Evaluating the Impact of Bailout Strategies on Financial Networks

Network System Science and Advanced Computing (NSSAC)

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Background

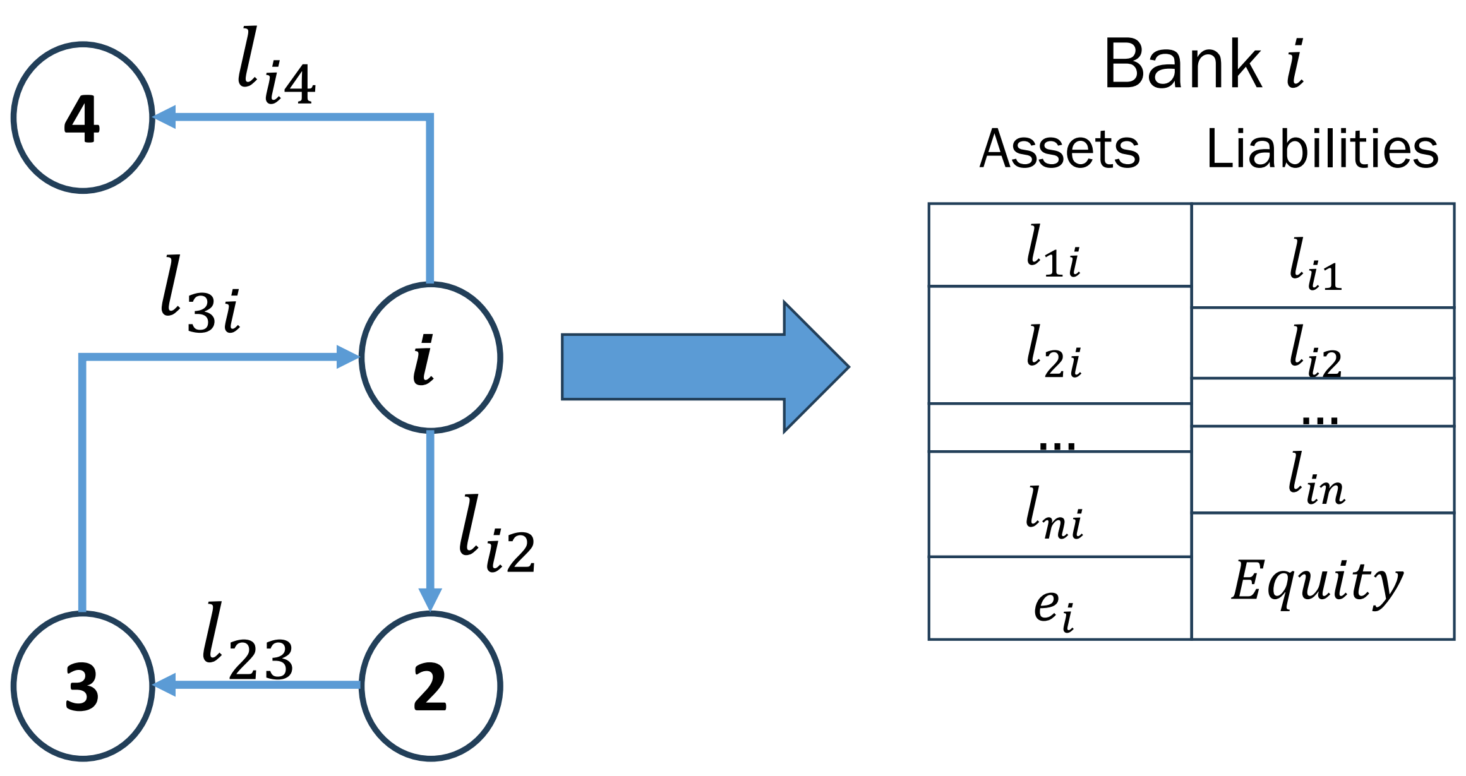
- Interbank lending can be considered an interconnected banking network comprising interbank liabilities and assets.
- In such networks, one bank's failure to pay its liabilities can lead to a cascading effect, triggering a system-wide shockwave, as seen in the infamous 2008 financial crisis and the recent Silicon Valley Bank collapse.
- The Eisenberg-Noe model provides a framework to simulate cascading failures as financial contagions[1].

Purpose

- To study and compare the effectiveness of graph centrality-based intervention strategies in mitigating financial contagions.

The Eisenberg Noe Model[1]

A directed graph $G = (V, E)$ of financial entities. Assuming $n = |V|$.



