) \frac{N - k}{N - 1}\right).$$

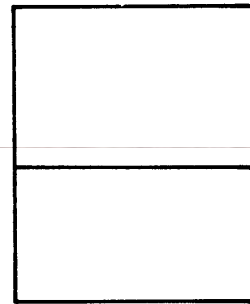
Limit distributions



$$\epsilon = 0.005$$

$$\delta = 0.01$$

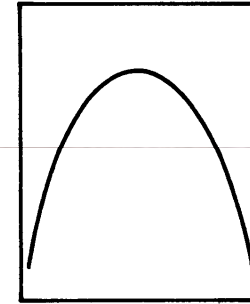
a



$$\epsilon = 0.01$$

$$\delta = 0.02$$

b



$$\epsilon = 0.15$$

$$\delta = 0.3$$

c

FIGURE I
Equilibrium Distributions for the Model with State Space $\{0, 1, \dots, N\}$ with Three
Different Values of ϵ and δ and $N = 100$

What happens with N large?

Thus, let $N \rightarrow \infty$ and $\epsilon = \alpha/N$ and $\delta = 2\alpha/N$. Redefine μ as $f(k/N)$, and consider the continuous limit distribution f as $N \rightarrow \infty$. Then we have the following.¹⁰

PROPOSITION. f is the density of a symmetric Beta distribution; i.e.,
 $f(x) = \text{const } x^{\alpha-1}(1-x)^{\alpha-1}$.



How might we use this idea to model financial markets?

- Think of two types of agents or forecasting rules
- Fundamentalists who believe that prices will come back to some « fundamental » level
- Chartists who extrapolate from previous prices.
- 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.

Herding and Imitation

“It is better (...) to fail conventionally than to succeed unconventionally.”

J.M. Keynes (1936)

“Forget about the fundamentals and think about the investors.”

The Economist (1998)

“The herd is never stupid for too long.”

T. Friedman (2000)

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.

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

$$e_t^a(p, \omega) := c_t^a (\hat{S}_t^a(\omega) - \log p) + \eta_t^a(\omega)$$

where \hat{S}_t^a and η_t^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:

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

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:

$$\hat{S}_t^a \in \{R_t^1, \dots, R_t^m\}$$

□ 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.

The Gurus' Recommendations

□ The recommendation of guru $i \in \{1, \dots, m\}$ is based on a subjective assessment F^i of some **fundamental value** and a **price trend**:

$$R_t^i := S_{t-1} + \alpha^i [F^i - S_{t-1}] + \beta^i [S_{t-1} - S_{t-2}]$$

□ The dynamics of stock prices is governed by the recursive relation

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

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.

Fundamentalists

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

$$R_t^i := S_{t-1} + \alpha^i [F^i - S_{t-1}], \quad \alpha^i \in (0, 1)$$

□ If only fundamentalists are active on the market

$$S_t = [1 - \alpha(\pi_t)]S_{t-1} + \gamma(\pi_t, \eta_t), \quad \sum_{i=1}^m \alpha^i \pi_t^i$$

and prices behave in a **mean-reverting** manner because

$$\alpha^i \in (0, 1)$$

□ 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.**

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

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

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

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.

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 guru's trading strategies:

$$P_t^i := (R_{t-1}^i - S_{t-1})(e^{S_t} - e^{S_{t-1}})$$

- 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 guru's recommendations with probabilities related to their current performance.

Performance Measures

- Propensities to follow individual gurus depend on **performances**:

$$\pi_{t+1} \sim Q(U_t; \cdot) \text{ where } U_t = (U_t^1, \dots, U_t^m)$$

- 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.

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 $\{l_t\}$ is generated in an **endogenous** manner.

□ The distribution of l_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.

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

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

- 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.

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:

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

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

Existence of Stationary Distributions

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

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

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** μ , and

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

i.e., time averages converge to their expected value under μ .

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

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.

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

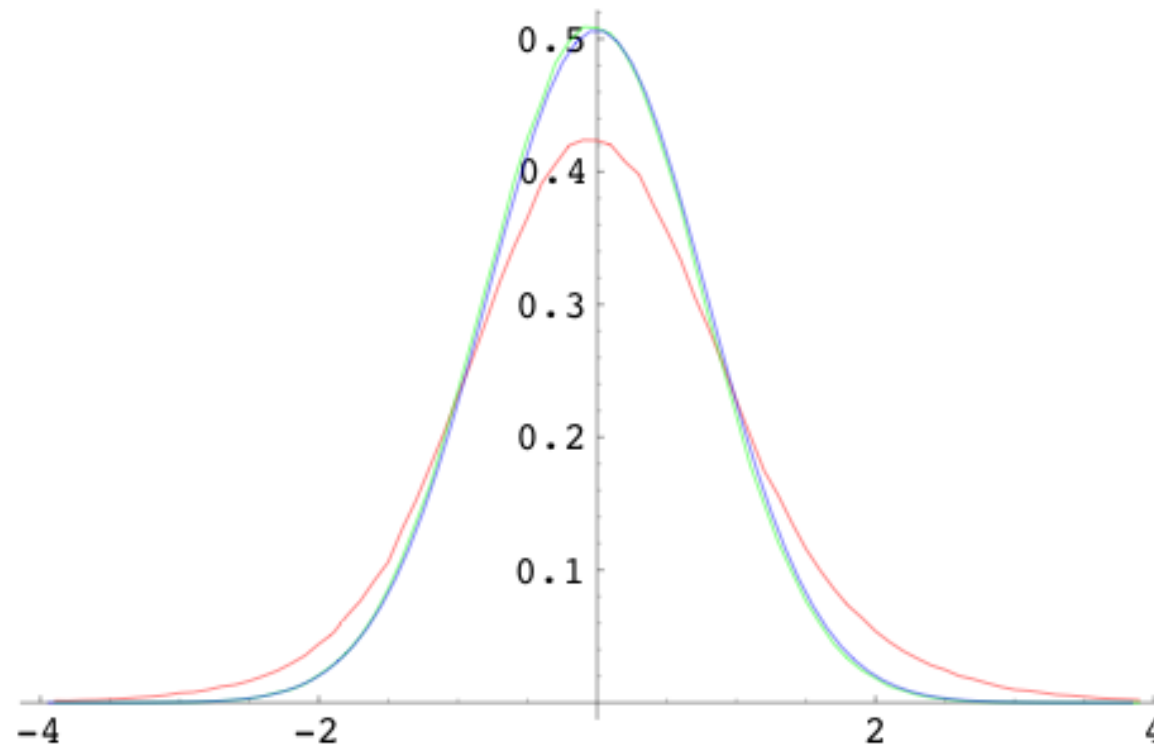


Figure 1: Empirical stationary distribution of asset prices in a model with (red) and without (green) chartists.

