Give Econophysics a Chance!

On the Plausibility of Modeling Stock Market Crashes as Critical Phase Transitions

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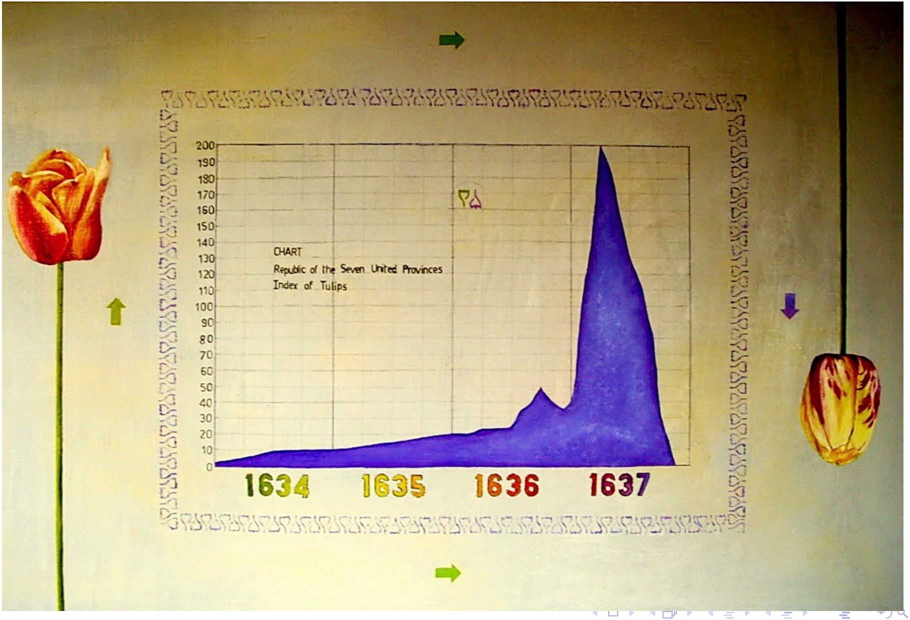
The Tulip Mania



There are empirical regularities characterizing the behavior of different stock market crashes.

Principal Goals of Stock Market Models

i. To capture "stylized facts": Macroscopic regularities such as power-law behavior; Gaussian distributions, etc.

ii. To provide a microscopic foundation for stock market crashes.

iii. To predict extreme events such as economic crashes.

The JLS model looks promising!

Stock market crashes can be treated as critical phase transitions

i It is supposed to capture stylized facts such as power law behavior of macroscopic quantities and volatility clustering (oscillating behavior before crashes).

ii It is supposed to provide a microscopic foundation for stock market crashes.

iii The model predicts the date where the system will go critical, which is supposed to coincide closely with the realized crash date.

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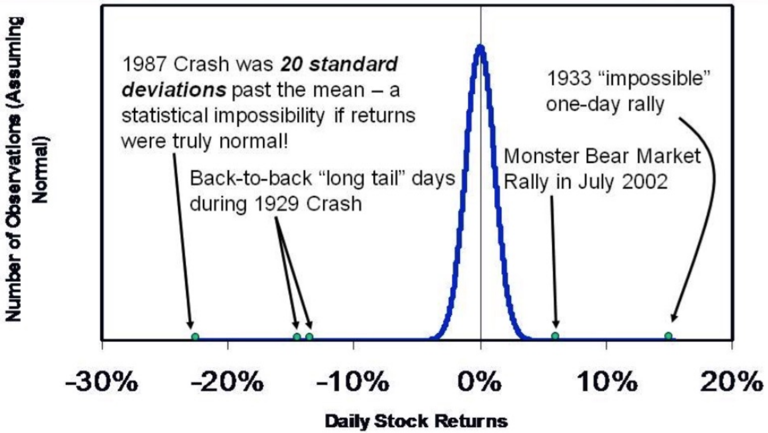
Preliminaries

