Financial Network Structure and Systemic Risk

An analysis on the structure of financial obligations in a network and its effect on insolvency cascades

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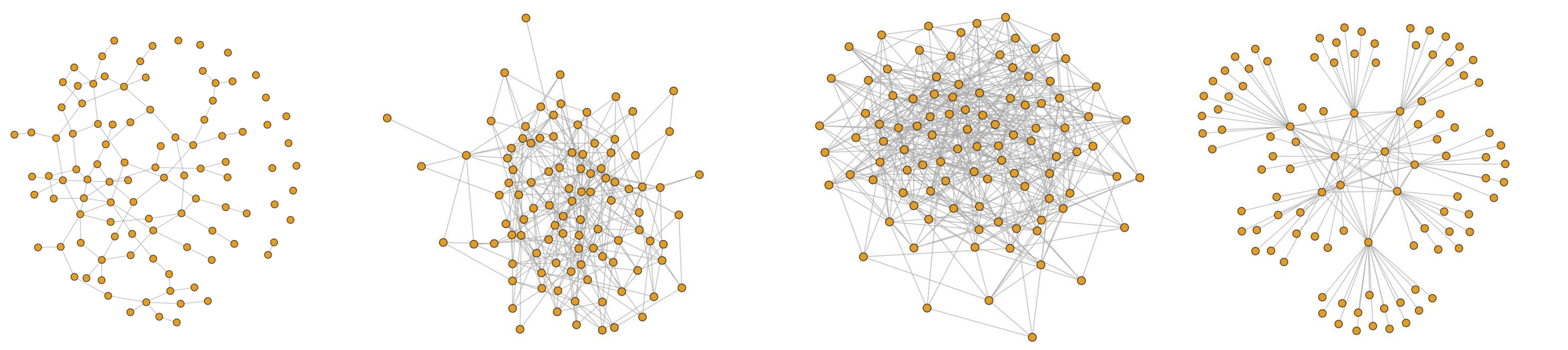
1) Abstract

Globalization has led to financial interdependence in organizations. This can be viewed as a network whose stability can have large impacts on the global economy. The organizations in this global network range from hedge funds and bank to governments. Their interdependence can be broken down into two factors. First is integration which is a measure of how heavily an organization is invested in operations outside of their own. Second is diversification measuring how many different organizations a firm is invested in. After individual organization structure, the role of network structure must be considered also. The main outcome of interest is what combination network characteristics can lead to significant instability when shocks are introduced. With regard to this it was found that at first, low levels of diversification make a sparsely connected network which does not allow for failures to travel far regardless of the integration level. Once a middle ground in diversification is reached failures are most likely to cascade leading to catastrophic results for almost all organizations in the network. Finally at a high level of diversification all organizations are too interdependent for a shock to do true damage as all firms absorb a small part of the impact. Overall low levels of integration make cascades less likely while high levels encourage failure propagation through the network due to organizations depending more on each other.



Random Network degree = 1 | **Random Network** degree = 3 | **Random Network** degree = 5 | **Core-periphery** 10 central orgs all connected, 90 peripheral with one central edge

Figure: Visualizations Of Various Networks To Be Tested

3) Motivation

Financial network stability became a hot topic after the 2008 financial crisis. A huge cause was a surplus of subprime loans. Many blame AIG's default as the catalyst for the cascade of failures(Glasserman, 2015). This means that AIG's default on payments caused other organizations they had obligations towards to also default. The default of payments propagated through the network doing damage to the world economy (Murphy, 2008).

The 2008 crisis resulted in an estimated $3 trillion sum in bailouts from the US government. Costing the world economy an estimated $10 trillion in losses (Murphy). In hindsight there were key nodes in the network that could have been bailed out to prevent cascades. This lack of understanding at the time furthered losses past a necessary degree. Currently the EU debt appears like it may be under a similar situation. Understanding how this process occurs may allow for such events to be prevented in the future.