Bubbles and Crashes

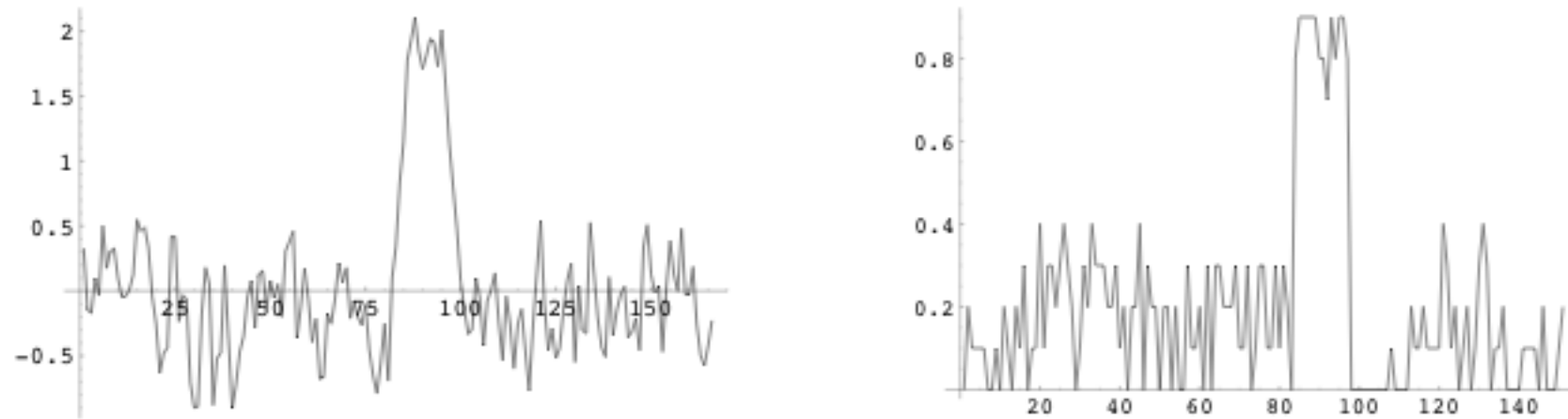


Figure 2: A bubble and the corresponding fraction of chartists.

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”.

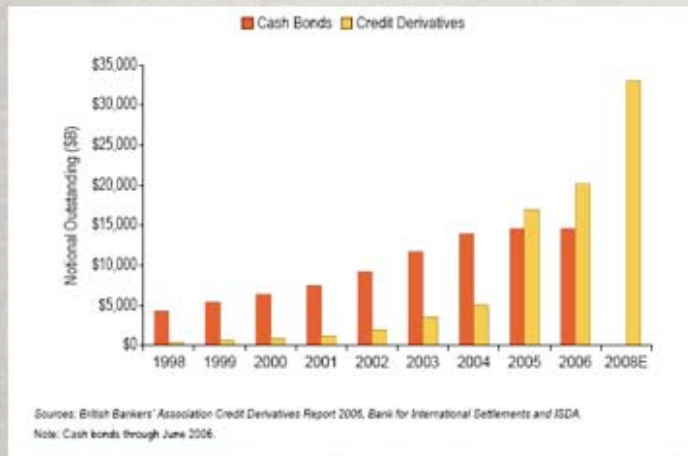


An example (with Kartik Anand and Matteo Marsili)

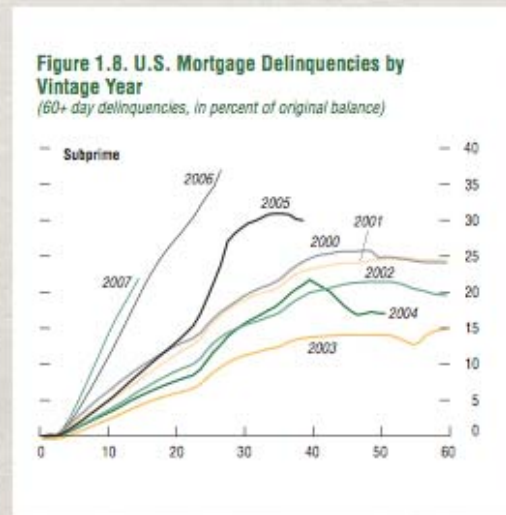
- The idea here is to show how the gradual but rational adoption of rules at the individual level may lead to radical change at the aggregate level

HISTORICAL MOTIVATION

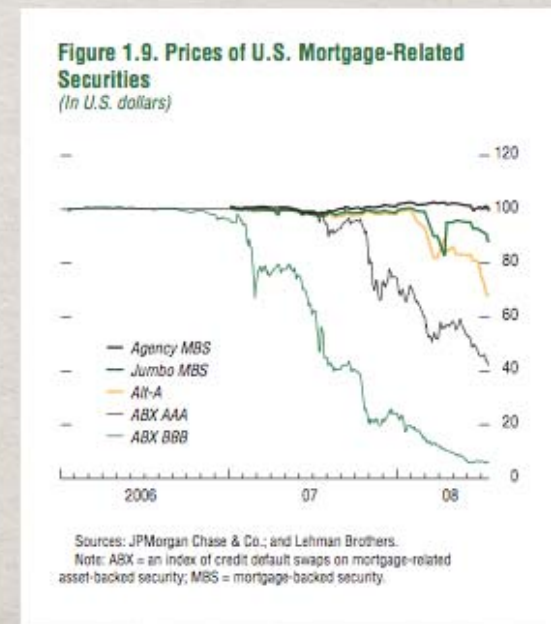
1. trading complex credit derivative products without really understanding what they're worth



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



3. Crash!!!



Why so sharp?

