Dragon-kings and Predictions
Diagnostics and Forecasts for the World Financial Crisis

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www.er.ethz.ch
Extreme events are epoch changing in the physical structure and in the mental spaces

- Droughts and the collapse of the Mayas (760-930 CE)... and many others... (J. Diamond, Collapse, 2005)
- Great depression and Glass-Steagall act
- Great Recession 2007-2009: Dodd-Frank act
- European sovereign debt crisis: Europe or collapse?
Standard view: fat tails, heavy tails and Power law distributions

\[ ccdf(S) = \frac{\text{const}}{S^\mu} \]
Most extremes are dragon-kings
Fig. 7. French agglomerations: stretched exponential and “King effect”.

Dragon-kings results from maturation towards an instability

Instead of
Water Level:
-economic index
(Dow-Jones etc…)

Crash = result of collective behavior of individual traders

(Sorin Solomon)
Generically, close to a regime transition, a system bifurcates through the variation of a SINGLE (or a few) effective “control” parameter

**Bifurcation**: Qualitative change in behavior as parameter is (slowly) varied

**Bifurcation surface**: B

**Strategy 1**: understand from proximity to a reference point as a function of a small parameter

**Strategy 2**: a few universal “normal forms”

Space of all dynamical systems: $\mathcal{M}$
a particular dynamical system: $M \in \mathcal{M}$
Signs of Upcoming Transition

Early warning signals as predicted from theory

- Slower recovery from perturbations
- Increasing (or decreasing) autocorrelation
- Increasing (or decreasing) cross-correlation with external driving
- Increasing variance
- Flickering and stochastic resonance
- Increased spatial coherence
- Degree of endogeneity/reflexivity
- Finite-time singularities
Diagnostic of Ariane rocket pressure tanks

- Increasing variance
- Increased spatial coherence
- Finite-time singularity

Our prediction system is now used in the industrial phase as the standard testing procedure.
PARTURITION and EPILEPTIC SEIZURES

Generic Critical Precursors to a Bifurcation

- Amplitude of fluctuations
- Response to external forcing
Beyond power laws: 8 examples of “Dragons”

**Financial economics:** Outliers and dragons in the distribution of financial drawdowns.

**Population geography:** Paris as the dragon-king in the Zipf distribution of French city sizes.

**Material science:** failure and rupture processes.

**Hydrodynamics:** Extreme dragon events in the pdf of turbulent velocity fluctuations.

**Metastable states in random media:** Self-organized critical random directed polymers

**Brain medicine:** Epileptic seizures

**Geophysics:** Characteristic earthquakes? Great avalanches? Floods? Mountain collapses? Meteological events? and so on

**Ionosphere and magneto-hydrodynamics:** Global auroral energy deposition
Extreme Risks: Dragon-Kings versus Black Swans

Special Issue EPJ ST

D. Sornette and G. Ouillon

Guest Editors (May 2012)

1. Geosciences of the solid envelop
   1.1. Earthquake magnitude.
   1.2. Volcanic eruptions.
   1.3. Landslides.
   1.4. Floods.

2. Meteorological and Climate sciences
   2.1. Rains, hurricanes, storms.
   2.2. Snow avalanches.

3. Material Sciences and Mechanical Engineering
   3.1. Acoustic emissions.
   3.2. Hydrodynamic turbulence.

4. Economics: financial drawdowns, distribution of wealth

5. Social sciences: distribution of firm sizes, of city sizes, of social groups...

6. Social sciences: wars, strikes, revolutions, city sizes

7. Medicine: epileptic seizures, epidemics

8. Environmental sciences: extinctions of species, forest fires
   8.1. Evolution and extinction of species.
   8.2. Forest fires.
bubble peaking in Oct. 2007
THE GREAT RECESSION (2008-2009)

- 30,000 billions US $
- 20,000 billions US $
- 10,000 billions US $

- Direct subprime loss
- World GDP loss
- Stock markets losses
positive feedback of increasing return

=> growth of the return (and not just of the price)