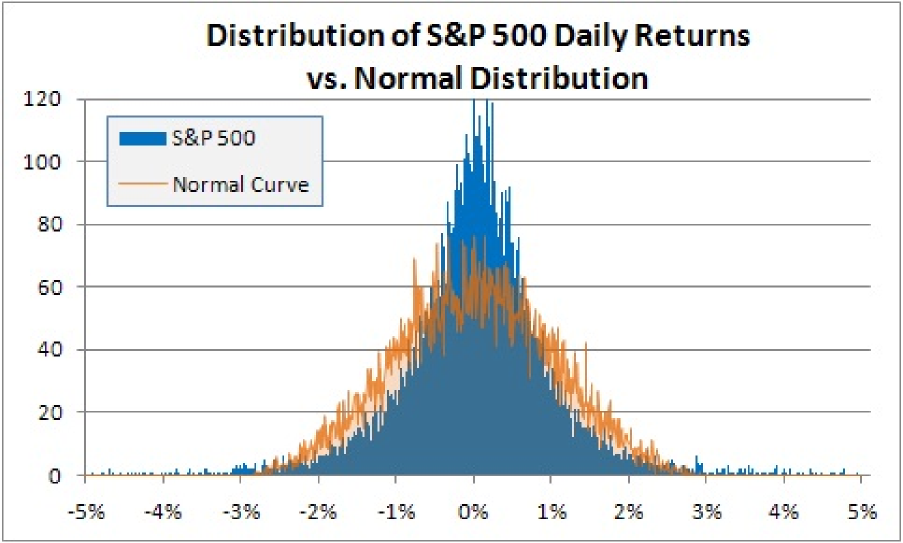
i) Limitations of normal distributions in the prediction of extreme events (Bachelier 1900, Fama 1970)



Number of Observations (Assuming Normal)
1987 Crash was **20 standard deviations** past the mean – a statistical impossibility if returns were truly normal!
Back-to-back "long tail" days during 1929 Crash
1933 "impossible" one-day rally
Monster Bear Market Rally in July 2002
-30%
-20%
-10%
0%
10%
20%
Daily Stock Returns

"By the conventional wisdom, August 1998 simply should never have happened. The standard theories estimate the odds of that final, August 31, collapse, at one in 20 million, an event that, if you traded daily for nearly 100,000 years, you would not expect to see even once. The odds of getting three such declines in the same month were even more minute: about one in 500 billion." (Mandelbrot & Hudson 2004)

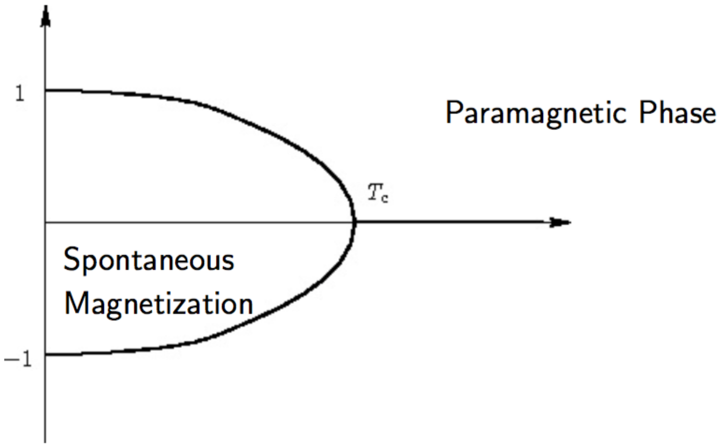
ii) Empirical indication of power law distributions

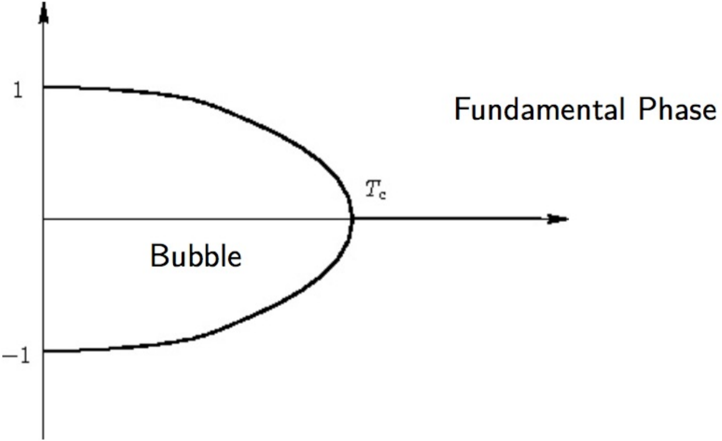

Distribution of S&P 500 Daily Returns
vs. Normal Distribution
S&P 500
Normal Curve
120
100
80
60
40
20
0
-5%
-4%
-3%
-2%
-1%
0%
1%
2%
3%
4%
5%

iii) Herding Behavior


I'VE GOT A STOCK HERE THAT COULD REALLY EXCEL
REALLY EXCEL?
EXCEL?
SELL?
SELL?
SELL
SELL!
SELL!
SELL!
SELL!
SELL!
THIS IS MADNESS! I CAN'T TAKE ANYMORE
GOOD BYE!
GOOD BYE?
BYE?
Buy?
Buy!
Buy!
BUY!!!
Buy!
BUY!
I'VE GOT A STOCK HERE..

iv) A (Rough) Analogy


1
Paramagnetic Phase
T_c
Spontaneous
Magnetization
-1


1
Fundamental Phase
T_c
Bubble
-1

The Macroscopic Model

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Dynamic of the asset price

$$dp = \mu(t)p(t)dt - \kappa p(t)dj \tag{1}$$

where κ is a fixed percentage of price drop and μ is a time-dependent drift.

