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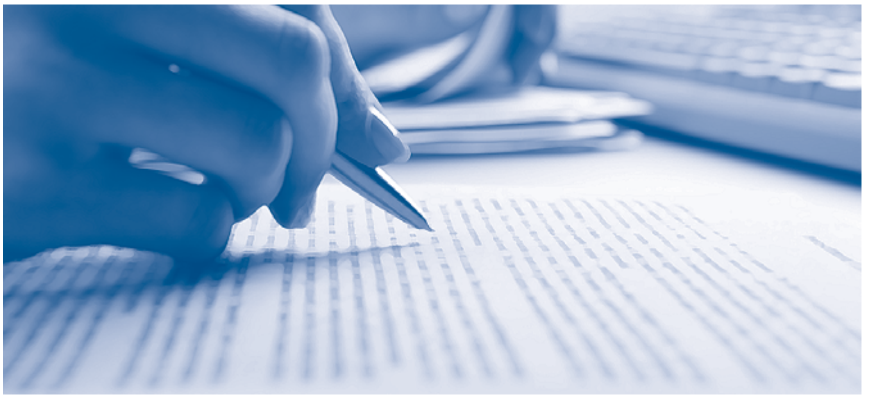

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Complex Networks and Banking Systems Supervision

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Abstract

Comprehensive and thorough supervision of all banking institutions under a Central Bank's regulatory control has become necessary as recent banking crises show. Promptly identifying bank distress and contagion issues is of great importance to the regulators. This paper proposes a methodology that can be used additionally to the standard methods of bank supervision or the new ones proposed to be implemented. By this, one can reveal the degree of banks' connectedness and thus identify "core" instead of just "big" banks. Core banks are central in the network in the sense that they are shown to be crucial for network supervision. Core banks can be used as gauges of bank distress over a sub-network and promptly raise a red flag so that the central bank can effectively and swiftly focus on the corresponding neighborhood of financial institutions. In this paper we demonstrated the proposed scheme using as an example the asset returns variable. The method may and should be used with alternative variables as well.

Keywords: Complex networks; Bank Systems; Core Banks; Connectedness; MST.
JEL Classification: E58, G21

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1. Introduction

The recent global financial crisis highlighted the importance of effective bank supervision and swift response from the regulator in times of bank distress. It has also become even more evident that assessing potential contagion risks from banking shocks must be done timely and efficiently. The cascade failures of 2008 and 2009 assert the need for additional monitoring tools and supervision of the financial system. These would allow prompt and decisive action to be taken limiting the associated losses. As a result, the E.U. leaders in October 2012 agreed to have the ECB closely supervise all six-thousand Eurosystem banks. The reasoning is that a single regulator will effectively assist struggling banks in receiving immediate bailout funds directly through the European Stability Mechanism (ESM). A single supervising authority will thus minimize the adverse effects of asymmetric information and uncertainty, building credibility for the ESM to raise the necessary funds for intervention. Comprehensive supervision of all six-thousand banks is of course cumbersome and may obstruct the identification of distress signals and possible contagion. This paper proposes a methodology to identify and reveal the "core" instead of just "big" banks that are central within a bank network and the potential pathways for contagion. We propose that this methodology may be used as an auxiliary early warning system within the central bank's arsenal. In addition to the current supervision procedure, the core banks suggested by the Minimum Spanning Tree (MST) methodology we employ here can provide a red flag to the regulator for close and detailed attention not only to the core bank but to the whole sub-network associated with it.

In section 2 we present the methodology. In section 3 we provide the empirical results, and finally section 4 concludes the paper.

2. The Methodology

We propose a methodology for additional parallel monitoring of the whole banking network using only a subset of banks that are identified as "core". This monitoring system can be used simultaneously to the existing ones. It can serve as a minimum cost early warning system increasing efficiency in terms of prompt and accurate intervention. The "core" banks are a subset that contains the most representative banks from the complete network in terms of cross banking linkages and correlations. These core banks can serve as control gauges for the rest of the network and highlight possible contagion paths. The concept is quite simple and easy to implement: first, we construct an undirected graph based on the cross-correlations from a chosen key relevant variable from the banks' financial statements. Then, we compute the Minimum Spanning Tree (MST) of the complete network: the minimum sized interconnected subset that connects all the vertices of the network. The MST has been used in the past in economics and finance to identify and describe stock market networks [3-5], interest rates of various maturities [6], bond markets [7], etc. It has an interesting property for our case: the cardinality of the direct neighbors for every vertex is a measure of its importance within the network (in graph theory jargon this is referred to as vertex degree). Finally, we use the algorithm of a simple and efficient heuristic method that identifies the core banks in the MST.