Figures from Global Financial Stability Report Oct. 2008

THE MODEL: RULE EPIDEMICS

- * The rule:
 buy an ABS without checking whether it is “toxic” or not
- * Strategy: follow the rule ($z_i=1$, $i=1,\dots,N$ labels agents)
 don't, i.e. check before buying ($z_i=0$)
 Idea: checking is costly, if majority follows the rule, then I better follow it too
- * Prob{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 $-\chi_i$ (drawn from pdf $\Phi(\chi)$)

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

	check & toxic	no check
$z_i=0$	$-\chi_i$	$1-c-\chi_i$
$z_i=1$	$-c$	$1-c$

ANALYSIS

☼ Expected payoffs:

$$\begin{aligned}u_i(z_i = 1) &= E_j [-p(1 - z_j)c + [1 - p(1 - z_j)](1 - c)] \\ &= 1 - p(1 - \bar{z}_i) - c\end{aligned}$$

$$u_i(z_i = 0) = (1 - p)(1 - c) - \chi_i$$

$$\bar{z}_i = \frac{1}{|N_i|} \sum_{j \in N_i} z_j$$

☼ Best response:

$$\begin{aligned}z_i^* &= \theta (u_1(1) - u_i(0)) \\ &= \theta (p(\bar{z}_i - c) + \chi_i)\end{aligned}$$

☼ Nash equilibria?

MEAN FIELD ANALYSIS

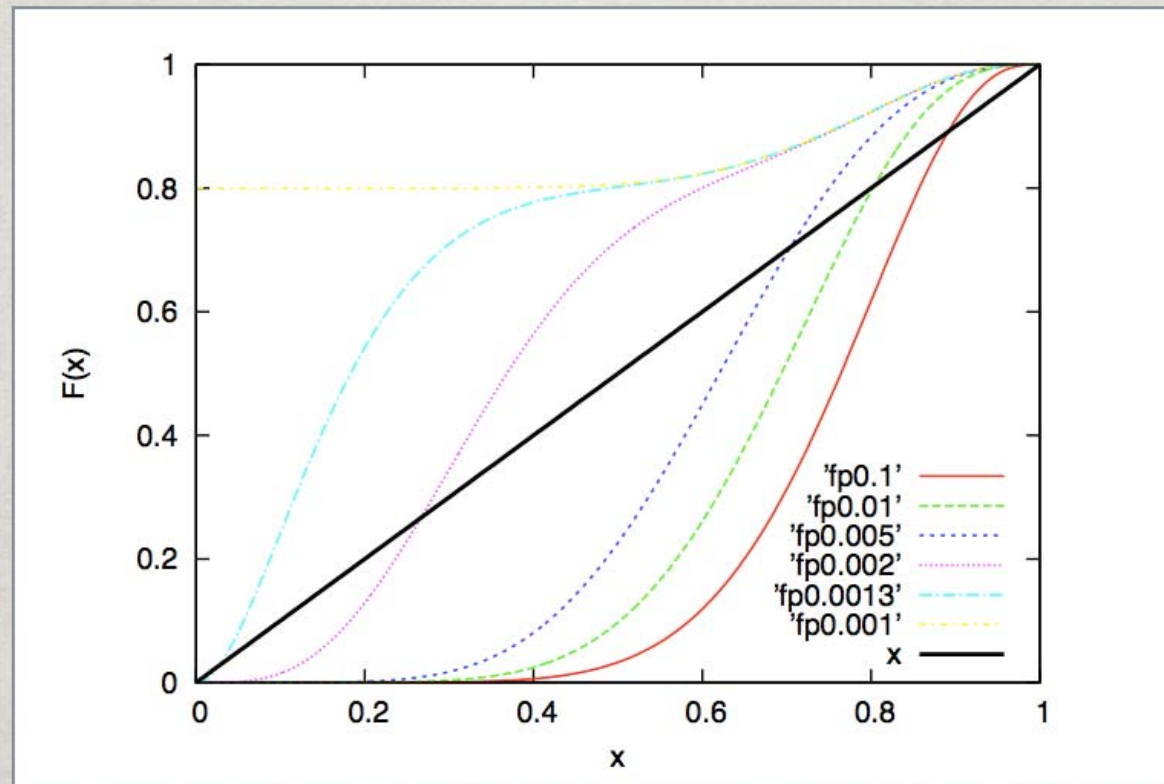
⊛ Regular random graph ($|N_i|=k$ for all i)

$$\begin{aligned}\text{⊛ } \pi(\chi) &\equiv P\{z_i^* = 1 | \chi_i = \chi\} \\ &= \sum_{\ell > (c-\chi/p)k} \binom{k}{\ell} \bar{\pi}^\ell (1 - \bar{\pi})^{k-\ell} \quad \bar{\pi} = E_\chi[\pi(\chi)]\end{aligned}$$

⊛ Taking expectation over $\chi_i \Rightarrow$ self-consistent equation

$$\begin{aligned}\bar{\pi} &= E[\chi_i > p(c - \bar{z}_i)] \\ &= \sum_{\ell=0}^k \binom{k}{\ell} \bar{\pi}^\ell (1 - \bar{\pi})^{k-\ell} P\{\chi > p(c - \ell/k)\} \\ &= F(\bar{\pi})\end{aligned}$$

