Int. J. Nonlinear Anal. Appl. In Press, 1–12
ISSN: 2008-6822 (electronic)
http://dx.doi.org/10.22075/ijnaa.2022.28459.3897

Comprehensive risk assessment of financial institutions in the Tehran stock exchange using centrality metrics and dynamic clustering based on the Markov process

Hamidreza Hosseinzadeh[a], Mirfeiz Falah Shams[b,*], Hamidreza Kordlouie[c], Reza Gholami Jamkarani[d]

[a]*Department of Financial Engineering, Qom Branch, Islamic Azad University, Qom, Iran*
[b]*Department of Finance, Central Tehran Branch, Islamic Azad University, Tehran, Iran*
[c]*Department of Finance, Eslamshahr Branch, Islamic Azad University, Tehran, Iran*
[d]*Department of Accounting, Qom Branch, Islamic Azad University, Qom, Iran*

(Communicated by Farshid Khojasteh)

Abstract

Systemic risk is the risk imposed by a financial institution on the entire economy, the importance of which has become clear to many policymakers and economists since the financial crisis of 2008, and its measurement has been put on the agenda of many researchers. The present study presents a combined method of systemic risk measurement, in which the shape of the communication graph and the structural characteristics of financial institutions are simultaneously considered. In the proposed method, first, the communication graph is clustered using the Markov clustering algorithm. Then the systemic risk of each financial institution is measured according to its position in the cluster and using the adjusted semi-local centrality systemic risk measure. The effectiveness of the proposed method has been investigated for banks registered with the Tehran Stock Exchange and Securities Organization from 2014 to 2018 with monthly periods. Based on the results, the linear correlation of systemic risk changes calculated based on the proposed method with systemic risk calculated through simulation (SIR) was higher than the correlation of systemic risk calculated with ΔCoVaR and PageRank measures. Also, based on the results, Mellat, Trade and Export banks have the highest systemic risk and the lowest systemic risk related to capital, and tourism banks.

Keywords: systemic risk, Markov clustering, semi-local centrality, communication graph, simulation, ΔCoVaR and PageRank.
2020 MSC: 91B05, 60J10, 94C60

1 Introduction

Systemic risk is considered a relatively new concept in the world financial literature, which is similar to systematic risk (which is a well-known concept in the financial world and indicates the probability of a macro-economic, financial or political event and the spread of its effects to companies economic is active in an economy) has a significant

*Corresponding author
Email addresses: hamidrezahosseinzadeh11@yahoo.com (Hamidreza Hosseinzadeh), mirfeizfallahshams1@gmail.com (Mirfeiz Falah Shams), kordlouie@iiau.ac.ir (Hamidreza Kordlouie), gholami@qom-iau.ac.ir (Reza Gholami Jamkarani)

Received: July 2022 *Accepted:* October 2022

difference. Systemic risk indicates the possibility of inappropriate financial stress in an economic enterprise and its spread to other economic enterprises and finally, the entire economy of a country, which is created and developed simultaneously with the occurrence of financial crises, including the financial crisis of 1999 and The financial crisis was in 2000 [14].

To better understand the deep relationship between systemic risk and the occurrence of some economic crises in the world, the best example is the financial crisis of 2008. This year, the inappropriate rating of mortgage bonds (assigning credit ratings higher than the real limit to mortgage bonds) by some rating agencies led to significant losses for some financial institutions. This loss was transferred from the aforementioned institutions to other financial institutions and banks and finally spread to the entire American and world economy. For this reason, since that time, the identification and measurement of risks arising from an economic enterprise on the whole economy has become very necessary and has been put on the agenda of many financial institutions, research centers and researchers [7].

Even though each economic enterprise creates systemic risk for the entire system based on the type of activity, the type of communication with other economic enterprises, and the size, according to the results obtained from most research, the highest level of systemic risk related to financial institutions in It is an economy. One of the reasons for this issue is that financial institutions have a much wider communication network than manufacturing and service companies, and therefore, the liquidity and financial crisis of these institutions, compared to other companies, has a greater speed and scale to the entire financial markets and economy. A country is transferred. In addition, the most important factor causing systemic risk is liquidity risk. Unlike manufacturing, service and commercial companies, which have various operational risks; The most important risk facing financial institutions such as banks, insurance, financial intermediaries and brokerages is liquidity risk. As a result, the potential of creating systemic risk on the part of these institutions is higher than other companies active in different industries [10].