Model Framework Applied to Debt Network in the EU

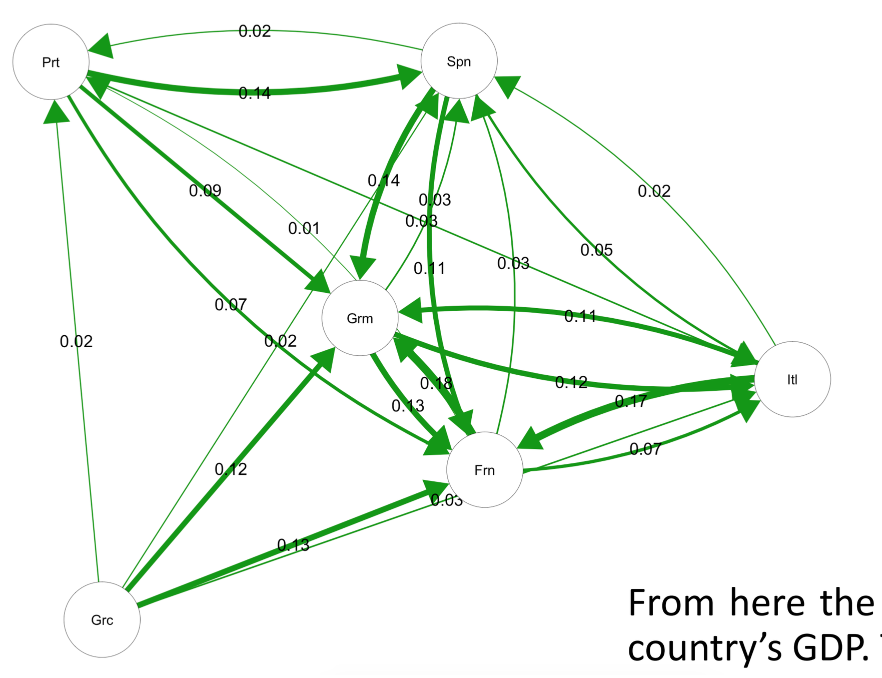
A financial debt network of major EU countries (in $ million) is provided to the right. Entries are defined by row i owing column j the corresponding amount. For example Germany owes Greece $266 (million). From here the dependency matrix can be calculated which is shown below the debt matrix. After this the network can be visualized as provided below.

Table: EU Debt Matrix

	France	Germany	Greece	Italy	Portugal	Spain
France	0	174862	1960	40311	6679	27015
Germany	198304	0	266	227813	2271	54178
Greece	39458	32977	0	2302	8077	1001
Italy	329550	133954	444	0	2108	29938
Portugal	21817	30208	51	3188	0	78005
Spain	115162	146096	292	26939	21620	0

Table: EU Dependency Matrix

	France	Germany	Greece	Italy	Portugal	Spain
France	0.71	0.13	0.13	0.17	0.07	0.11
Germany	0.18	0.72	0.12	0.11	0.09	0.14
Greece	0.00	0.00	0.67	0.00	0.00	0.00
Italy	0.07	0.12	0.03	0.70	0.03	0.05
Portugal	0.01	0.00	0.02	0.00	0.67	0.02
Spain	0.03	0.03	0.02	0.02	0.14	0.68



From here the dependency matrix is multiplied by a vector containing each country's GDP. This is because GDP is considered the 'asset' generating value. Then the failure thresholds can be set as a proportion of the country's original value. By multiplying the dependency matrix with the GDP the true 'market value' of each country is received. If the true value falls below the failure threshold then it can be said that the country will default. The algorithm stops when no country fails in the next step. Below are the results of this simulation based on multiple failure thresholds.