In what follows, we present the theoretical aspects of the proposed methodology. Empirical demonstration with an application on a small bank network using the log return of total assets as the key variable will be presented in section 3. Other variables can alternatively be employed, such as credit portfolios, return on equity, total deposits, interbank loans and non-performing loans. The regulator of course can use high frequency daily data providing a real time illustration of the MST.

The initial dataset consists of the selected variable of N banks for a set of T periods: $a_i(t)$, where $i = 1, \dots, N$ is the individual bank index and $t = 1, \dots, T$ is the time index. We calculate the symmetric $N \times N$ correlation matrix C, where every element $C_{i,j}$ corresponds to the correlation between the i-th and the j-th banks' log asset returns [1]. The similarity distance between a couple of banks is calculated by the D metric:

$$D_{i,j} = \sqrt{2(1 - C_{i,j})} \tag{1}$$

The higher the correlation, the closer the banks are. The $D_{i,j}$ distances are used to create a complete [1] undirected graph, where each vertex corresponds to a bank, and each edge corresponds to the similarity distance between two banks. The next step is to compute the Minimum Spanning Tree [2] of this network. This is the subgraph that a) has the property to connect all the vertices in the netwrok and b) has the minimum possible length (according to the vertices distances $D_{i,j}$). The idea used in producing the MST is quite simple: in every step, link the nodes with the lowest distance (in our problem highest correlation), ensuring that there are no cyclic subgraphs. The algorithm stops when all the nodes appear in the sub-graph.

[1] Complete is a network where every node is connected with all the rest of the network nodes.

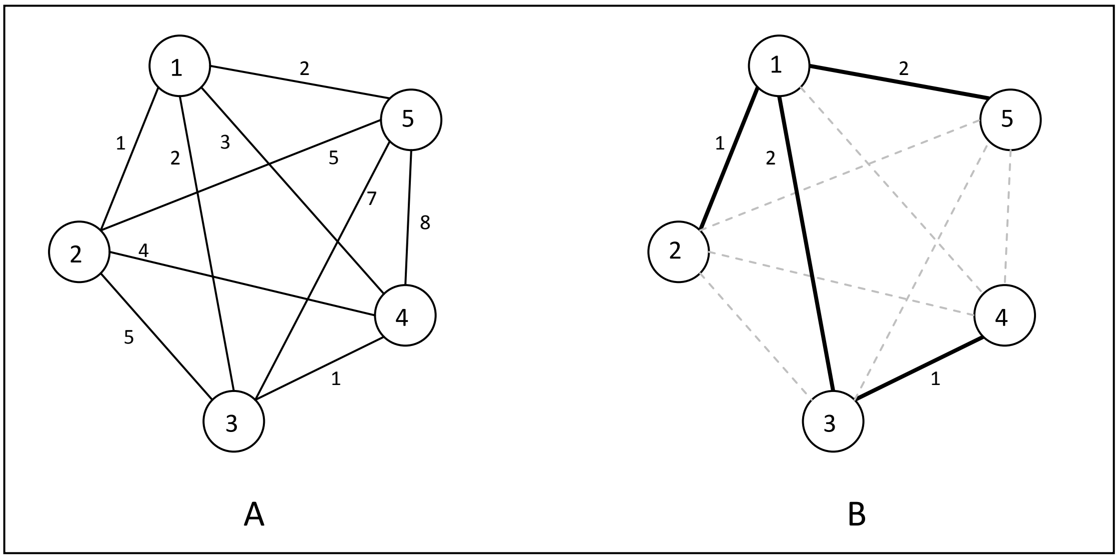

Figure 1: A. The complete undirected graph of five nodes and the corresponding distances between each couple of nodes and B. The corresponding Minimum Spamming Tree.