With the increasing awareness of the risks of the system on the part of different financial institutions, the International Monetary Fund, the Bank for International Settlements and the Financial Stability Board have decided to identify important financial institutions in terms of systemic risk. Based on this, each of the financial institutions in the country whose size is larger than a certain limit; takes a systemic risk balance. Institutions with higher leverage must maintain more safety reserves with the Federal Reserve. For example, JPMorgan is placed in basket 4 and maintains 2.5% of reserves more than the minimum safety reserve; While HSBC Bank is placed in basket 3 and they are required to maintain 2% safety reserve higher than the minimum safety reserve [6].

However, the decision-making system used to identify significant institutions in terms of systemic risk (SIFIs) is not effective according to researchers [8]. The first problem is that the current methods are calculated in a multi-criteria form and based on different characteristics of financial institutions such as the amount of debt, assets and balance sheet information of financial institutions. In this way, the existing relationships between financial institutions are not examined in the calculation of the systemic risk balance. In addition, considering that financial institutions' balance sheet information is available in an audited form every 6 months and in an unaudited form every 3 months; The preventive aspect of identifying significant institutions in terms of systemic risk (SIFIs) has become weaker and, in fact, systemic risk assessment loses its dynamic aspect [12]. For this reason, the development of new criteria for measuring systemic risk by considering the shape of the communication graph in recent years has attracted the attention of many researchers. The newly introduced criteria, instead of focusing on the structural characteristics of each financial institution, mainly focus on the form of the graph of connections between financial institutions. In fact, based on these criteria, the importance of spreading risk through a financial institution is significantly greater than the importance of risk creation by an institution. As a result, the higher the centrality of an institution in the communication graph, the higher the estimated systemic risk for it.

The current research, emphasizing the important role of the position of a financial institution in the communication graph in order to measure systemic risk, develops a method of measuring combined systemic risk. In this method, semi-local centrality is used to measure systemic risk. However, to determine the local location of a financial institution, the communication graph is first clustered using the Markov clustering method. Also, in the calculation of semi-local centrality, in addition to the position of the financial institution in the relevant cluster, the structural characteristics of the financial institution, including the size and financing structure, are used. In this way, the proposed method will show a combination of the capabilities of classical and modern measures of systemic risk measurement.

In the continuation of this research, firstly, the various methods of systemic risk and the research done in connection with it will be discussed. Then, the proposed research method for measuring systemic risk is expanded and how to calculate systemic risk using other competing methods is reviewed. In the following, using the trading information of recent years, the system risk is calculated with the proposed method and its efficiency is measured through the crisis simulation method and is calculated with the efficiency of competing methods

2 Theoretical foundations

The existence of systemic risk between financial and credit institutions has been proven by various researches in different time frames and different geographical areas. Among others, we can refer to Bhattacharya et al. [4] who in a research investigated the communication network of commercial banks in 39 countries between 1988 and 2014 and concluded that with the increase in credit risk and liquidity risk, the probability of a crisis Finance and its transfer to other banks will increase. It is worth noting that these results have been confirmed in many other studies.

Among these researches, we can mention Andris and Galasan [2], who measured the size and direction of crisis transmission between European commercial banks in the years 2006 to 2016. Using a value-at-risk model, researchers have calculated systemic risk using parameters such as size, geographic location, and position in the communication network between financial institutions. By conducting crisis simulations, researchers have found that there is a significant systemic risk in the European banking network, and for this reason, monitoring and managing the performance of large banks with a wide level of communication becomes very important.

Wang et al. [16] investigated the systemic risk with the approach of the communication network between four areas including banking, insurance, construction and investment between 2006 and 2015. Based on the results obtained from the performed simulations, the bank and building sectors are mainly creating systemic risk. Therefore, it can be seen that in various researches, the existence of systemic risk based on the communication network of financial and credit institutions has been proven.