THE FUNCTION $F(\bar{\pi})$

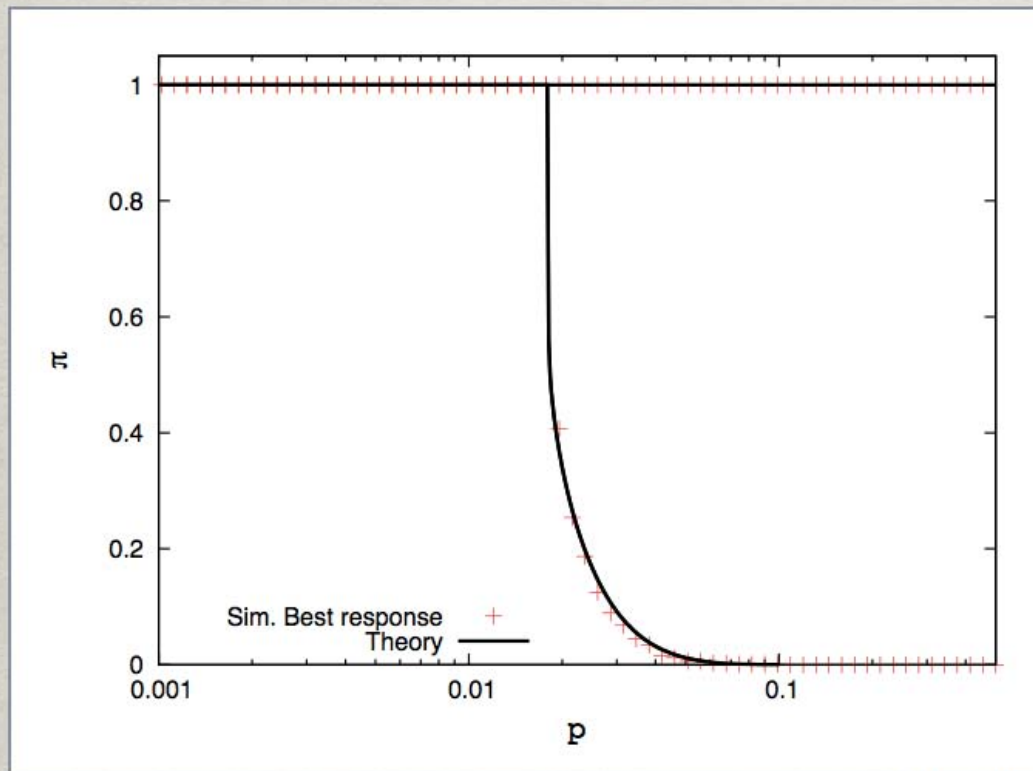


$p=0.1, 0.01, 0.005, 0.002, 0.0013, 0.001$

$\chi_i = 0.01$ for 80% of agents, 20% informed minority ($\chi_i=0$)

