Understanding Financial Risk Through Complexity: Application to Real Time Series

Catherine Kyrtou
University of Macedonia, CAC, IXXI-ENS Lyon, and University of Paris 10 and Strasbourg, ckyrtsou@uom.gr

Anastasios Malliaris
Loyola University Chicago, tmallia@luc.edu

Christina Mikropoulou
University of Macedonia, cmikro@uom.gf

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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)
Complexity and Economic Analysis

• 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
Methodology: Recurrence Plots

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:

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

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

\[
R_{i,j}^m(\varepsilon) = \begin{cases} 
1 & \text{if} \quad \vec{x}_i \approx \vec{x}_j \\
0 & \text{if} \quad \vec{x}_i \neq \vec{x}_j 
\end{cases}
\]
Shannon Entropy uses as inputs the values of the main diagonal. In the context of RPs, Shannon entropy (ENTR) refers to the probability \( p(l) = P(l)/N_l \) to find a diagonal line of exactly length \( l \).

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

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

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

• 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.

• Datasets: monthly observations

• 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.
Implied & Historical Volatility behavior I

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.
• **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