Understanding Financial Risk Through Complexity: 
Application to Real Time Series 
by 
Catherine Kyrtsou, Anastasios Malliaris, and 
Christina Mikropoulou
Mainstream (Fama)

• Markets are fully functional and efficient machines, producing white noise processes.
• Short-run perturbations are permitted as markets need time to correct themselves.
• Computationally, quasi-linear models can describe their operation and estimators asymptotically are stable.
• Extreme points (i.e. outliers) are exogenous, unpredictable and “innocent” events.
• Risk results from short-term divergence

Alternative (Shiller, Lo...)

• Modern economies are fluctuating persistently, giving hard time to the participants assigning probabilities.
• Irrationality and asymmetry in information are detrimental parts of the observed outcome.
• Linear schemes are quite restrictive to capture the multiplicative evolution of the profit-maximizing units.
• Extreme behaviors emerge endogenously, are repeated and can be accommodated in power lawed distributions.
• Risk encompasses qualitative attributes.
• Knightian (1921) Uncertainty vs. Risk
  – Risk is known and measurable
  – Uncertainty is unknown and immeasurable

• 3-dimensional nature of uncertainty [Jacklin et al., (1992); Romer (1993); Avery and Zemsky (1998)]: the synergetic action of these kinds of uncertainty may provide a more complete framework of price bubble formation.
  – Value
  – Composition
  – Event

• Kyrtsou's (2008) experimental approach. Proves that even in the absence of exogenous information, trading schemes can produce a nonlinear outcome (see also Ashley, 2012). Exogenous heteroskedasticity vs Endogenous heteroskedasticity (as a result of neglected nonlinear structure)
• The presence of complex dynamics undermine two mainstream economic hypotheses:
  – Self-stabilizing mechanisms lead to equilibrium
  – Rationality

• Absence of unique equilibrium
  – Economic systems are evolving because of the interactions among their components
  – The presence of feedback mechanisms is the root cause of multiple equilibria

Nonlinear Interdependence
Dealing with Nonlinear Interdependence: Why RP’s are useful in Applied Finance?

- The RP framework addresses efficiently several debating issues of standard regression time series analysis, since it makes no assumptions about the nature or the generating process of the observational data.

- Features of RP analysis:
  - no stationarity
  - recognition of path-dependent dynamics
  - turning points (outperforms linear structural tests)
  - quantification of phase transition
Recurrence Plot (RP), firstly introduced by Eckman et al. (1987), constitute a clear representation of the topological features of the underlying signal and, by construction, is independent of all the limiting constrains imposed by linear parametric peers.

The construction of the $n \times n$ Recurrence matrix is achieved by calculating the distances:

$$R_{i,j}^m(\varepsilon) = \Theta(\varepsilon - ||\vec{x}_i - \vec{x}_j||) \text{ for } i, j = 1, 2, \ldots, N$$

Recurrence Plot depicts pixels of the distance value lower than the threshold ($\varepsilon$), for all $(i,j)$ coordinates.

- White noise
- Sine function
- Lorentz process
Quantification measures: Entropy I

Shannon Entropy uses as inputs the values of the main diagonal. In the context of RPs, Shannon entropy (ENTR) refers to the probability $p(l) = P(l)/N_1$ to find a diagonal line of exactly length $l$.

$$ENTR = - \sum_{l=l_{\min}}^{N} p(l) \ln p(l)$$

ENTR addresses the complexity in the RP.

– For uncorrelated noise, ENTR takes small values, indicating low complexity.
ENTR addresses the complexity in the RP.
- High entropy values are observed when a phase transition occurs.
Cross RPs and Line of Synchronization

• Cross recurrence plots (CRPs) can be used for the investigation of the simultaneous evolution of two different time series.

\[ CR_{i,j}^{x,y}(\varepsilon) = \Theta(\varepsilon - \|x_i - y_j\|) \quad \text{for} \quad i = 1, \ldots, N, \quad j = 1, \ldots, M \]

• Line of Synchronization (LOS): this method tests if the two trajectories visit the same region in the phase space.

• An off-set of the LOS away from the main diagonal is an indication of a phase shift or a delay between the two considered systems.
• We use as a proxy for output, monthly data of the Industrial Production index, in order to obtain the longest available sample.


• For the selection of embedding parameters (τ and m) and threshold level (δ) we follow the Marwan et al., (2007) and Kyrtsou & Vorlow (2005) rationale.
Dataset:

i. CBOE Volatility Index (VIX): fear gauge (Whaley, 2000).

ii. GARCH(1,1)

iii. Industrial Production: as proxy of the Business Cycle (BC)

• The dynamic behavior of both VIX and BC in the RPs indicate a lead of the BC phase transition
• LOS between VIX-Industrial Production: Gradual offset to the right indicating the leading behavior of the BC phase transition point
The dynamic behavior of both S&P500 Entropy and BC in the RPs indicate similarities in the phase transition point.
LOS between S&P500-Industrial Production: mainly synchronized
• LOS between Cross-Entropy of S&P500/WTI and Industrial Production: mainly synchronized until 2002 and then leading of Industrial Production
• Low volatility regime: stock and oil market interdependence is due to sectoral (endogenous) shocks leading to moderate heteroscedasticity (Kyrtsou, 2008; Ashley, 2012).
• High volatility regime: stock and oil market interdependence is due to global shock exacerbating heteroscedasticity.
• Guo et al., (2011): multifaceted nature of financial risk because of the complex interactions between oil, stock, credit and real estate markets.
Conclusions

• **Goal:** Examine the behavior of traditional and dynamic risk measures, under different conditions of financial distress

• **Implied and Historical Volatility:**
  – Describe riskiness when the outcome of risky strategies or negative events has been already incorporated into the market prices.

• **Entropy:**
  – Takes into account the dynamics in the (cross) RPs.
  – Able to address the fact that financial markets discount information.
  – It is not a simple representation of risk but merges features that the complex nature of uncertainty implies.
THANK YOU