$k=11$ neighbors, $c=0.8$

COEXISTENCE

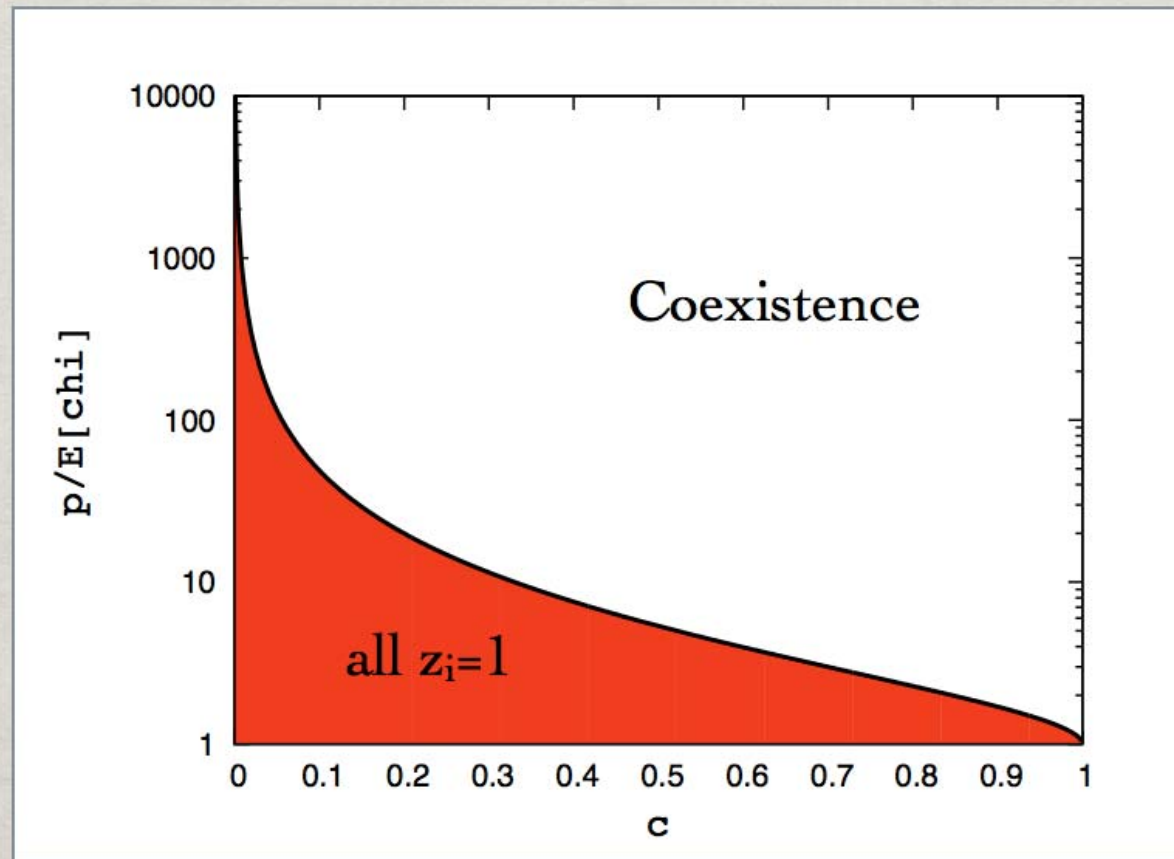


$z_i = 1$ for all agents is always an equilibrium

If p is small enough it is the only equilibrium

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

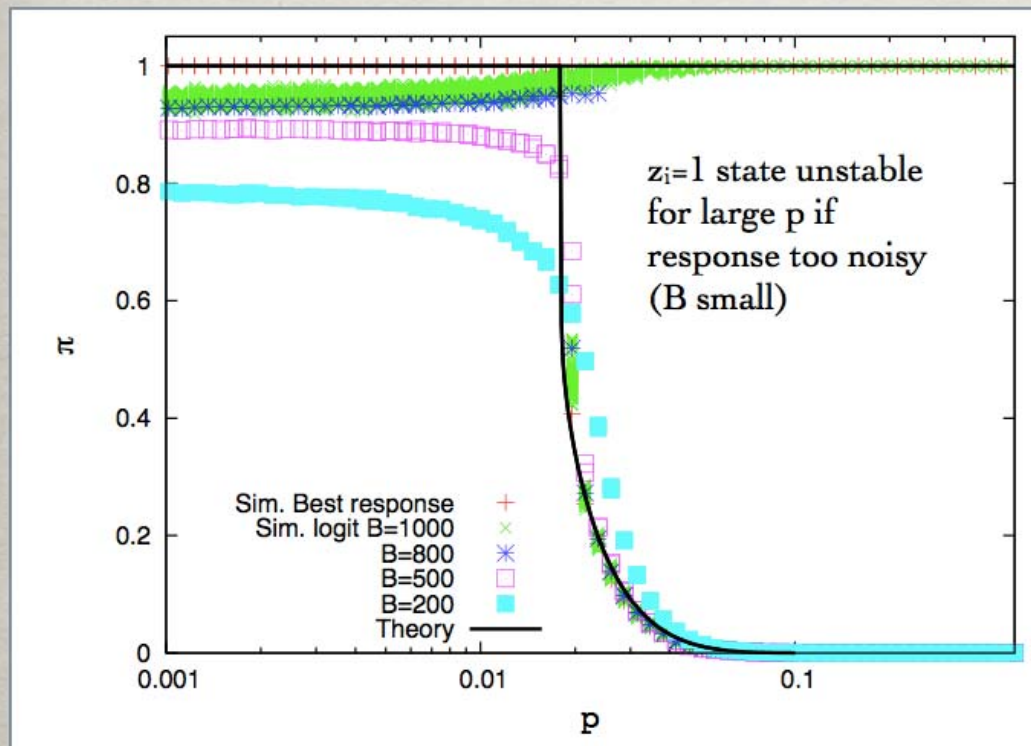
PHASE DIAGRAM



Exponential distribution of χ_i with k large

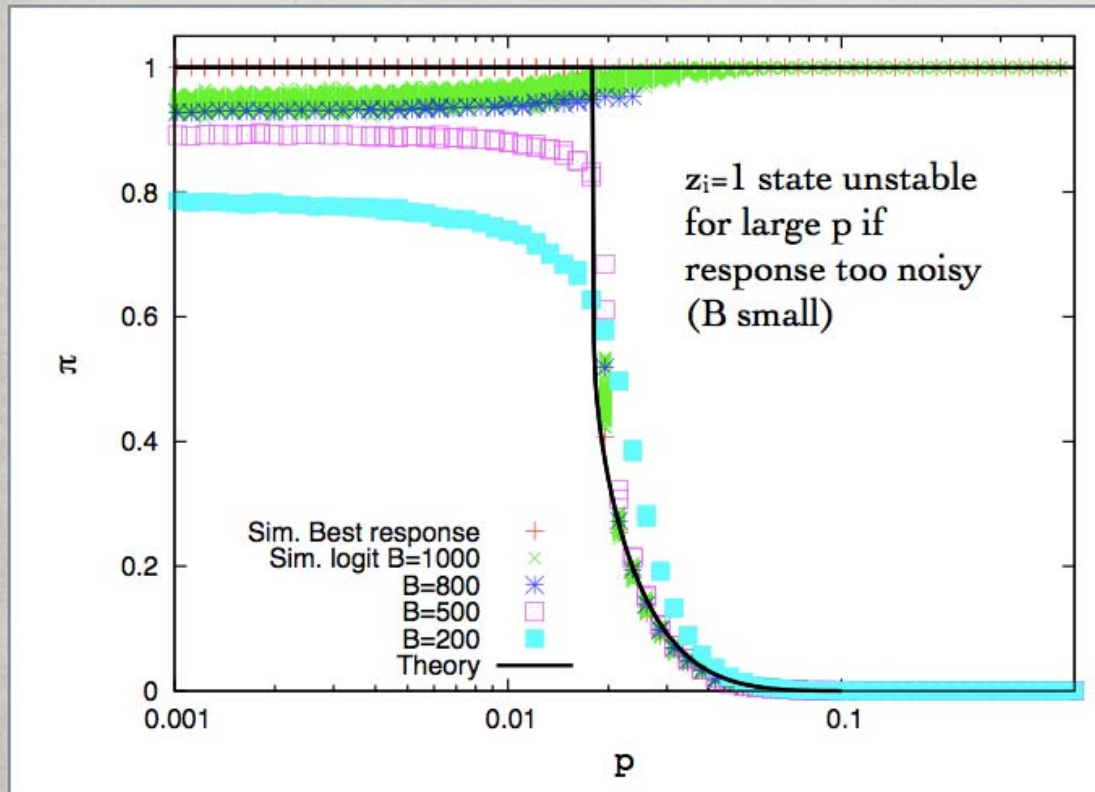
NOISY BEST RESPONSE

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



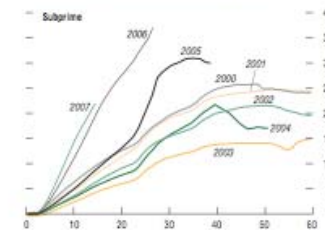
NOISY BEST RESPONSE

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



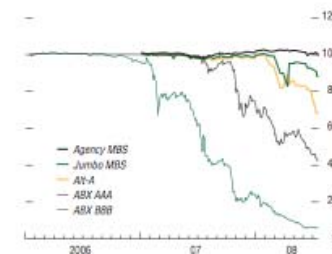
Back to ABS story:

Figure 1.8. U.S. Mortgage Delinquencies by Vintage Year
 (60+ day delinquencies, in percent of original balance)



increasing p ...