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$$dp = \mu(t)p(t)dt - \kappa p(t)dj \tag{1}$$

where κ is a fixed percentage of price drop and μ is a time-dependent drift.

$\mu(t)$ of equation (1) is chosen so that the price satisfies the martingale condition: $E_t[dp] = \mu(t)p(t)dt - \kappa p(t)h(t)dt = 0$.

Thus, $\mu(t) = \kappa h(t)$

The Macroscopic Model

The Hazard Rate Drives the Market Price

The solution of the differential equation (1) is given by:

$$\log[\frac{p(t)}{p(t_0)}] = \kappa \int_{t_0}^{t} h(t)dt \quad (2)$$

The Microscopic Model

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Assumptions

- A(n endogenous) crash happens when a large group of agents place sell order simultaneously.

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- A(n endogenous) crash happens when a large group of agents place sell order simultaneously.
- $h(t)$ is the collective result of the interaction between traders.

Crashes as critical points

Divergence of the magnetic susceptibility at the critical point:

- $\chi \approx A(t_c - t)^{-\gamma}$

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General solution for the power law with complex exponents.

- $h(t) \approx B_0(t_c - t)^{-\alpha} + B_1(t_c - t)^{-\alpha} cos[\omega \log(t_c - t) + \psi]$

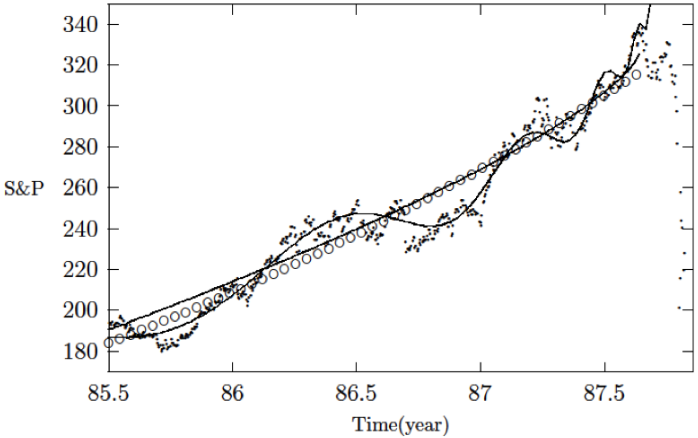
Plugging $h(t)$ into (2)

Evolution of the price before the crash:

$$log[p(t)] \approx \log[p_c] - \frac{\kappa}{\beta}[B_0(t_c - t)^{\beta} + B_1(t_c - t)^{\beta} cos[\omega \log(t_c - t) + \psi] \quad (3)$$

where $\beta = 1 - \alpha$

Optimal fit of log-periodic oscillations for the crash of 1987



The estimation procedure yields a critical exponents of $\beta = 0.57$. The position of the critical time is within a few days of the actual crash date. (Sornette et al. 1996, 2008)

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Universality and other properties of critical phenomena

Power law behavior with anomalous exponents:

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Power law behavior with anomalous exponents:

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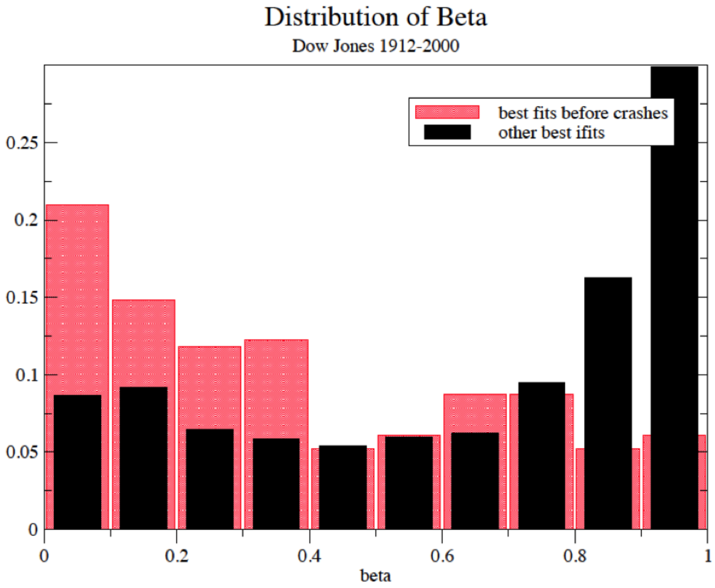
Universality:

- Different systems happen to have the same critical exponents. Those systems are said to belong to the same *universality class*.