If the communication network between financial institutions is considered as a graph; This graph consists of nodes and edges. Each node represents a financial institution and each edge represents one of the types of dependence of one institution on another institution. These relationships include short-term and long-term financial facilities, approved credit limits and ownership relationships and exist in a directed manner between two institutions. Depending on the comprehensiveness of systemic risk measurement criteria, existing attitudes to systemic risk can be divided into three categories: attitudes based on size, attitudes based on communication, and attitudes based on centrality.

The size-based approach works on the premise that larger financial institutions have higher leverage and therefore higher systemic risk. In the communication-based approach, the input and output relations of a node of the graph are examined. In fact, in this approach, only the amount of systemic risk created by a financial institution on neighboring institutions and vice versa is considered, and the systemic risk resulting from non-adjacent financial institutions that is created indirectly; Not considered. Finally, the most comprehensive form of systemic risk analysis that shows the entire graph of connections between financial institutions; The approach is based on centrality, which considers the systemic risk of financial institutions in relation to an institution at the first level and other levels, and therefore the entire graph of communication between financial institutions is considered in measuring systemic risk. The figure below compares different approaches to calculating systemic risk [9].

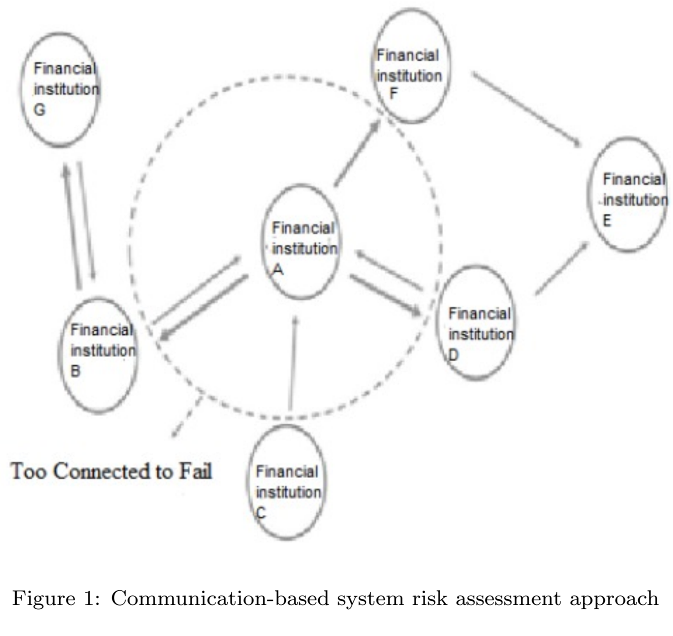

Figure 1: Communication-based system risk assessment approach

Figure 1: Comparison of different attitudes of calculating systemic risk with respect to communication graph [9].

