A complex evolving system approach to the study of economic fluctuations

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Extreme events in economics

- Extreme events are quite important in economics. One financial markets or GDP, whose fluctuations are well approximated by fat-tailed distributions.

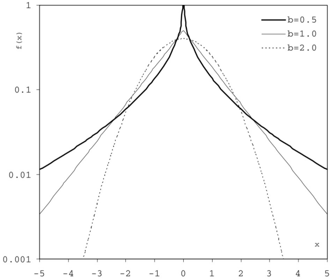


Fig. 1. The exponential-power (Subbotin) density for $m = 0$, $a = 1$ and different shape parameter values: (i) $b = 2$: Gaussian density; (ii) $b = 1$: Laplace density; (iii) $b = 0.5$: Subbotin with super-Laplace tails. Note: Log scale on the y-axis.

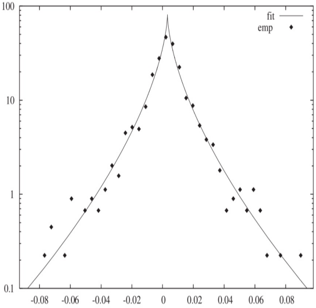


Fig. 3. Binned empirical densities of US IP growth rates vs. Subbotin fit. Time period: $1921M1 - 2005M10$.

Figure: Source: Fagiolo, Napoletano and Roventini (2008)

- Traditional approaches have certainly had the merit of posing fundamental questions on the economic incentives that lead to an increase in either financial or macroeconomic risk
    - Heterogeneity of agents
    - Distributed externalities diffusing via networks of interactions
    - Non-linearity and positive feedback loops.
    - Endogeneity of extreme events

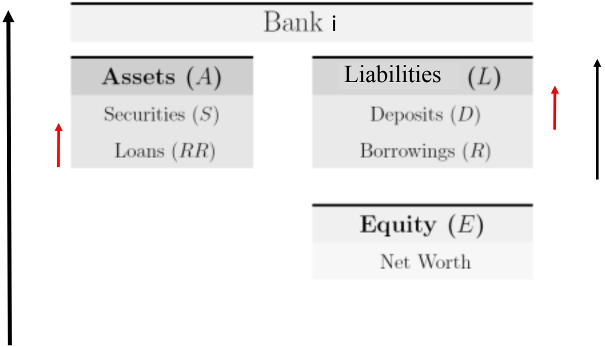
- Network and agent-based models help to shed lights on the above aspects.
- This is because network models allow one to represent the very structure of interaction among agents
- Agent-based models (ABMs) represent economies as dynamical systems of heterogeneous agents interacting out of equilibrium

Bottom-up approach and emergent properties

- Both network and ABMs follow a bottom-up approach to the explanation of phenomena in economics.
- Aggregate phenomena are explained as emergent properties of the interaction of heterogeneous agents
- One starts with simple behavioural rules (the primitives of the model) and then studies whether the interaction of heterogeneous agents is able to generate the macroeconomic phenomenon under study (or not).
- **Generative approach.** Lack of isomorphism between aggregate dynamics and the hypotheses concerning single agents (contrast with reductionism).

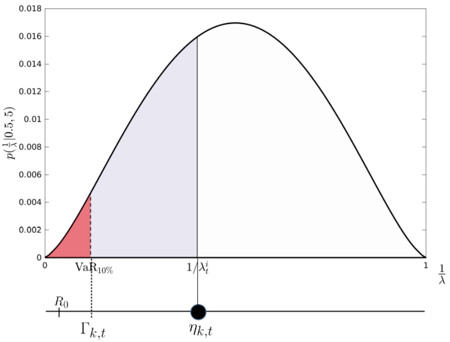
Leverage dynamics and fluctuations in financial markets

- Most money circulating in the economy is endogenously created by banks as a result of their lending activity and leverage expansion (McLeay et al., 2014).