=> Faster-than-exponential transient unsustainable growth of price

=> Mathematically, this translates into FINITE-TIME SINGULARITY
Growth Processes

- **exponential growth**
  \[ p(t) \sim e^t \]
  \[ \frac{dp}{dt} \sim p(t)^{1+\delta} \]
  \[ \delta = 0 \]

- **finite-time singularity**
  \[ p(t) \sim \frac{1}{(t_c - t)^{1/\delta}} \]
  \[ \delta > 0 \]

- **power-law**
  \[ p(t) \sim t^{1/|\delta|} \]
  \[ \delta < 0 \]
Super-exponential growth
(positive feedbacks)

Diagram 1.5. Correlation between World Population Size and World Population Annual Growth Rate, 1650–1970

Korotayev, Malkov, Khaltourina (2006)
Multivariate endogeneous growth models and FTS

Case $\theta+\beta>1 : FTS$

\[
\frac{dA}{dt} = bA^\theta K^\beta ,
\]

\[
\frac{dK}{dt} = aA^{1-\alpha} K^\alpha .
\]

$\alpha = 0.6; \beta = 0.9; \theta = 0.9$
Mechanisms for positive feedbacks in the stock market

- **Technical and rational mechanisms**
  1. Option hedging
  2. Insurance portfolio strategies
  3. Market makers bid-ask spread in response to past volatility
  4. Learning of business networks, human capital
  5. Procyclical financing of firms by banks (boom vs contracting times)
  6. Trend following investment strategies
  7. Algorithmic trading
  8. Asymmetric information on hedging strategies
  9. Stop-loss orders
  10. Portfolio execution optimization and order splitting
  11. Deregulation (Grimm act repelling the Glass-Steagall act)

- **Behavioral mechanisms:**
  1. Breakdown of “psychological Galilean invariance”
  2. Imitation (many persons)
    a) It is rational to imitate
    b) It is the highest cognitive task to imitate
    c) We mostly learn by imitation
    d) The concept of “CONVENTION” (Orléan)
  3. “Social Proof” mechanism
Thy Neighbor’s Portfolio: Word-of-Mouth Effects in the Holdings and Trades of Money Managers

HARRISON HONG, JEFFREY D. KUBIK, and JEREMY C. STEIN

ABSTRACT

A mutual fund manager is more likely to buy (or sell) a particular stock in any quarter if other managers in the same city are buying (or selling) that same stock. This pattern shows up even when the fund manager and the stock in question are located far apart, so it is distinct from anything having to do with local preference. The evidence can be interpreted in terms of an epidemic model in which investors spread information about stocks to one another by word of mouth.

IN THIS PAPER, WE EXPLORE THE HYPOTHESIS that investors spread information and ideas about stocks to one another directly, through word-of-mouth communication. This hypothesis comes up frequently in informal accounts of the behavior of the stock market. For example, in his bestseller Irrational Exuberance, Shiller (2000) devotes an entire chapter to the subject of “Herd Behavior and Epidemics,” and writes

A fundamental observation about human society is that people who communicate regularly with one another think similarly. There is at any place and in any time a Zeitgeist, a spirit of the times.... Word-of-mouth transmission of ideas appears to be an important contributor to day-to-day or hour-to-hour stock market fluctuations. (pp. 148, 155)
Universal Bubble and Crash Scenario

Displacement

Credit creation

Euphoria

Critical stage / Financial distress

Revulsion

Charles Kindleberger, Manias, Panics and Crashes (1978)

Famous historical bubbles

Gouda Tulip Bulbs
Dec. 1, 1634 to Feb. 5, 1637
Selected Prices in Guilders/Aas
Log Scale

South Sea Company
1719-1722
Log Scale

Source: Elliott Wave International; data source for South Seas, Global Financial Data
Positive feedbacks and origin of bubbles

Prices in the learning-to-forecast market experiments (Hommes et al., 2008).
Five out of six markets exhibit long lasting bubbles with asset prices increasing to more than 15 times fundamental value.

Next period returns $r(t+1)$ versus current returns $r(t)$ for group 2. Points on the diagonal correspond to constant growth rate ($r(t+1)= r(t)$), points above the diagonal ($r(t+1) > r(t)$) correspond to accelerating growth. Returns are defined as discrete returns: $r(t+1) = [p(t+1)/p(t)] - 1$.