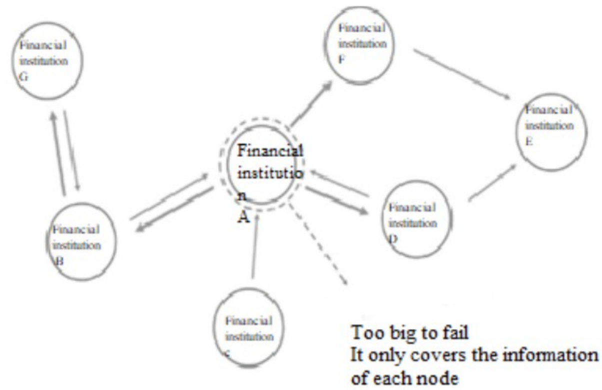

Figure 2: The size-based system risk assessment approach

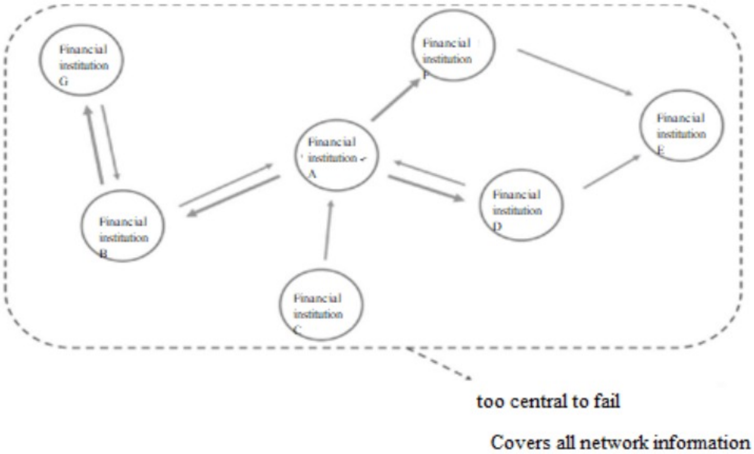

Figure 3: Centralized system-based risk assessment approach

According to Figure 1, it is clear that the comprehensiveness and therefore the expected accuracy of the centrality measures are higher than the measures based on connections and size. However, according to some researchers, the mere use of these metrics cannot provide an accurate picture of systemic risk; Because the importance of communication at different levels is not equal to each other and the effectiveness of some communication in critical situations is much more than other communication. As a result, the aforementioned researchers argue that a method for classifying the type of communication should be used in the calculation of systemic risk and the use of different metrics of systemic risk should be done in the form of classified communication.

The Markov clustering algorithm is one of the well-known methods of graph clustering, which is generally considered one of the most important methods of communication classification, and in recent years, it has attracted the attention of researchers in the field of systemic risk assessment.

Among the research conducted in this regard, we can mention Sun et al. [13], by using a simulation system based on game theory, simulated how to create and spread risk in a network of financial institutions. The researcher has used the Markov chain in order to optimize the policies of financial institutions in simulation conditions. In the performed simulation, the amount of borrowing or lending resources between financial institutions depends on their structural and managerial preferences. Based on the results, the researcher has concluded that the systemic risk does not have a fixed value and is influenced by some external factors, the most important of which are the changes in the banks' deposit rates. Based on the results obtained from this research, in this research, the change of external factors is used to simulate the crisis and investigate its spread, which is discussed in the research method section.

Bianchi et al. [5] identified systemic risk in credit institutions using SUR modeling. Researchers have used the MS-GSUR model and the factors of multi-factor ranking models to measure systemic risk. The main model is based on the Markov chain and Monte Carlo simulation, and a weighting method based on centrality criteria is used to create its initial state. Based on the results obtained from the model test, it has been used in the companies present in the S&P 500 index. The results obtained from this research showed that systemic correlation has increased significantly in the years 2003-1999 (1999 financial crisis) and 2008-2009 (2008 financial crisis). This issue shows that the use of Markov clustering method had a good impact on the accuracy of systemic risk measurement metrics and justified the changes that occurred in the correlation of financial institutions during the period of economic crisis.

Kaukab [11] has studied the measurement of systemic risk in the Indonesian banking system. The researcher has used principal component analysis, dynamic Granger causality test and switching Markov chain in order to measure the degree of generality and volatility of financial institutions. Based on the obtained results, systemic risk in general increases sharply during financial crises. However, the systemic risk of smaller, less risky institutions increases much more than other institutions in normal times.

Similar to the research done by [13] investigated the effectiveness of the absorption rate measure that was developed after the financial crisis of 2008; Paid. Absorption rate is a measure that shows the amount of absorption of economic and financial pressures of one financial institution by another financial institution. In this research, the researcher has introduced a new criterion called entropy efficiency based on the absorption rate criterion, which measures the amount of entropy of financial institutions in an economic system. In the method presented by the researcher, the amount of entropy of financial institutions is measured using the Monte Carlo simulation method and the switching Markov chain. Based on the results obtained from fitting the measured systemic risk to economic parameters, the researcher believes that the amount of systemic risk of an institution depends on the systematic risk, in addition to the financial factors of the financial institution and the economic factors of the country where that financial institution operates. In fact, systemic risk is also a function of systematic risk.

Tiwari et al. [15] have studied the spread of risk of oil price and exchange rate changes between BRICS member countries. Researchers have used non-parametric conditional value-at-risk Granger causality test to measure systemic risk. Also, to measure the mentioned criterion, the switching Markov chain has been used. Based on the results obtained, economic crises in an interconnected network of economic enterprises of the mentioned countries can spread to different countries through exchange rates and oil prices.