Every node i has these attributes,

- $\boldsymbol{l_{ij}}$ - Value owed to other entities ($\forall\, \mathbf{j} \in \boldsymbol{V}, \boldsymbol{j} \neq \boldsymbol{i}$). Also known as liabilities.
- $\boldsymbol{l_{ji}}$ - Value owed by other entities ($\forall\, \mathbf{j} \in \boldsymbol{V}, \boldsymbol{j} \neq \boldsymbol{i}$) to $\boldsymbol{i}$. Also known as assets.
- $\boldsymbol{e_i}$ - External assets

Model Equations

$\mathbf{L}$, a liability matrix of dim $\mathbf{n} \times \mathbf{n}$ where each element $\boldsymbol{l_{ij}}$ represents liability of node $\mathbf{i}$ to node $\mathbf{j}$

$$\bar{p}_i = \sum_{j=1}^{n} l_{ij}$$

Let $\bar{p} = (\bar{p}_1, \bar{p}_2, \dots, \bar{p}_n)$ represent the total obligation vector, which represents the payment level required for the complete satisfaction of all contractual liabilities by all nodes.

$$\Pi_{ij} = \begin{cases} \frac{l_{ij}}{\bar{p}_i} & \text{if } \bar{p}_i > 0 \\ 0 & \text{otherwise} \end{cases}$$

represents the relative liabilities matrix, which captures the nominal liability of one node to another in the system as a proportion of the debtor's node total liabilities.

$\sum_{j=1}^{n} \Pi_{ij}^{T}(p_j + e_i - p_i)$ represents the equity of node i

Clearing Payment Vector

$$p_i^* = \min\left[e_i + B_i - X_i + \sum_{j=1}^{n} \Pi_{ij}^{T} p_j^*, \bar{p}_i\right]$$

The clearing payment vector for the financial system $(\Pi, \bar{p}, e)$ satisfies the following conditions:

(a) Limited Liability:

This requires that the total payments made by a node must never exceed the cash flow available to the node. Mathematically, we can represent this as follows:

$\forall i \in \{1, 2, \dots, n\}, p_i^* \leq \Pi_{ij}^{T} p_j^* + e_i$

(b) Priority of Debt Claims:

This requires that stockholders in the node receive no value until the node is able to completely pay off all of its outstanding liabilities. This can be defined as follows:

$$p_i^* = \sum_{j=1}^{n} \Pi_{ij}^{T} p_j^* + e_i$$

(c) Proportionality:

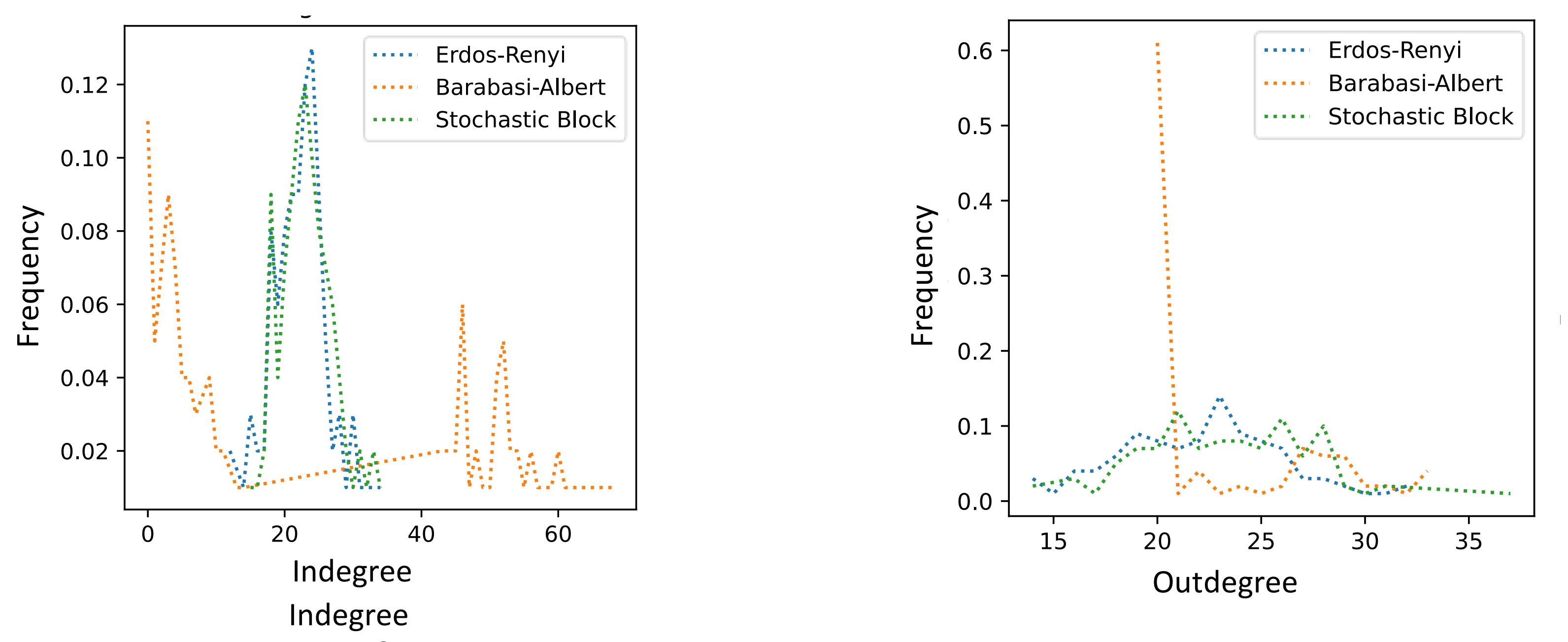
This requires that if default occurs, all claimant nodes are paid by the defaulting node in proportion to the size of their nominal claim on firm assets.