The market is never following the average growth; it is either super-exponentially accelerating or crashing.

Patterns of price trajectory during 0.5-1 year before each peak: Log-periodic power law
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**Complex systems** approach:

The crash is a tipping point (critical point), around which the system exhibits self-similar properties:

$$ f(K) = g(K) + \mu^{-1} f[R(K)] $$

The renormalisation group solution has the form:

$$ f(K) = \sum_{n=0}^{\infty} \mu^{-n} g[R^{(n)}(K)] $$

Where the log-periodic oscillations for hazard rate are the first order approximation of the RG solution.

$$ E[\ln p(t)] = A + B |t_c - t|^m + C |t_c - t|^m \cos[\omega \ln |t_c - t| - \phi] $$
The **Log-Periodic Power Law** is a combination of Classical methods of **economics:**

Diffusive dynamics of log-price in the presence of discontinuous jump $j$:

$$\frac{dp}{p} = \mu(t)dt + \sigma(t)dW - \kappa dj$$

Under the no-arbitrage condition

$$E_t[dp] = 0$$

the excess returns are proportional to the hazard rate:

$$\mu(t) = \kappa h(t)$$
The **Log-Periodic Power Law** is a combination of

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$$\mu(t) = \kappa \lambda(t)$$

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$$E[\ln p(t)] = A + B|t_c - t|^m + C|t_c - t|^m \cos[\omega \ln |t_c - t| - \phi]$$
Positive feedback
\[ \frac{dp}{dt} = cp^d \quad \text{with } d > 1 \]
e.g. as a result of herding in dynamics of “noise traders”

Faster-than exponential growth
\[ p(t) \sim (t_c - t)^{-m} \]

Discrete scale invariance
\[ p(\lambda_n t) \sim \lambda_n^\alpha p(t), \quad n \in \mathbb{N} \]
as a result of RG solution around the tipping point (end of bubble)

Log-periodic oscillations
\[ p(t) \sim \cos[\omega \ln(t_c - t) + \phi] \]

Martingale hypothesis
(no “free lunch”)

Johansen-Ledoit-Sornette (JLS) model
(Log-Periodic Power Law)
\[ \mathbb{E}[\ln p(t)] = A + B|t_c - t|^m + C|t_c - t|^m \cos[\omega \ln|t_c - t| - \phi] \]
Extensions of the **Log-Periodic Power Law** model

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Construction of alarms

Prices converted in stochastic singular times for crash

\[
\tilde{T}_{c,i}(t) = t_i + \left( \frac{A - \ln p(t)}{B} \right)^{\frac{1}{1-\beta}}, \quad t = t_i - 899, \ldots, t_i.
\]

\[
T_{c,i} = \frac{1}{750} \sum_{t=1}^{750} \tilde{T}_{c,i}(t) \quad \tilde{t}_{c,i}(t) = \tilde{T}_{c,i}(t) - T_{c,i}
\]

Bubble diagnostic if

(i) $0 < \beta^* < 1$ such that $m > 2$ (the signature of a positive feedback in the momentum price dynamics model) and

(ii) $-25 \leq T_{c,i} - t_i \leq 50$, such that the estimated termination time of the bubble is close to the right side of the time window.

(iii) We further refine the filtering by considering three levels of significance quantified by the value of the exponent $m$: level 1 ($m > 2$), level 2 ($m > 2.5$) and level 3 ($m > 3$).

(iv) Dickey – Fuller unit – root test is rejected at 99.5% significance level.
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A Consistent Model of ‘Explosive’ Financial Bubbles With Mean-Reversing Residuals
L. Lin, R. E. Ren and D. Sornette (2009)

http://papers.ssrn.com/abstract=1407574

\[
\frac{dI}{I} = \mu(t) dt + \sigma_Y dY + \sigma_W dW - \kappa dj
\]

\[
dY = -\alpha Y dt + dW.
\]
Volatility Confined LPPL = deterministic component + Ornstein-Uhlenbeck process