Based on the reviewed research, it can be concluded that the high efficiency of the Markov clustering algorithm in measuring systemic risk has been proven in various researches. However, some researchers such as Sun [13] and Tiwari et al. [15] have shown that systemic risk, in addition to the shape of the communication graph and related clustering, depends on external factors such as macroeconomic variables and internal factors. It is also dependent on the financial structure of the financial institution. The introduction of a measure that includes these factors in the measurement of systemic risk can have a great impact on the more accurate measurement of systemic risk and predicting the occurrence of financial crises.

Quick and Hoffert have also presented a new system risk measure called MCMC, which is based on simulation, using Monte Carlo simulation based on Markov chain. In the method proposed by the researchers, the occurrence of crisis is simulated by the Monte Carlo method and its transmission by the Markov chain process. The results show the superiority of the proposed method over the classic measures of CoVaR, CoES and RVaR.

Based on the research reviewed in this section, the aim of this research is to develop a method based on graph clustering using the Markov clustering algorithm, by applying a semi-local risk measure, the effect of external and internal factors on systemic risk. and at the same time by using the Markov clustering algorithm, it also uses its capabilities in simulating the crisis and how it is transmitted in the communication network.

3 Research method

The current research seeks to develop a new system risk measurement method that combines the clustering capabilities of the Markov algorithm with the capabilities of centrality-based risk metrics and also considers the effect of internal and external factors on systemic risk. It is worth noting that the questions that this research aims to answer are as follows:

- Is it possible to cluster the graph of connections between financial institutions based on the correlation of the market price changes of the institutions?
- Does the clustering of financial institutions using the Markov algorithm provide a better understanding of the creation and spread of systemic risk among financial institutions?

- Is the use of the proposed hybrid method based on clustering and semi-local centrality better in measuring systemic risk than the existing metrics?

Based on the results obtained from previous similar researches that were reviewed in the previous section, it is expected that the use of Markov clustering method will improve the efficiency of systemic risk metrics. Also, the measurement of systemic risk should not be based solely on the size of institutions or the shape of the communication graph, and the capabilities resulting from these two dimensions should be combined with each other. Therefore, a measure based on semi-local centrality has been proposed to measure systemic risk, which is expected to be more effective than other classical measures based on the size or shape of the communication graph.

In order to describe how the proposed method works, it is necessary to first explain the Markov clustering algorithm.

The first step in the Markov clustering process is to form a communication graph using random walk concepts. In this case, if there is no direct relationship between two nodes (a) and (b), the probability of moving from these nodes to each other is zero. If there is a connection, the intensity of this connection determines the probability of moving from node (A) to (B) and vice versa. As a result, the first step in using this method is the formation of the covariance matrix, based on which the communication graph is formed and the probability of movement from one node to other nodes is determined. Figure 4 shows a simple example of a communication graph with 7 nodes, where the intensity of communication between nodes is considered the same.

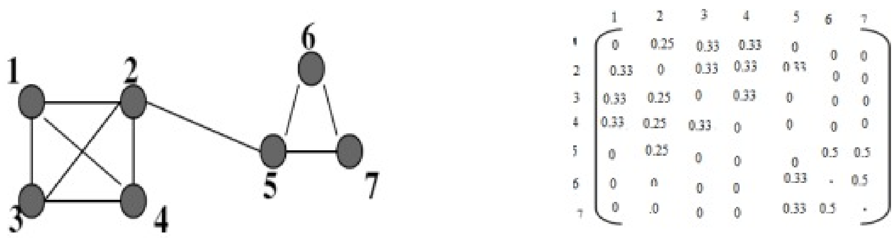

Figure 4: An example of a communication graph and its corresponding random walking matrix

The second step is to normalize the weighted matrix, in which each of the weights in a column is divided by the total weight of the column and the sum of the weights in each column is equal to one. The following relationship shows how to normalize the matrix in the second step.

$$a_{ij}^{N} = \frac{a_{ij}}{\sum_j a_{ij}} \tag{3.1}$$

in this regard, a_{ij}^{N} is the normalized array value of the matrix.

The third and fourth steps are repeated in which, first, the normalized weighted matrix obtained from the second step is expanded using the matrix exponentiation operator, and then it is inflated using the array inflation operator. The result of this is the strengthening of the weights inside the clusters and the weakening of the weights between the clusters. In this way, the necessary separation is created in the matrix in order to identify the clusters and the relationships of entities within the clusters.