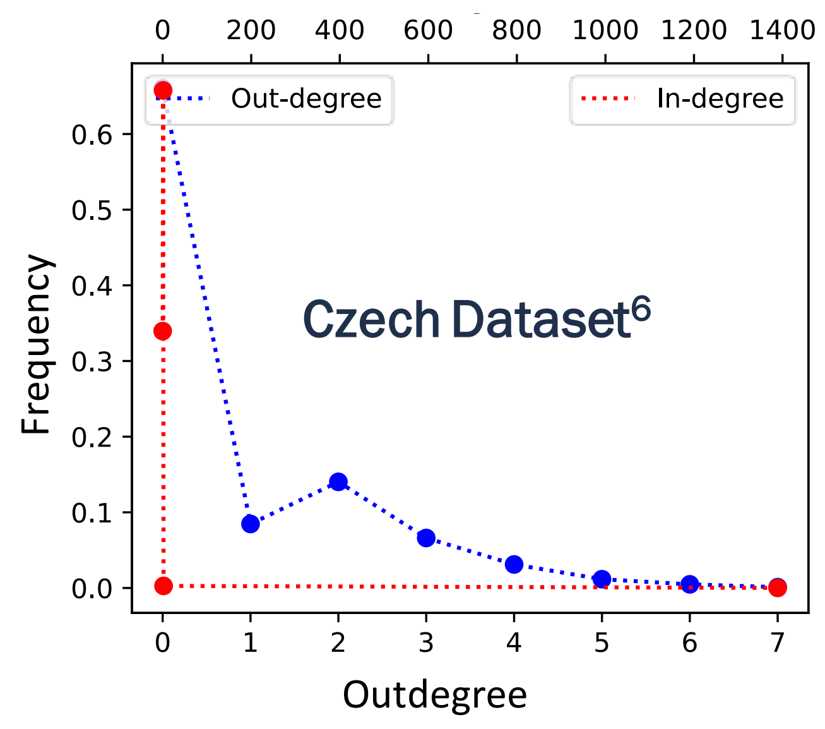
Experimental Setup

- We utilize six network centrality measures (*degree, betweenness, closeness, clustering, PageRank*) to select target banks for capital injection. Each centrality metric uniquely computes a node's importance in the network. The amount of capital injection is determined by the mean of nominal obligations of all bank nodes.
- We use the NetworkX graph analytics library in Python.
- Code based on EN model code from *Allocating Stimulus Checks in Times of Crisis*[2].