In Figure 1 there is an example of (A) a complete undirected graph with 5 nodes/banks and (B) the corresponding MST. In the MST and subgraph (B), bank 2 is connected with bank 1. This means that the behavior of bank 2 is mostly related to the behavior of bank 1 according to the examined variable than with any other bank on the graph. Thus, banks 1 and 2 exhibit similar behavior. Moreover, we can see that bank 1 is also related with bank 3 and bank 5. So, by monitoring the selected variable on bank 1, we also effectively monitor bank 2, bank 3, and bank 5 without monitoring them individually. In general, it is straightforward to see that by monitoring **just** bank 1 and bank 3 (or bank 4), we can effectively and efficiently monitor the whole network.

It is important to note here, that the presented idea does not lead to less banking supervision, but quite the opposite: The proposed scheme is intented to be used as an additional tool for the Central Bank over and beyond any current or future regulatory framework.

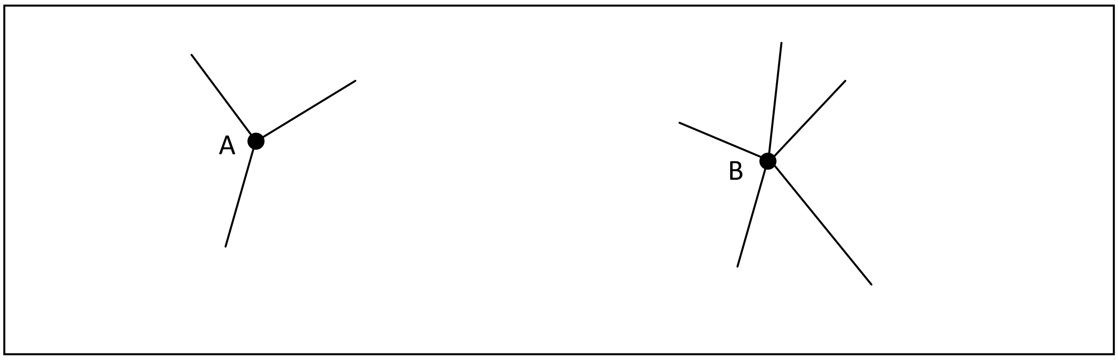

Figure 2: Two vertex constellations: vertex A has degree 3 ($\boldsymbol{d_A = 3}$), vertex B has degree 5 ($\boldsymbol{d_B = 5}$). Vertex B is more important for our research, since it is closer to more other nodes, which means that Bank B is correlated with more banks, than Bank A.

In Figure 2, there are two constellations of banks centered in bank A and bank B. We claim that it is more important to monitor bank B, than to monitor bank A, in the sense that bank B offers information for a larger part of the network: five banks are closely correlated with bank B and have similar behavior according to the specific variable while three banks are correlated with bank A. This point does not mean that we will not eventually use both banks for monitoring the whole network, but merely that bank B offers more information for the network, than bank A does.

So, the MST may be a useful tool to adopt in order to enhance the supervising efficiency of the Central Bank on the complete network of commercial banking institutions. By monitoring in detail the "core" banks on the MST we can efficiently monitor the directly connected nodes/banks. The members of this subset will act as bank distress gauges. Once a red flag is raised on a core bank then the regulator can focus immediately and in detail on all banks that are directly connected with the core. Additionally, the MST captures the strongest ties between banks and therefore if bank j suffers an adverse shock then there is historical evidence that it could be transmitted to adjacent banks. Using the proposed scheme, the Central Bank can a) concentrate on monitoring the small sub-set of core banks for any signs of distress and b) when a warning is issued take precautionary measures to reduce contagion to all adjacent to the core institutions. These steps may effectively contain a crisis, limit contagion and possibly avoid a system wide crisis swiftly and efficiently.

It is important to note that changing the variable under consideration may yield different networks and consequently different sets of core banks. It is at the discretion of the central bank to either use alternative or additional core bank sets produced by different choices of key variables. For example, by using variables such as the non-current loans and leases or the core capital (leverage) ratio will provide a network based on risk and capital adequacy factors.