Figure 1.9. Prices of U.S. Mortgage-Related Securities
 (in U.S. dollars)



Sources: JPMorgan Chase & Co.; and Lehman Brothers.
 Note: ABX = an index of credit default swaps on mortgage-related asset-backed security; MBS = mortgage-backed security.

... sharp transition!

Regulating the system

- My main argument in this context is that the sort of complex system I have described is intrinsically difficult to control
- If we put in place a set of constraints and rules today they will have to be continually adapted as markets adapt
- We cannot simply design from scratch a « new regulatory framework » and then let things run.

Regulating the system

- 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

If only!

- 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 if only we can find it we can establish the right rules and leave markets to sort things out.
- But, in reality the economy is constantly evolving and therefore so must the rules.

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

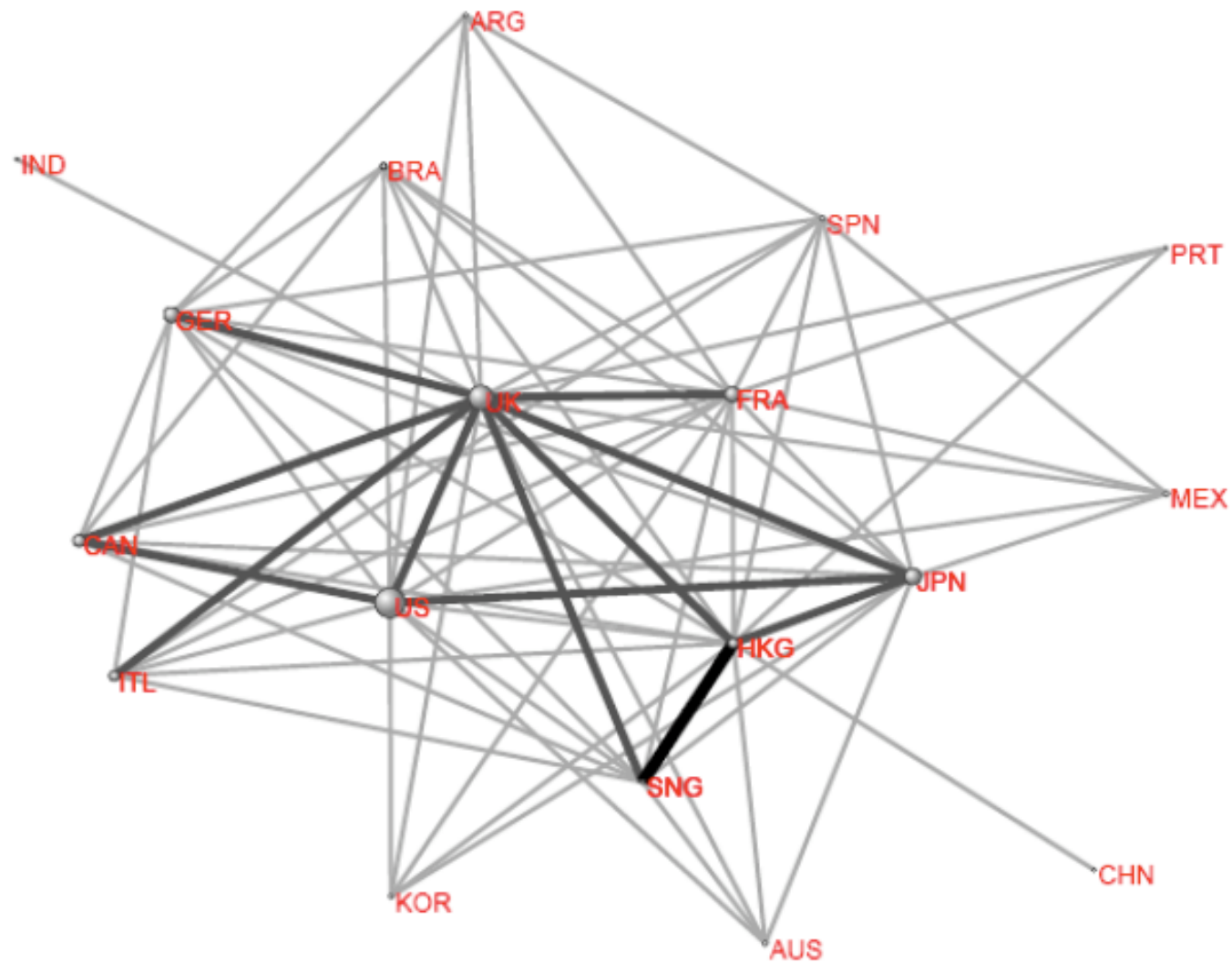
When comparing the failure of Lehman Bros and the epidemic of bird flu, Haldane says,

« 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.