Divergences:

- Physical quantities diverge at the critical point. $\chi \approx A(t_c - t)^{-\gamma}$

Do Stock Market Crashes Constitute a Universality Class?



Graf v. Bothmer and Meister (2008). Distribution of Beta in the best fits of eq. (4) for 88 years of Dow Jones.

Uh Oh...

Actual stock market crashes are not in any particular universality class.

Query:

So...what does this say about the JLS's predictive or explanatory power? What kind of help does appealing to methods in physics do for us?

Contents

The physics of phase transitions

1. In thermodynamics, phase transitions are defined as discontinuities of the Free Energy F.

2. In statistical mechanics, the free energy cannot have discontinuities $F[K_n] = -k_B T \log Z$.

3. In order to obtain those discontinuities, assume the thermodynamic limit: $f_b[K] = \lim_{N(\Omega)\to\infty} \frac{F_\Omega[K]}{N(\Omega)}$

The Role of Infinite Idealization

The infinite idealization is essential for explanatory purposes (Batterman 2009)

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1. ... "Notice the absolutely essential role played by the divergence of the correlation length, in this explanatory story [RG methods]. It is this that opens up the possibility of a fixed point solution to the renormalization group equations"...

The Role of Infinite Idealization

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Why?

1. … "Notice the absolutely essential role played by the divergence of the correlation length, in this explanatory story [RG methods]. It is this that opens up the possibility of a fixed point solution to the renormalization group equations"…

2. … "I'm suggesting that an important lesson from the renormalization group successes is that we rethink the use of models in physics. If we include mathematical features as essential parts of physical modeling then we will see that blowups or singularities are often sources of information"…

Idealization in Minimal Models

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1. …"We have argued that what accounts for the explanatory power of this model is not that it correctly mirrors, maps onto, or otherwise accurately represents the real systems of interest [common features account]. Instead, *the model is explanatory and can be employed to understand the behavior of real fluids primarily because of a backstory about why various details that distinguish fluids and fluid models from one another are essentially irrelevant*."

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2. …"The renormalization group strategy, in delimiting the universality class, provides the relevant modal structure that makes the model explanatory."

The physics of financial crashes

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Crashes do not constitute universality classes.

So RG methods aren't applicable here...

The physics of financial crashes

So if not universality classes, then what?

The physics of financial crashes

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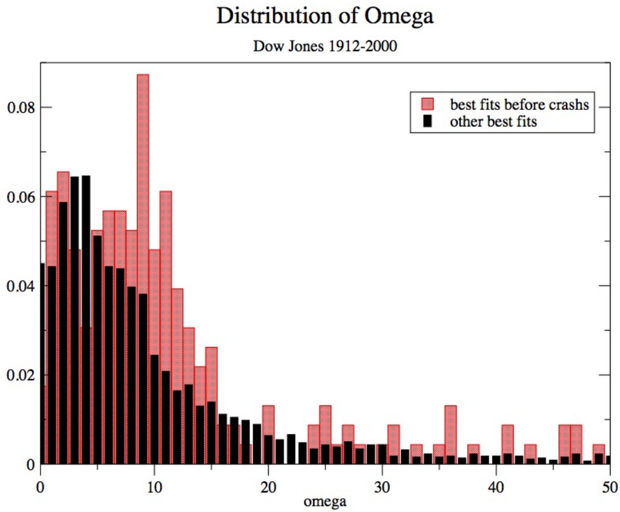
Despite that we cannot assign crashes to a particular a universality class, we still find similar behaviors across crashes.

The physics of financial crashes



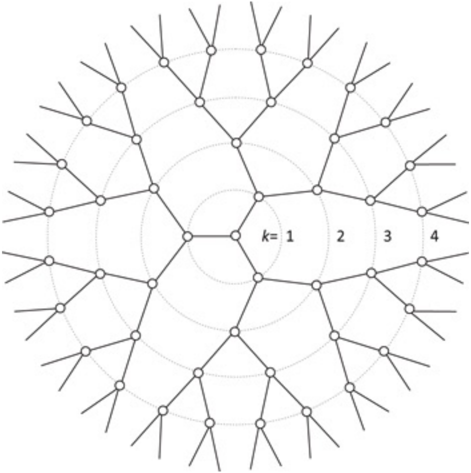
"One can clearly observe an unexpected peak around $\omega = 9$ before the crashes." (Grav v. Bothmer and Meister 2003)

The Role of the Analogy in the JLS model

We use the same kind of idealizations being used in condensed-matter physics because it allows us to take advantage of the following:

- **Abstraction from finitary effects**:
  In infinite systems edge/boundary effects are absent. The model is robust under different shapes of the system.
- **Discrete scale invariance**:
  If the hazard rate (susceptibility) diverges, the correlation length diverges, what give rise to scaling behavior. The existence of log-periodic oscillations decorating the power laws in infinite systems describes a family of discrete scale invariant hierarchical networks.