- first model: based on Rational Expectation (RE) condition
  - Original price process: \( \frac{dp}{p} = \mu(t)dt + \sigma_YdY + \sigma_wdW - k\delta \)
    \[ dY = -\alpha Ydt + dW \]
  - Stochastic Discount Factor: \( \frac{d\Lambda_t}{\Lambda_t} = -rdt - \rho_YdY - \rho_wdW \)
  - Under no-arbitrage condition:
    \[ \mu(t) = \text{LPPL component} + \alpha(\sigma_Y - \rho_Y)Y_t^{\circ} \]
    \[ r_{i+1} = \ln p_{t_{i+1}} - \ln p_{t_i} \sim N(\Delta H_{t_{i+1}, t_i} - \alpha(\ln p_{t_i} - H_{t_i}), \sigma_u^2(t_{i+1} - t_i)) \]
    \[ H_{t_i} = A - B(t_c - t_i)^\beta \left[ 1 + \frac{C}{\sqrt{1 + \left( \frac{\omega}{\beta} \right)^2}} \cos(\omega \ln(t_c - t_i) + \phi) \right] \]

There is also a Behavioral discount factor formulation.
Bayesian approach
S&P500 1987 and Hong-Kong 1997
(answering to Chang and Feigenbaum, 2006)

- **Bayesian Factor**
  - $B(\text{model}_1, \text{model}_2) = \frac{\text{Marginal Likelihood (model}_1)}{\text{Marginal Likelihood (model}_2)}$

- **Model_1**: Volatility Confined LPPL
- **Model_2**: Black–Scholes model

- Calculation Results
  - $\mathcal{L}_{LPPL}(2.5\% - 97.5\%) = 3173.546 - 3176.983$
  - $\mathcal{L}_{BS}(2.5\% - 97.5\%) = 3169.808 - 3170.097$

- LPPL outperform BS here

- Parameters
  - $\mu \sim N(0.0003, (0.01)^2)$
  - $\tau \sim \Gamma(1.0, 10^5)$
  - $\alpha \sim \Gamma(1.0, 0.05)$
  - $A \sim N(6, 0.05)$
  - $B \sim \Gamma(1, 0.01)$
  - $C \sim U(0, 1)$
  - $\beta \sim B(40, 30)$
  - $\omega \sim \Gamma(16, 0.4)$
  - $\phi \sim U(0, 2\pi)$
  - $t_c - t_N \sim \Gamma(1, 30)$
From the perspective of complex systems:

- Rational expectation models of negative bubbles and anti-bubbles
- Rational expectation bubble model with beta-function-type solution of the RG
  (RG: renormalization group)
- Rational expectation bubble model with higher order solutions of the RG
Extensions of the Log-Periodic Power Law model

From the perspective of complex systems:

Rational expectation models of negative bubbles and anti-bubbles
Rational expectation models of negative and anti-bubbles

Positive bubble
(the pressure builds up, generally in multiple stages)

Positive anti-bubble
(the pressure is progressively released, generally in multiple stages)

Negative bubble
(pressure towards panic = herding in bearish phase)

Negative anti-bubble
(negative pressure released, progressively)
Extensions of the Log-Periodic Power Law model

From the perspective of complex systems:

- Rational expectation models of negative bubbles and anti-bubbles
- Generalized Weierstrass functions (RG: renormalization group)
- Rational expectation bubble model with higher order solutions of the RG
From the perspective of complex systems:

Extensions of the Log-Periodic Power Law model

Early warning of the 2008-20?? crisis

1945-1970: reconstruction boom and consumerism

1971-1980: Bretton Woods system termination and oil shocks / inflation shocks

1981-2007: Illusion of the “perpetual money machine” and virtual financial wealth

2008-2020s: New era of pseudo growth fueled by QEs and other Central Banks+Treasuries actions

- very low interest rate for a very long time (decades)
- net erosion even in the presence of apparent low (disguised) inflation
- reassessment of expectation for the social and retirement liabilities
- a turbulent future with many transient bubbles
- need to capture value and be contrarian => exploit herding and fear

2020s-20xx: Interconnection of many systemic risks
The illusionary “PERPETUAL MONEY MACHINE”

Rate of profit and rate of accumulation: The United States + European Union + Japan
* Rate of accumulation = rate of growth rate of the net volume of capital * Rate of profit = profit/capital (base: 100 in 2000)

Sources and data of the graphs: http://hussonet.free.fr/toxicap.xls

The gap widens between the share of wages and the share of consumption (gray zones), so as to compensate for the difference between profit and accumulation. FINANCE allows increasing debt and virtual wealth growth... which can only be transitory (even if very long).