Table: Results of Framework Applied to EU Debt

		Failure Threshold: θ			
		0.9	0.93	0.935	0.94
Iteration of Algorithm	1st	Greece	Greece	Greece	Greece & Portugal
	2nd	X	X	Portugal	Spain
	3rd	X	X	Spain	France
	4th	X	X	France & Germany	Germany & Italy
	5th	X	X	Italy	X

Acknowledgments

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References

Acemoglu, Daron and Ozdaglar, Asuman E. and Tahbaz-Salehi, Alireza, Systemic Risk and Stability in Financial Networks (August 30, 2014). American Economic Review, 105(2): 564-608, 2015; Columbia Business School Research Paper No. 13-4. Available at SSRN: https://ssrn.com/abstract=2207439 or http://dx.doi.org/10.2139/ssrn.2207439

Elliott, Matthew and Golub, Benjamin and Jackson, Matthew O., Financial Networks and Contagion (January 2014). Available at SSRN: https://ssrn.com/abstract=2175056 or http://dx.doi.org/10.2139/ssrn.2175056

Glasserman, Paul and Young, Peyton, Contagion in Financial Networks (October 20, 2015). Office of Financial Research Working Paper No. 15-21. Available at SSRN: https://ssrn.com/abstract=2681392 or http://dx.doi.org/10.2139/ssrn.2681392

Murphy, Austin, An Analysis of the Financial Crisis of 2008: Causes and Solutions (November 4, 2008). Available at SSRN: https://ssrn.com/abstract=1295344 or http://dx.doi.org/10.2139/ssrn.1295344

2) Methods

Variables:

- C_{ij} → proportion of j held by i
- $\hat{C}_i$ → proportion of org i held by outside investors
- V_i → equity value of org i
- v_i → market value of org i
- p_k → value of primitive asset *k* that generates income in the network
- $\underline{v}$ → Failure value threshold
- D_{ik} → proportion of asset *k* owned by org *i*
- β_i → failure cost of org i
- I_{v_i} → vector containing list of failed orgs (1 if bankrupt, otherwise set to 0)
- A → dependency Matrix
- Z_t → vector used in algorithm to detect what orgs failed during iteration t

Calculating Organizational Values:

Equity value represents the value an organization provides to firms in the network along with outside investors. It is derived from an organization's investment in other firms and the sum of liabilities it is owed.

$$V_i = \sum_{j \neq i} C_{ij} V_j + \sum_k D_{ik} p_k - \beta_i I_{v_i < \underline{v}_i}$$

Equity value: *matrix equation*

$$\mathbf{V} = (\mathbf{I} - \mathbf{C})^{-1}(\mathbf{Dp} - \mathbf{b}(\mathbf{v}, \mathbf{p}))$$

Dependency Matrix describes how i's value depends on both j's operations and i's proportion held outside the network

$$\mathbf{A} = \widehat{\mathbf{C}}(\mathbf{I} - \mathbf{C})^{-1}$$

Market value conveys how much revenue accrues to final investors by multiplying equity value by the proportion of the firm held by outside investors.

$$\mathbf{v} = \widehat{\mathbf{C}}(\mathbf{I} - \mathbf{C})^{-1}(\mathbf{Dp} - \mathbf{b}(\mathbf{v}))$$

$$= \mathbf{A}(\mathbf{Dp} - \mathbf{b}(\mathbf{v}, \mathbf{p}))$$

The Cascade Algorithm

1. Calculate $Z_t = A[Dp - \tilde{b}_i] - \underline{v}$, every value that is negative in Z_t represents an organization that has gone under its failure threshold. Adding it to Z_t represents that it failed in iteration t.
2. Terminate once $Z_t = Z_{t-1}$, this indicates that network is stable and no more organizations will fail due to the chain of defaults caused by the initial shock.

