High Clustering Protects Against Catastrophic Collapse of Cooperation

Gwen Spencer, PhD

Motivation: *network games*

Highly-cited Human Studies Claim:

Topology has no impact for cooperation.

- Prisoner's Dilemma: Gracia-Lázaro et al. [1]

- Public Goods Games: Suri and Watts [4]

VS.

Classical Prediction:

Stable network interactions should encourage cooperation.

- Outbreaks of cooperation

- Clustered Structure allows stability

Explain Discrepancy?

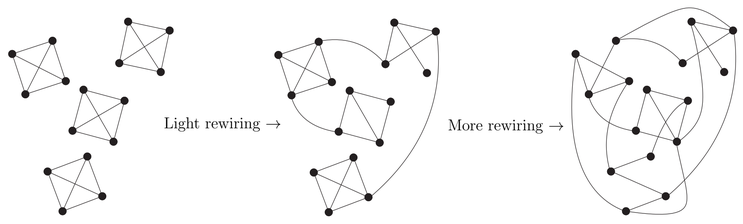
Q: Possible to Reconcile Classical Models with Modern Empirical Observations?

A: Yes. Predictions vary with parameters [3]

- High *round-1 defection* forces *catastrophic collapse* across topologies *(Suri and Watts [4] documented* $\approx 45\%$*)*
- Above *critical threshold*: clustering does protect cooperation against randomly-distributed *shocks of defection*. *(Gracia-Lázaro et al. [1] only test low-clustering networks)*
- At *low cost of cooperation* (or, with many altruists) no protective effect predicted.

Complex Parameter Space

Smooth Erosion of Community Structure:



Decision Rules for Spread:

- *Conditional Cooperation: threshold* h

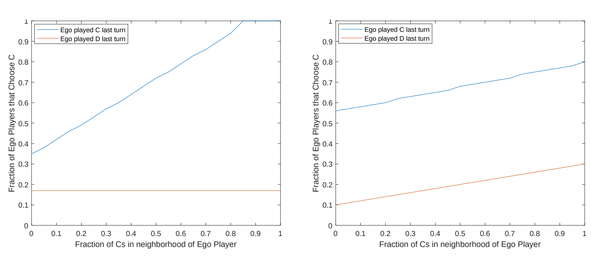
  At time t, node $v \in V$ updates behavior depending on behavior of v's neighbor set, $\delta(v)$, at time $(t-1)$:

$$c_{t+1}(v) = \begin{cases} 1 & \text{if } \sum_{u \in \delta(v)} c_t(u) \geq h * |\delta(v)|, \\ 0 & \text{otherwise.} \end{cases}$$

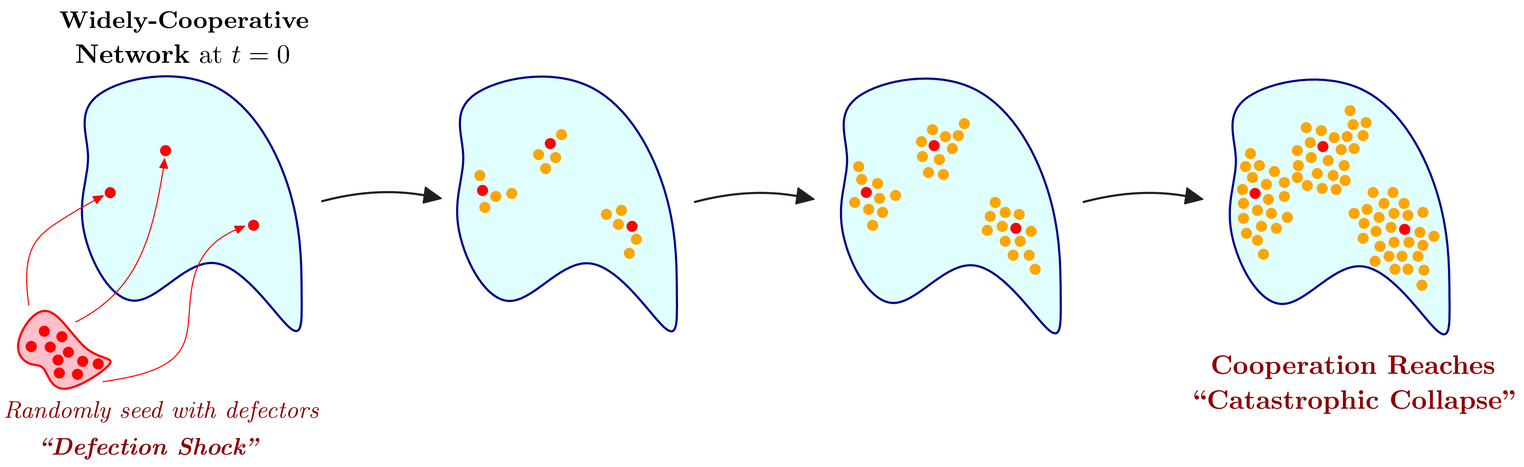
- *Empirical Moody Conditional Coop [1, 2]*

  - threshold conditioned on own past action

  - heterogeneous population



Experiments: Seeding Until *Catastrophic Collapse [3]*



What size *Defection Shock* at $t = 0$ is required to force a cooperative network into *Catastrophic Collapse of Cooperation*?