Chart 1: Global Financial Network: 1985

1985



Key: — 0.003-0.03 — 0.03-0.2 — >0.2

Chart 2: Global Financial Network: 1995

1995

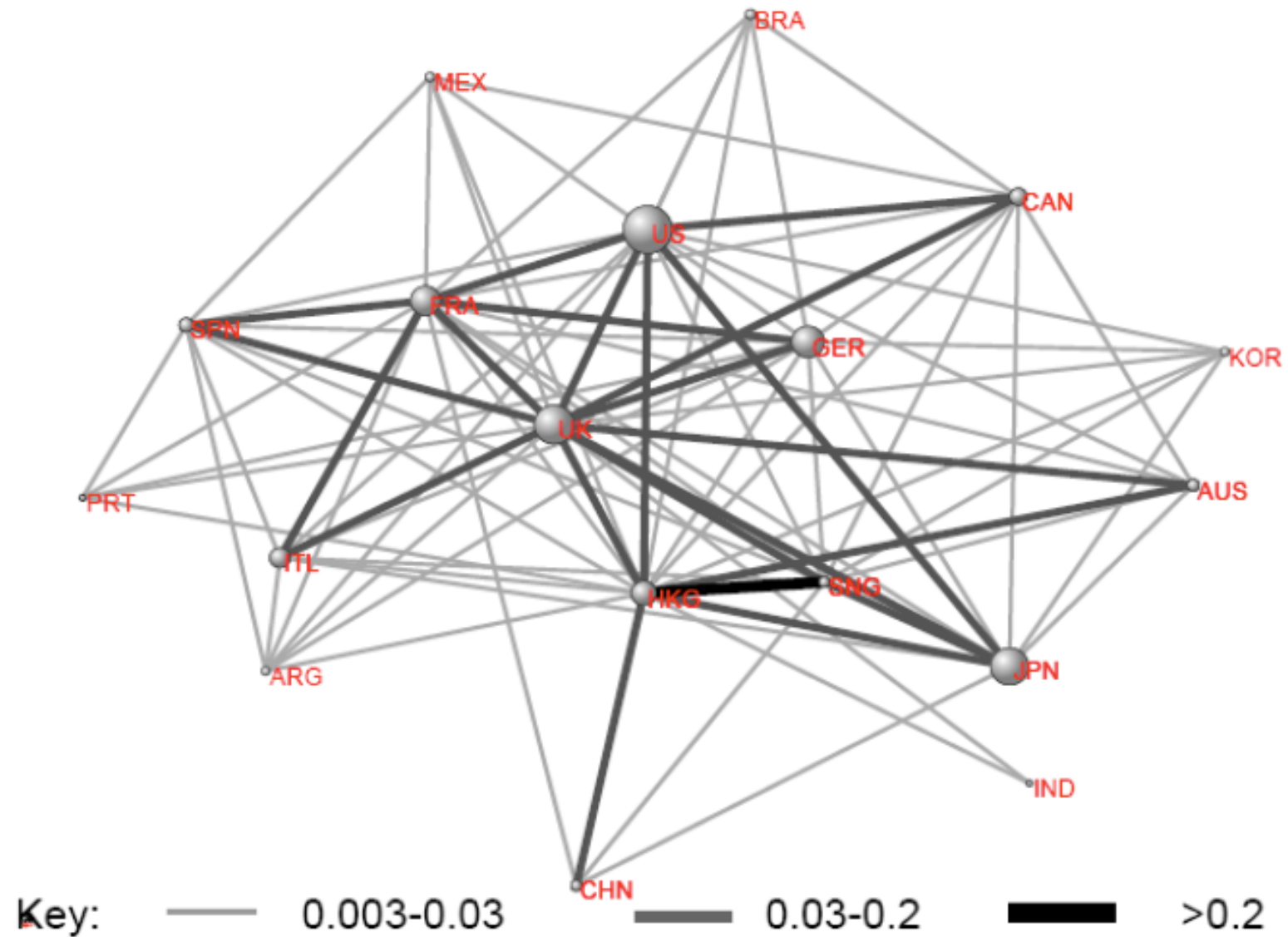
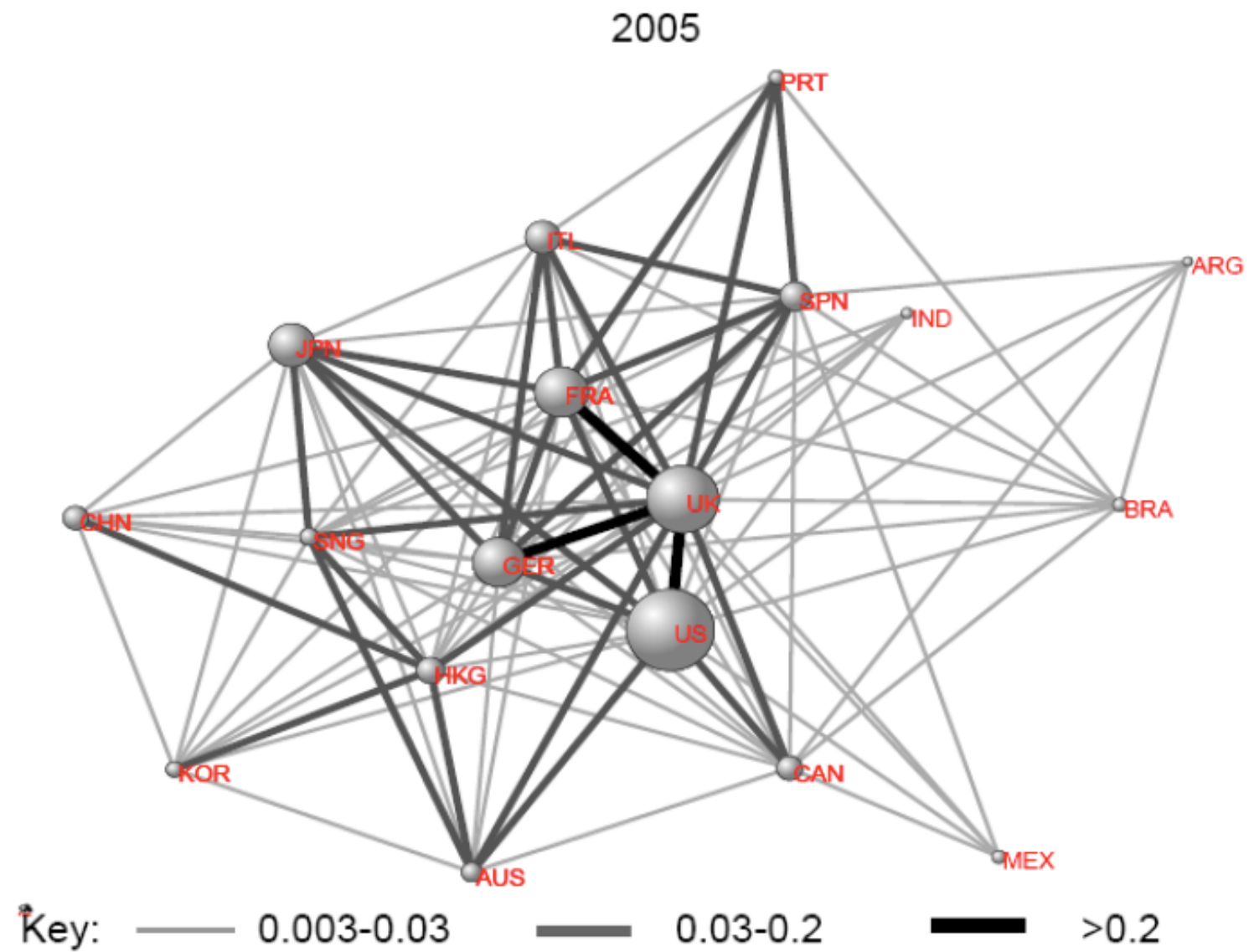