United States Share of wages and of private consumption in Gross Domestic Product (GDP)
Source of data and graphics: http://hussonet.free.fr/toxicap.xls
An economy which grows at 2 or 3 per cent cannot provide a universal profit of 15 per cent, as some managers of equities claim and many investors dream of.

Financial assets represent the right to a share of the surplus value that is produced. As long as this right is not exercised, it remains virtual. But as soon as anyone exercises it, they discover that it is subject to the law of value, which means, quite simply, that you cannot distribute more real wealth than is produced.

From 1982 until 2007, the U.S. only experienced two shallow recessions that each lasted just 8 months. This stretch of 25 years may be the best 25 years in the US economic history. But much of this prosperity was bought with debt, as the ratio of debt to GDP rose from $1.60 to $3.50 for each $1.00 of GDP.
Predictability of the 2007-XXXX crisis: 30 year History of **bubbles** and of **Endogeneity**

- Real-estate bubbles (2003-2006)
- MBS, CDOs bubble (2004-2007)
- Stock market bubble (2004-2007)
- Commodities and Oil bubbles (2006-2008)
- Debt bubbles


THE CRASH OF OCTOBER 1987

7 years

6 months
THE NASDAQ CRASH OF APRIL 2000

Super-exponential growth
Fig. 1. (Color online) Plot of the UK Halifax house price indices from 1993 to April 2005 (the latest available quote at the time of writing). The two groups of vertical lines correspond to the two predicted turning points reported in Tables 2 and 3 of [1]: end of 2003 and mid-2004. The former (resp. later) was based on the use of formula (2) (resp. (3)). These predictions were performed in February 2003.

Fig. 5. (Color online) Quarterly average HPI in the 21 states and in the District of Columbia (DC) exhibiting a clear upward faster-than-exponential growth. For better representation, we have normalized the house price indices for the second quarter of 1992 to 100 in all 22 cases. The corresponding states are given in the legend.

Our study in 2005 identifies the bubble states.

Local bubbles (Froths) of Housing Markets in US, 1998-2006.
Real-estate in the USA

Chart 1: HOME PRICES — STILL DEFLATING AFTER ALL THESE YEARS

United States

S&P/Case-Shiller Home Price Index: Composite 20
(Jan 2000 = 100, seasonally adjusted)

Source: Haver Analytics, Gluskin Sheff

W.-X. Zhou and D. Sornette, Is There a Real-Estate Bubble in the US?
One prominent financial figure held the greatest sway in debates about the regulation and use of derivatives — exotic contracts that promised to protect investors from losses, thereby stimulating riskier practices that led to the **financial crisis**. For more than a decade, the former **Federal Reserve Chairman Alan Greenspan** has fiercely objected whenever derivatives have come under scrutiny in Congress or on Wall Street. “What we have found over the years in the marketplace is that **derivatives have been an extraordinarily useful vehicle to transfer risk from those who shouldn’t be taking it to those who are willing to and are capable of doing so,**” Mr. Greenspan told the Senate Banking Committee in 2003. “We think it would be a mistake” to more deeply regulate the contracts, he added.

“**Not only have individual financial institutions become less vulnerable to shocks from underlying risk factors, but also the financial system as a whole has become more resilient.**” — **Alan Greenspan** in 2004
bubble peaking in Oct. 2007
Typical result of the calibration of the simple LPPL model to the oil price in US$ in shrinking windows with starting dates $t_{\text{start}}$ moving up towards the common last date $t_{\text{last}} = \text{May 27, 2008}$.