Value at Risk and Leverage

- Financial institutions have incentives to increase leverage (because it increases profits). At the same time increasing leverage implies also increasing the probability of bankruptcy.
- Financial institutions typically use Value at Risk (VaR) rules arbitrate between these two conflicting objectives.



Rehypothecation networks

joint with D.T. Luu, P. Barucca, S. Battiston

- Rehypothecation is the right to re-use the collateral of a transaction many times over.
- Rehypothecation increases the liquidity of market players, as those players can use the collateral received to honor another obligation.
- At the same time rehypothecation lowers actual coverage against counterparty risk, because the same collateral secures more than one transaction. It can thus be a source of systemic risk.
- Different networks of rehypothecation under VaR may imply different trade-offs between liquidity and systemic risk

Rehypothecation, the velocity of collateral and liquidity in financial markets

- One fundamental equation in economics is the quantity theory equation. We can use this equation to understand how rehypothecation affects the total amount of transactions (liquidity) in a financial market.

$$M \cdot V = P \cdot T \tag{1}$$

- M: quantity of collateral; V: velocity of collateral;P:price of a transaction; T:volume of transactions
- Rehypothecation increases the total amount of transactions in the system because, for a given M it allows an increase in velocity V
- The (interesting) issue is however that different (rehypothecation) network structures can have imply different velocities but also different aggregate losses in response to small local shocks.

The determination of total collateral in rehypothecation networks

- We can write the following expression for the dynamics of $A_i^{C^{out}}$, i.e. the total amount collateral **flowing out of the box** of the bank i

$$A_i^{C^{out}} = A_i^{0^{out}} + (1-h)\delta_i\theta_i \sum_{j\in B_i} s_{i\leftarrow j} A_j^{C^{out}} \quad (2)$$

- In matrix form Equation (2) reads

$$A^{C^{out}} = A^{0^{out}} + (1-h)\mathcal{M}A^{C^{out}} \quad (3)$$

- The solution to the above equation returns the vector of outflowing collateral $A^{C^{out}}$.

$$A^{C^{out}} = (\mathcal{I} - (1-h)\mathcal{M})^{-1} A^{0^{out}} = \mathcal{B}_1 A^{0^{out}} \quad (4)$$

with $\mathcal{I}$ is the identity matrix of size N, $\mathcal{B}_1 = (\mathcal{I} - (1-h)\mathcal{M})^{-1}$

Value-at-Risk and collateral hoarding effects

- Let us now assume that banks decide how much collateral to hoard on the basis of a Value at Risk criterion (VaR). Start with the net liquidity position of the bank:

$$NL_j = (1-h)(1-\theta_j)A_j^C(\theta_1, \theta_2, ..., \theta_N, G) - \epsilon_j \tag{5}$$

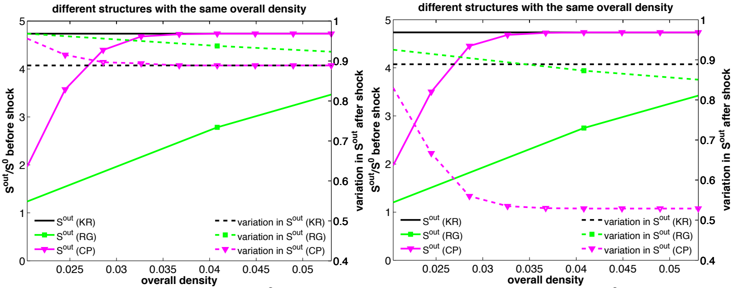
- Each bank j set the fraction of collateral to hoard so that the probability of default is not higher than a target $1 - c_j$.

$$\text{prob.}(\epsilon_j > (1-h)(1-\theta_j^*)A_j^C) \leq 1 - c_j \tag{6}$$

- If we assume that the shocks ϵ_j are either uniformly or normally distributed, the expression for the determination of the target θ_j^* becomes

$$\theta_j^* = 1 - \frac{c_j^0}{(1-h)A_j^C}, \tag{7}$$

Emergence of a trade-off between endogenous liquidity and endogenous systemic risk



(a) random attacks at $\langle \tilde{c}_i^0 \rangle = 1.5$ (b) target attacks $\langle \tilde{c}_i^0 \rangle = 1.5$

Figure: Collateral creation and collateral variation under local uncertainty shocks. In each panel, the left y-axis shows $\frac{S^{out}}{S^0}$ (before shocks) and the right y-axis shows variation in S^{out} (after shocks) at $\langle \tilde{c}_i^0 \rangle = 1.5$.