3. Data and Empirical Results

For our dataset we selected 49 U.S. banking institutions of various characteristics (in January 2011, 11 banks from our dataset have a AA rating, 22 banks are rated A, 9 rated BBB, and 7 of them are rated lower, according to Fitch Ratings). We gathered quarterly data for each bank's total assets, and use the log asset returns as the variable under consideration in this example. We use the returns on total assets to avoid the possibility of a spurious correlation between the underlying banks. The data span a period of ten years from 2002Q1 to 2011Q4 for a total of 40 observations for each bank. We then calculate the cross-correlations of the log returns of each bank's total assets. All bank data came from the database provided on the website of the Federal Deposit Insurance Corporation (FDIC). We created, a complete network using the metric of Eq. (1) and produced the corresponding MST.

Table 1: Vertex Degree of the Bank Network

Name	Degree	Name	Degree
Amegy Bank	4	PNC Bank	2
Bank of NY Mellon Trust	4	Sovereign Bank	2
Comerica Bank	4	Trustmark National Bank	2
Fulton Bank	4	U.S. Bank N.A.	2
Bank of The West	3	Wells Fargo Bank, N.A.	2
Discover Bank	3	Banco Popular	2
Doral Bank	3	Bank of Guam	1
East West	3	Bank Of NY	1
Frost National Bank	3	BNY Mellon, N.A.	1
State Street Bank and Trust	3	BOKF, N.A.	1
Webster Bank	3	Capital One	1
Wells Fargo Bank NW	3	Citibank, N.A.	1
American Express Pers.Trust	2	City National Bank of Colorado	1
Bank Of America	2	Commercial Bank	1
Bank of Hawaii	2	Emigrant Savings Bank	1
BB&T Financial, FSB	2	Fifth Third Bank	1
California Bank	2	Firstbank of Puerto Rico	1
Cathay Bank	2	Hancock Bank	1
Chase Bank	2	HSBC Bank Nevada	1
FIA Card Services, N.A.	2	Lafayette Ambassador	1
First Hawaiian Bank	2	Manufacturers & Traders Trust	1
JPMorgan Chase	2	Morgan Stanley	1
N.Y. Community Bank	2	SunTrust Bank	1
Northern Trust Company	2	TD Bank	1
People's United	2		

In Table 1, we present the 49 Banks and their corresponding vertex degree. In this contribution we aim at finding the minimum size subset of banks, which can be used as gauges to monitor the whole network. We created a simple and efficient iterative method for identifying the "core" banks. The basic concept is to label as "core" the bank with the maximum neighbors (the bank with the maximum vertex degree), adjust the network (remove the "core" bank and its neighbors), and repeat until all the banks are considered. The proposed method is described in Algorithm 1.

Consider an MST of n nodes (banks), d_i describes the degree of the i-th node and v_i is the set of adjacent nodes to the i-th node.

Algorithm 1

Step 1. Repeat until all the nodes are removed from the network

Step 2. Find $m = \max_i\{d_i\}$ (the "core" node)

Step 3. Remove m and all the nodes in v_m from the network:

- $d_m = 0$
- $\forall j \in v_{m,}\, d_j = 0$

Step 4. Adjust the nodes degrees:

- $\forall j \in v_{m,} \forall k \in v_k, d_k = d_k - 1$

In Step 2 we find the "core" node e.g. the one with the most neighbors. In Step 3 a) we remove the "core" node from the network, b) we also remove the immediate neighbor nodes from the network since they will be represented by the "core" node. To fully understand the proposed algorithm, we must note that "remove m from network" is equivalent to "the degree $d_m = 0$", i.e. node m has no neighbors at all. In Step 4 we update the vertex degrees after the removal of the core node and its neighborhood.

Figure 3 presents the MST created from the correlations of total bank asset returns. The average size of the node represents the average asset size for each bank. Nodes shaded black represent the identified "core" banks of the network. As we can see there are some very large banks that are connected with smaller banks i.e. although there may be large differences in the levels of total assets they are interconnected through the growth rates of total assets. Nonetheless, an important feature of this network is that average sized or even small banks occupy a core position in the network e.g. they can be used to indirectly monitor other institutions. The remaining banks seem peripheral in the network.