Input Data

Synthetic Datasets



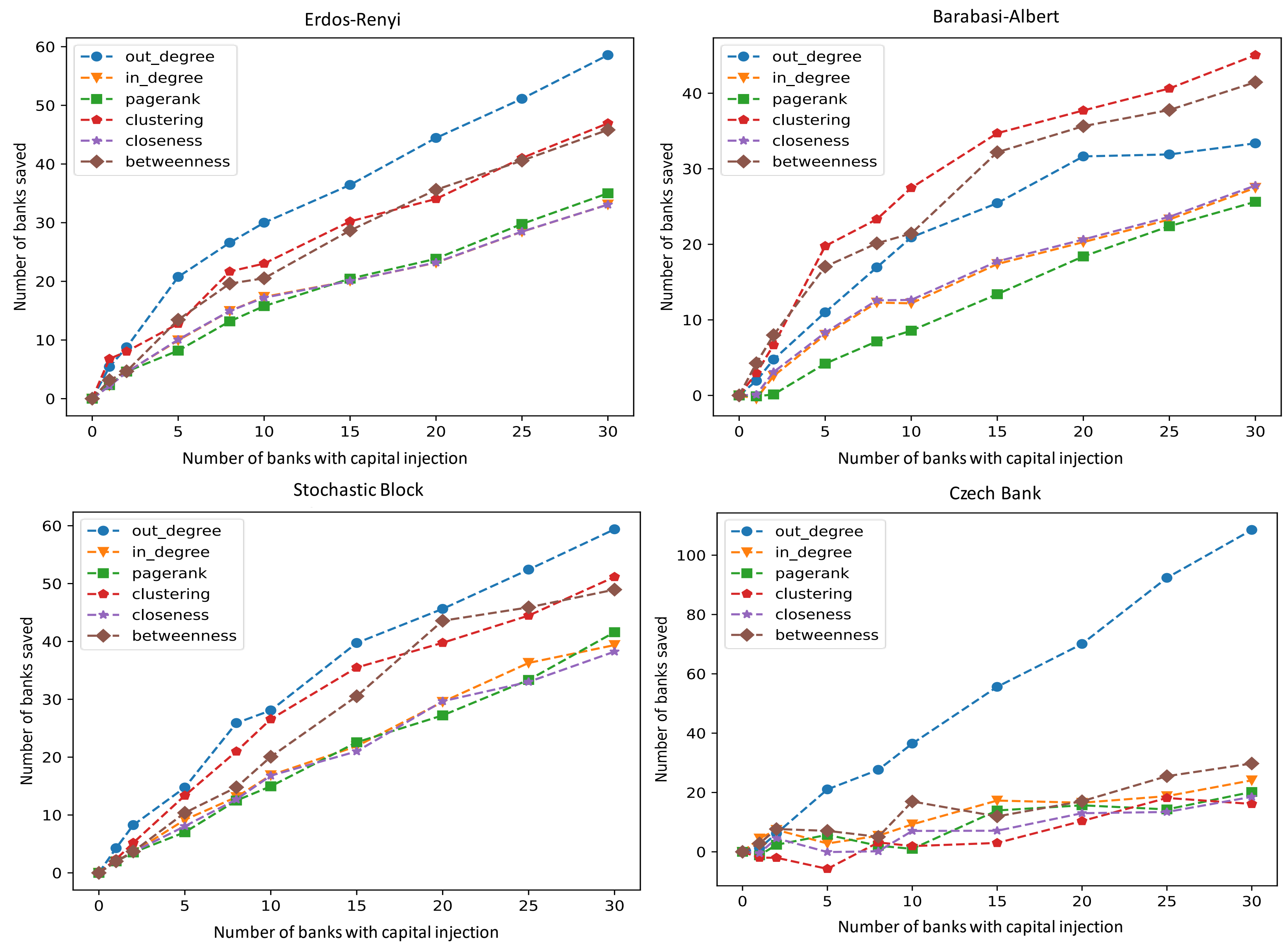


Network Parameters and Details

Erdos-Renyi: 100 Nodes with edge creation probability of 0.22.
Stochastic-Block: 3 communities (30,30,40) with intra and inter com. prob. as 0.5 and 0.1, respectively.
Barabasi-Albert: 100 nodes with using 40 node seed graph and 20 edges for each incoming node.
Czech Bank: 11605 nodes with 9085 edges.

Results

Effect of Bailout Strategies on Various Models



The plots compare the impact of six selection strategies for bailing out banks in the four networks. As the number of banks with an injection of capital increases, the plots depict an increase in the number of banks saved from defaulting. Notably, the effectiveness of the strategies varies across network types, pointing toward the influence of network structure on intervention outcomes.

Conclusion

- Our analysis provides insight into different bailout strategies and their respective impacts on the stability of several synthetic graphs and a real-world financial network.
- The results indicate how network structure can play a role in centrality-based bailout strategies and how their combination can lead to notably different outcomes. This emphasizes the importance and feasibility of tailor-made bailout strategies for specific types of networks.

Future Work

- Extending the model beyond the context of interbank lending networks and applying it to other complex network systems such as ride-sharing applications[3], power grids, and any other system which benefits from a tailored approach to analyzing cascading failures and identifying critical nodes to mitigate system-wide failures

References

[1] Eisenberg, L., & Noe, T. H. (2001). Systemic Risk in Financial Systems. [Online]. Available: https://www.jstor.org/stable/2661572
[2] Papachristou, M., & Kleinberg, J. (2022). Allocating Stimulus Checks in Times of Crisis. [Online]. Available: https://dl.acm.org/doi/abs/10.1145/3485447.3512047
[3] Papachristou, M., Banerjee, S., & Kleinberg, J. (2023). Dynamic Interventions for Networked Contagions. [Online]. Available: https://dl.acm.org/doi/10.1145/3543507.3583470
[4] Glasserman, P., & Young, H. P. (2015). How likely is contagion in financial networks? [Online]. Available: https://www.sciencedirect.com/science/article/pii/S0378426614000600
[5] Bardoscia, M., Barucca, P., et al. (2021). The Physics of Financial Networks. [Online]. Available: https://www.nature.com/articles/s42254-021-00322-5
[6] (1999). 1999 Czech Financial Dataset - Real Anonymized Transactions. [Online]. Available: https://data.world/lpetrocelli/czech-financial-dataset-real-anonymized-transactions

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