Hierarchical lattices and the JLS model



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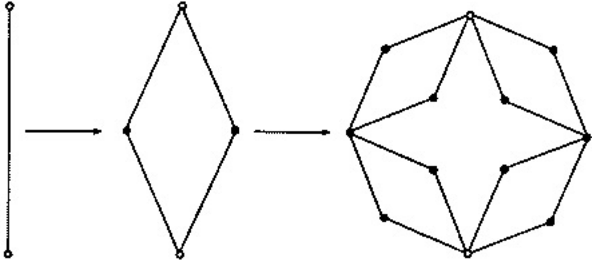

Idealization and Explanation

We use the same idealizing strategy to help uncover some different piece of information that Batterman and Rice.

It helps us identify a potential family of difference makers that are associated with the occurrence of a crash (discrete scale invariance, hierarchical networks, imitation procedure).

These are causal features that the model has (approximately) in common with the real world that may help with prediction.

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Does the JLS model predict anything?

In some local sense, it does.

Read the LPPL as: If there is log-periodic oscillating behavior present, then ceteris paribus, there is likely to be a crash.

But this is not enough...

Lots of other statements in economics take on the form of ceteris paribus laws.

E.g. "a decrease in the supply of a good leads, ceteris paribus, to an increase in prices."

This is a (hypothetical) single-variable manipulation, (cf. Woodward 2003). This yields a causal claim that will hold in some range of circumstances.

"When a relationship is invariant under at least some interventions...it is potentially usable in the sense that...if an intervention on X were to occur, this would be a way of manipulating or controlling the value of Y" (2003, 16).

...the market anticipates the crash in a subtle self-organized and cooperative fashion, hence releasing precursory "fingerprints" ob- servable in the stock market prices. We propose that the underlying cause of the crash must be searched years before it in the progressive accelerating ascent of the market price, reflecting an increasing built-up of the market cooperativity.

Does the JLS model explain anything?

And if it does, what kind of explanation is it?

In some sense a reductive one...

> *"... we will show that macro-level coordination can arise from micro-level imitation. Furthermore, it relies on a somewhat realistic model of how agents form opinions."*

The JLS model suggest that local imitation between noise traders might cascade through the scales into large-scale coordination and cause crashes.

Guiding Interventionist Projects

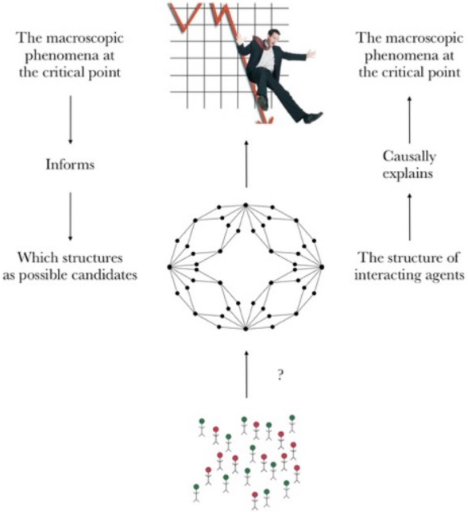
How does the government try to calm down financial panics?

The lattice helps make salient possible avenues of intervention. E.g.:

NYSE "circuit breaker" trading curbs

These kinds of strategies aim to disrupt the structure of the underlying network.

Summary


The macroscopic phenomena at the critical point
Informs
Which structures as possible candidates
The macroscopic phenomena at the critical point
Causally explains
The structure of interacting agents
?

Contents

Conclusion

- For Batterman and Rice: Infinite idealizations as sources of information and a first step to providing a *non*-reductive explanation
- For us: The infinite idealizations actually *helps* us provide a reductive, causal-mechanical account!
- The JLS equation and associated micro-story has a clear interventionist interpretation: if you see oscillating behavior at the macroscale, disrupt goings-on at the micro-scale.

  BUT it is not aim to provide an "atomistic" account of individual agents.

All done. Thank you!