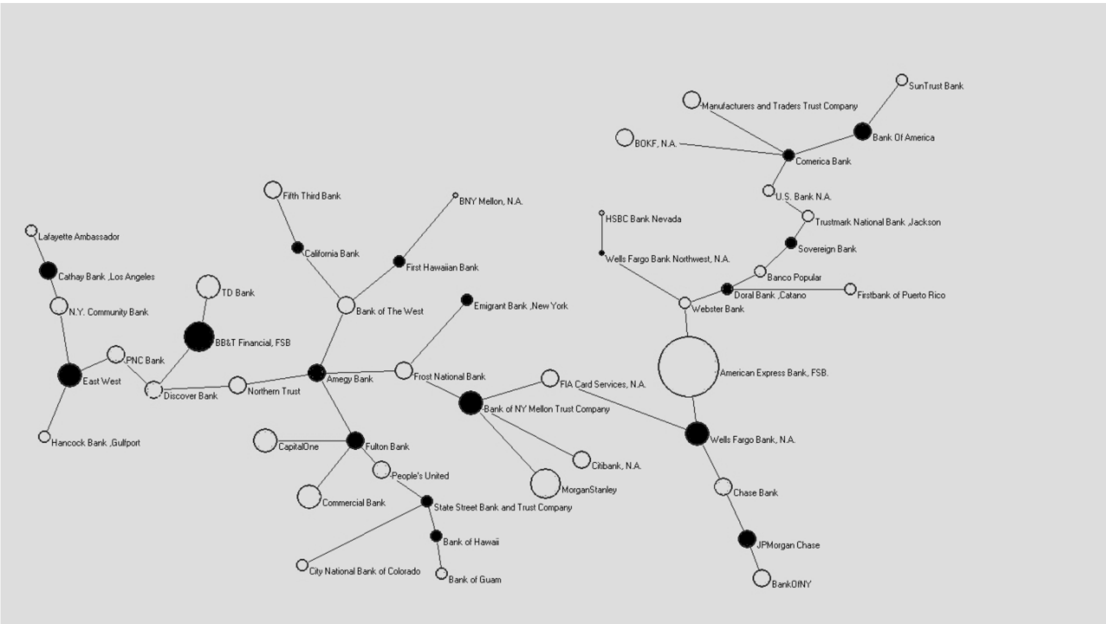

Figure 3. Minimum Spanning Tree representation for the Banks' Assets. The nodes in black are the core banks.

In Table 2, we present the result of Algorithm 1 when applied to the MST of Figure 3. 18 "core" banks (less than 37% of the network) are sufficient to monitor the whole network. The efficiency of supervision through "core" banks and the MST will be higher as the network gets larger and more complex.

Table 2: Core Banks, Cumulative Network Percentage under Supervision

Bank	Banks Monitored	Netowork %
Bank of NY Mellon Trust	5	10,2%
Comerica Bank	10	20,4%
Fulton Bank	15	30,6%
Discover Bank	19	38,8%
Doral Bank	22	44,9%
East West	25	51,0%
State Street Bank and Trust	28	57,1%
Wells Fargo Bank Northwest	31	63,3%
First Hawaiian Bank	34	69,4%
Wells Fargo Bank, N.A.	37	75,5%
California Bank	39	79,6%
Cathay Bank, Los Angeles	41	83,7%
JPMorgan Chase	43	87,8%
Sovereign Bank	45	91,8%
Bank of Hawaii	46	93,9%
Emigrant Savings Bank	47	95,9%
Bank Of America	48	98,0%
BB&T Financial, FSB	49	100,0%

4. Final Considerations

In this paper we propose a methodology that may be useful at improving the current supervisory framework as an additional tool in the central bank's arsenal. With the use of an MST and the proposed heuristic method it is possible to pinpoint the so-called "core" banks within the network. Within the extra layer of supervising effort proposed by this scheme, core banks can be the focus of the monitoring effort by the Central Bank. In this setting they can serve as strategically placed gauges that can signal a red flag whenever there is evidence of bank distress in their neighborhood of connected banks. The regulator can thus swiftly focus on the neighborhood of the core bank that signaled the alarm and take all necessary actions to avoid or contain a shock. Moreover, the construction of the MST allows us to identify possible contagion pathways that a central bank can exploit to minimize the cascade effects and the associated costs of a banking crisis. According to the above analysis, the proposed methodology may significantly improve the supervisory control of a central bank and reduce the costs of systemic shocks through swift and accurate intervention to the troubled institutions and prevention of contagion to other sub-groups.

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