Abnormal relationship signaling a bubble

Monthly Corn Price Index and USDA Stocks
Subprime Mortgage Loans Outstanding

US$ billions

Source: Inside Mortgage Finance.
Over the past decade and a half, $(B - F)$ has been closely correlated with realized capital gains on the sale of homes. $B-F=$ change in home equity debt outstanding less unscheduled repayment on RMDO

Mortgage Equity Withdrawal impact on GDP

source: John Mauldin (April 09)

Alan Greenspan and James Kennedy (Nov. 2005)
1981-2007: The illusionary “PERPETUAL MONEY MACHINE” continues..

Total liabilities of the U.S. financial and non-financial sectors divided by the GDP

The data are taken from the Flow of Funds accounts of the U.S. (http://www.federalreserve.gov/releases/z1/), the non-financial sector includes the federal government, government sponsored entities, household and non-profit and non-financial business. The smooth curves show the fits of the models.

This picture demonstrates that debt levels are on unsustainable tracks that, according to our bubble models, are expected to reach a critical point towards the end of the present decade.

Total U.S. Debt as a % of GDP

annual

1875 = 156.4
1916 = 170.4
1933 = 299.8
2003 = 306.2
2008 Q3 = 358.2


$ 50 trillions
The Global Bubble

Index of over-valuation

The “perpetual money machine” broke.

PCA first component on a data set containing, emerging markets equity indices, freight indices, soft commodities, base and precious metals, energy, currencies...

Predictability of the 2007-XXXX crisis: 
30 year History of bubbles and of Endogeneity

- Real-estate bubbles (2003-2006)
- MBS, CDOs bubble (2004-2007)
- Stock market bubble (2004-2007)
- Commodities and Oil bubbles (2006-2008)
- Debt bubbles

Didier Sornette and Ryan Woodard, 

D. Sornette and P. Cauwels, 
Financial Crisis Observatory

The Financial Crisis Observatory (FCO) is a scientific platform aimed at testing and quantifying rigorously, in a systematic way and on a large scale, the hypothesis that financial markets exhibit a degree of inefficiency and a potential for predictability, especially during regimes when bubbles develop.

Current analysis and forecasts

**CDS** (19 February 2009)
Our analysis has been performed on data kindly provided by Amjed Younis of Fortis on 19 February 2009. It consists of 3 data sets: credit default swaps (CDS); German bond futures prices; and spread evolution of several key euro zone sovereigns. The data range of the data is between 4 January 2006 and 18 February 2009. Our log-periodic power law (LPPL) analysis shows that credit default swaps appear bubbly, with a projected crash window of March-May, depending on the index used. German bond futures and European sovereign spreads do not appear bubbly. (See report for more information.)

**OIL** (27 May 2008)
Oil prices exhibited a record rise followed by a spectacular crash in 2008. The peak of $145.29 per barrel was set on 3 July 2008 and a recent low of $40.81 was recorded on 5 December, a level.
Financial Crisis Observatory

• **Hypothesis H1**: financial (and other) bubbles can be diagnosed in real-time before they end.

• **Hypothesis H2**: The termination of financial (and other) bubbles can be bracketed using probabilistic forecasts, with a reliability better than chance (which remains to be quantified).

The Financial Bubble Experiment
advanced diagnostics and forecasts of bubble terminations

• **Time@Risk**: Development of dynamical risk management methods
Financial Crisis Observation

Date: 2013-09-08
Name: Hang Seng Index Ho
Show: hr_at_t2

Graph showing price movements from October 2011 to July 2013.
Slaying dragon-kings
predictability and control of extreme events in complex systems

possibility to control by small targeted perturbations

Hugo L. D. de S. Cavalcante, Marcos Oriá, Didier Sornette, and Daniel J. Gauthier (2013)
Big problems are piling up...

Suggested solutions:

- Study history ("this time is different", really?)
- Recognition that crises are the norms rather than the exception
- Understand underlying mechanisms (positive feedbacks are grossly under-estimated)
- Diagnostic: fundamental vs proximal
- Weak signal, advance warning and collective processes
- Monitoring and forecasting (managing and governing needs predicting)
- Decouple and diversify
- Fiduciary principle; principled ethical behavior; reassessment of expectations; risk monitoring
- Incentives + human cognitive biases + individual resilience
Further Reading