Results: *A Protective Effect of Clustering [3]*

- **Threshold-based Conditional Cooperation:** Increasing Rewiring Reduces Ability to Withstand *Defection Shocks*. Equivalently: High Clustering Increases Ability to Withstand *Defection Shocks*:

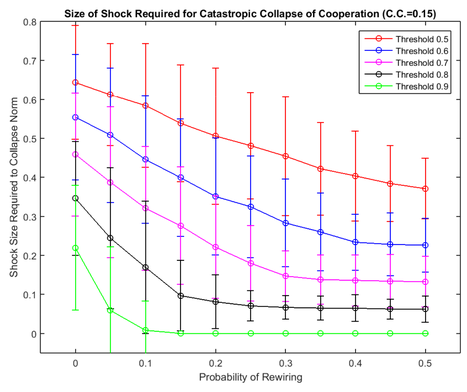
Protective Effect above critical threshold.

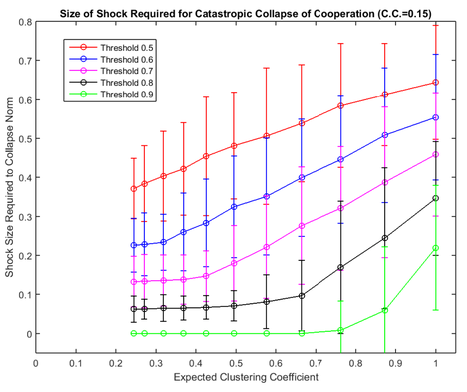
Consistent behavior for:

- small synthetic networks (50 vs. 200 nodes)
- variable small community sizes (10 vs. 20)
- non-uniform community sizes (normal dist.)
- large real-data example (1,421 nodes)

**Slope decreases to 0 for lowest thresholds h*

**Shock required for collapse has high variance*

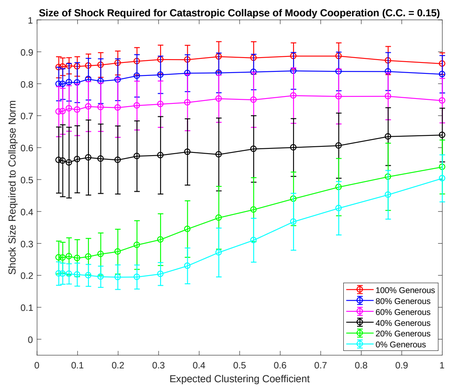


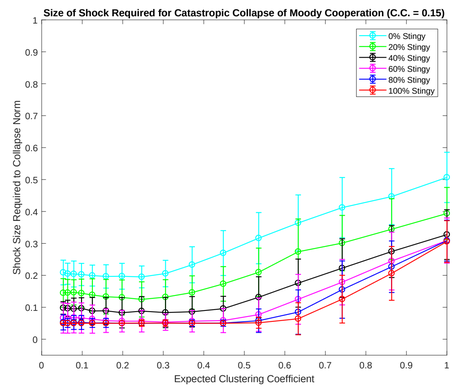


- **A Novel View on Suri and Watts [4]** Simple threshold-based model predicts: Catastrophic cooperation collapse was *the most likely outcome* across all topologies.

Network Topology *Initial Defection Rate of 45%*	Estimated Probability of Final Cooperation ≤ 0.30	2 Std. Dev.- confidence interval for number of final cooperators (of 24)
Cliques	89.5%	$4.3\ (+/-\ 9.2)$
Paired Cliques	91.5%	$4.1\ (+/-\ 8.7)$
Cycle Cliques	94.0%	$1.7\ (+/-\ 7.1)$
Small World	99.5%	$0.2\ (+/-\ 3.6)$
Random Regular	99.5%	$0.1\ (+/-\ 3.4)$

- **Moody Conditional Cooperation:** We study two *Suites of Distributions* over moody conditional cooperator *Player Types*:





Player Type	h_v^c	h_v^d
Base Type	0.6	0.9
Generous Type	0.1	0.4
Stingy Type	0.8	1.1

Extra Takeaways: 1. Networks in *catastrophic collapse* are nearly impossible to distinguish. 2. To refute role of topology in supporting cooperation, tests must examine a portion of the parameter space where a topology effect is truly predicted, and account for *round-1 defectors*.

References

[1] C. Gracia-Lázaro, A. Ferrer, G. Ruiz, and A. Tarancón, J.A. Cuesta, A. Sánchez, Y. Moreno, Heterogeneous networks do not promote cooperation when humans play a Prisoner's Dilemma. In *Proceedings of the National Academy of Sciences, vol. 109, num. 32, 2012.*

[2] J. Grujić, C. Gracia-Lázaro, M. Milinski, D. Semmann, A. Traulsen, J. A. Cuesta, Y. Moreno, and A. Sánchez. A comparative analysis of spatial Prisoner's Dilemma experiments: Conditional cooperation and payoff irrelevance. In *Scientific Reports, vol. 4, April, 2014.*

[3] G. Spencer. Clustered Networks Protect Cooperation Against Catastrophic Collapse. Accepted at *Network Science.*

[4] S. Suri, and D.J. Watts. Cooperation and Contagion in Web-based, Networked Public Goods Experiments. In *PLoS ONE, vol. 6, num. 3, 2011.*