4) Results: simulations of generated networks

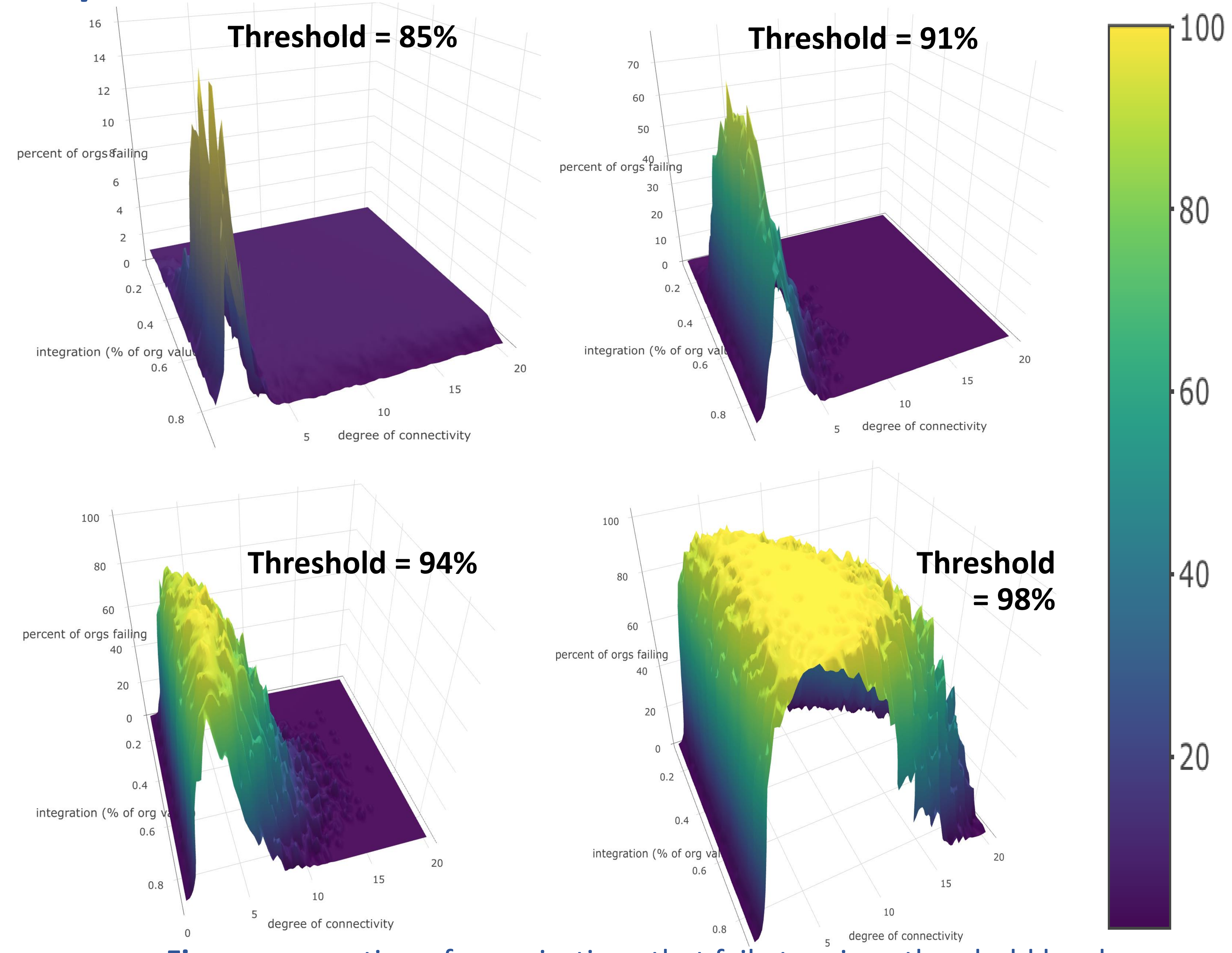

Figure: proportion of organizations that fail at various threshold levels plotted against diversification and integration.

Findings and Conclusion

The graphs above are from random networks where a shock is introduced to the network in the form of one or multiple organizations failing. 100 simulations were ran for each combination of diversification and integration on a randomly generated network. This revealed tradeoffs for diversification and integration; both show nonmonotonic effects meaning the middle of the range is actually the most dangerous for both. While low or high levels of diversification and integration lead to a more stable network.

The results of this experiment provide powerful insights, however in practice there are many more factors that come into play that were not considered. Some of these include liability structure which is private information for many organizations meaning it is impossible to gauge the effect of this and similar factors. Other factors that can not be considered are ones that include individual organization interests. For example some firms have incentives to affect bankruptcy in ways that are bad for the network but serve themselves well. In all this framework provides useful background for policy makers. As the financial industry is being deregulated findings from this and similar studies can inform law makers of dangerous loan structuring so it be prevented.