Chart 3: Global Financial Network: 2005



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.

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.

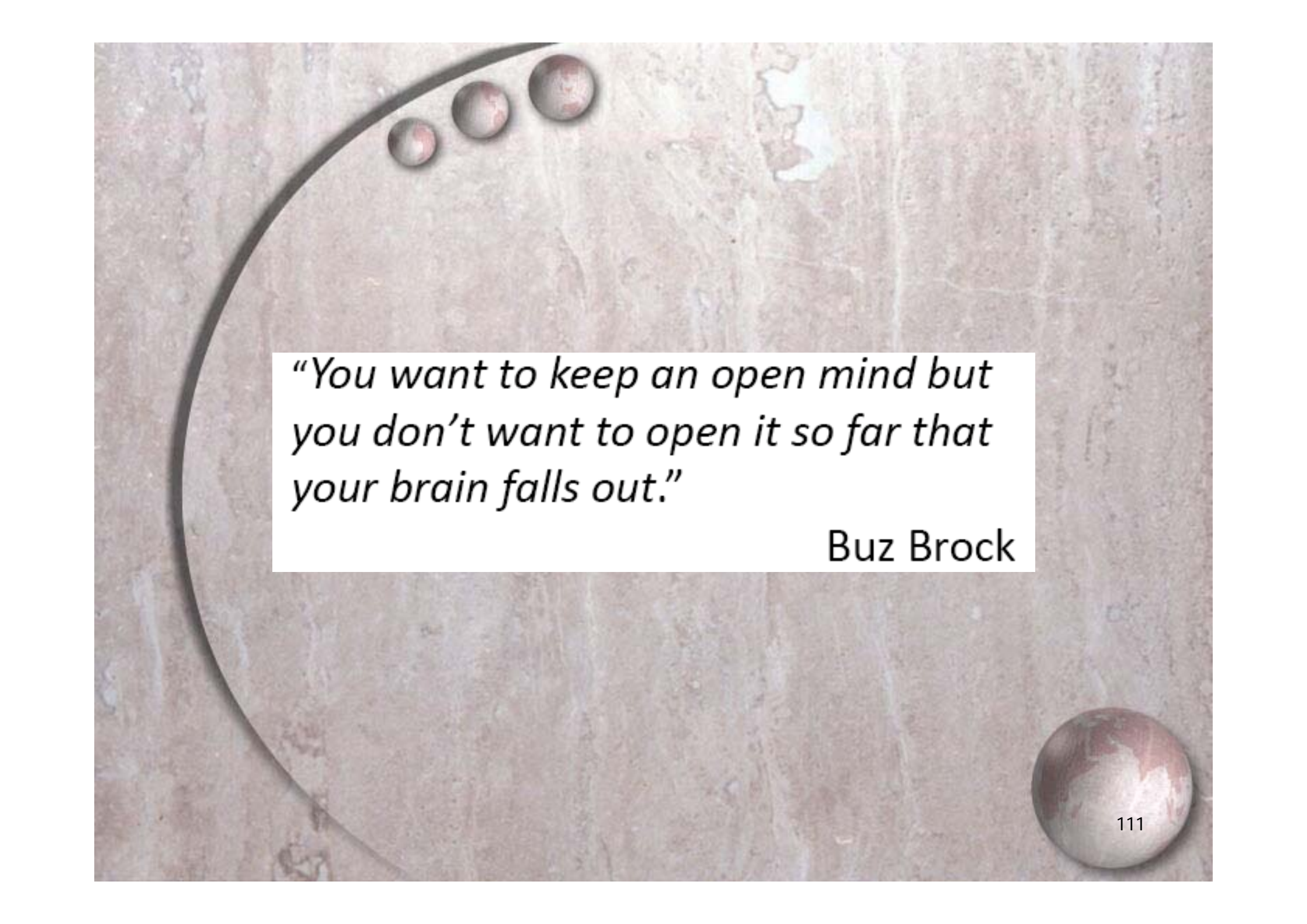
Conclusions

- What we have to do is to make models of the economy which take into account the direct interaction between individuals. This is a central, not a peripheral, concern
- In financial markets prices are constantly moving and do not settle down to a steady state.
- The economy should be viewed as a system made up of individuals following simple rules.
- To repeat we are not guilty of not having been able to forecast the onset of the current crisis but we are guilty of having built models in which it could not happen!

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 »

Max Planck, A Scientific Autobiography (1949).



*"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



Complex Economics

Individual and Collective Rationality

Alan Kirman

THE GRAZ SCHUMPETER LECTURES