VaR and fluctuations in financial markets

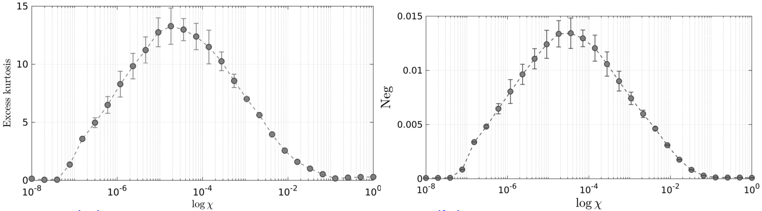
joint with F. Vanni, A. Roventini, G. Dosi

- A simple model where leverage grows with the network
- Banks for whom VaR is not binding create links and invest in a common asset. This investment pushes the asset price up.
- Banks for whom VaR is binding destroy links, and disinvest in the the common asset. This pushes the asset price down.
- Price fluctuations arise from changes in the composition between links creators and links destroyers.
- VaR threshold is adjusted following changes in leverage

$$\Gamma_{k,t+1} = \Gamma_{k,t} - a\,\Delta\eta_{k,t} + \xi \qquad \text{where } \xi \sim \mathcal{N}(0\,,\,\chi)$$

$\rightarrow$ where a is intensity of adjustment and χ is the intensity of uncertainty on the evaluation of the perception of risk respect to the a change on the leverage.

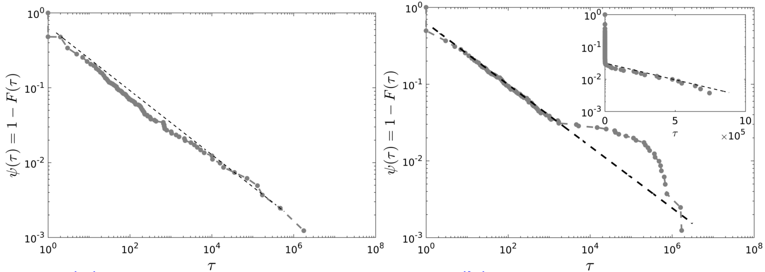
Heterogeneity, VaR and asset price fluctuations



(a) kurtosis vs noise χ (b) negentropy vs noise χ

Figure: **Phase transitions**. For small uncertainties on the VaR threshold the price returns distribution is Gaussian. For intermediate noise intensities we have an important deviation from the normality condition. Lately, for large values of the noise we go back to the normality condition.

Predictability of asset price fluctuations and leverage caps



(a) Leverage cap=0.1 χ (b) Leverage cap=0.9

Figure: Complementary cumulative distribution for The time between two consecutive cycles. Higher leverage gaps confine the duration of long cycles to an exponential rate in the long period. In fig (a) we observe the clear extended power law , meanwhile in (b) we have a strong truncation with exponential decay. In the inset we can see the clear exponential nature of the cutoff.

Conclusions

- Extreme events are pervasive in the economic reality
- A complex evolving system approach to economic analysis help to shed light these extreme events
- Network models and agent-based models embed several features of this complex evolving approach and they are therefore useful to shed lights on the mechanisms generating such extreme events
- We explored how heterogeneous interacting agents following simple heuristics followed by agents (e.g. VaR leverage expansions by banks) or adopting some financial practices (rehypothecation) can generate large aggregate fluctuations in financial markets
- A complex evolving approach can also offer novel perspectives on policy with respect to traditional approaches

Thank you!