Finally, in the fifth step, the connections within the clusters take a value of 1 and the connections between the clusters take a value of zero.

After clustering the communication graph, it is time to use systemic risk metrics. As it was mentioned before, in the current research, the modified semi-local risk measure is used to measure the systemic risk. The reason for this is that in measuring systemic risk using risk metrics based on centrality and communication, only the ability to transfer the crisis from one financial institution to other institutions is examined; While, in addition to the risk of crisis transmission, the risk of creating a crisis in a financial institution should also be effective in determining systemic risk. In other words, the systemic risk measurement should be a combination of centrality-based and size-based metrics. For this reason, in this research, the semi-local centrality risk measure is used to measure the systemic risk in each of the clusters formed by the Markov clustering algorithm.

The following relationship shows the basis for calculating the local centrality of each node.

$$M_j^w = \sum_{j \in u} C_j^w \tag{3.2}$$

in the mentioned relationship, the set u is the set of nearest neighbors of node i, and in fact, the final centrality of each node is equal to the centrality of the same node plus the centrality of the adjacent nodes. By adjusting the degree of centrality according to the structural characteristics of financial institutions, the adjusted centrality criterion of each node is calculated according to the following relationship:

$$Q^w = \sum_{j\in u}(M^w(j) * (S + A + G)) \tag{3.3}$$

in the above relationship, S is the size of the financial institution, which is calculated from the logarithm of its total assets. Parameter A indicates the capital adequacy ratio of each financial institution and G indicates the percentage of free floating shares of the financial institution. In this way, in addition to the size of the financial institution, which indicates the magnitude of the shock created in it, the capital adequacy ratio, which indicates the risk of creating a liquidity and credit crisis in financial institutions, and free floating shares, which indicates the degree of corporate governance in the financial institution, will be effective in measuring systemic risk. Finally, the value of semi-local centrality of each node in the network is defined according to the following relationship.

$$DDSC(v) = \sum_{u\in v} w_{vu} Q^w(u) \tag{3.4}$$

in this regard, the semi-local centrality of each node is equal to the weight of the input edges of each node in the adjusted centrality of the same node.

In this way, by applying the proposed method of the research that uses the Markov clustering algorithm to determine the cluster of financial institutions and the use of the semi-local centrality measure to measure the systemic risk of each financial institution depending on the cluster in which it is located; It is possible to combine the capabilities of metrics based on the structural characteristics of financial institutions and metrics based on centrality, and in addition to the ability to spread a crisis, the ability to create a crisis can also be considered in the measurement of systemic risk. Also, in order to check the effectiveness of the proposed method in measuring systemic risk, its performance with the performance of two other well-known metrics that have been widely used in various researches to measure systemic risk; is compared.

The measure of conditional value at risk was proposed by Adrian and Brunermeier in [1] and is based on the concept of value at risk or VaR [3]. Conditional value at risk as the name suggests; Value is at risk in certain situations. This measure expresses the value at risk of the financial system under the condition that the institution is at risk of crisis. An entity's contribution to systemic risk is calculated by the conditional value-at-risk delta $\triangle$CoVaR(α). In the context of measuring systemic risk, delta value at conditional risk means the difference between the maximum expected loss of the system in case of any company being critical and the maximum expected loss of the system in case of normal conditions of the relevant company, and in fact, the desired condition is the condition Financial is a company that intends to measure its systemic risk. According to these explanations, the value of ΔCoVaR(α) is calculated as follows [3]:

$$\Delta CoVaR(\alpha) = (\Delta CoVaR_{mt}|r_{it} \leq VaR_{it}(\alpha)) - (\Delta CoVaR_{mt}|r_{it} = Median_{it}) \tag{3.5}$$

in this regard, $\mathrm{VaR_{it}}(\alpha)$ means value at risk with a confidence interval of 1- α for company i. Also, how to calculate CoVaR is as described in the following relationship:

$$p(r_{mt} \leq CoVaR_{it}|C(r_{it})) = \alpha \tag{3.6}$$

The value of α is usually considered equal to 5% and therefore the confidence interval will be equal to 95%. $\mathrm{r_{it}}$ is the stock yield of company i in time period t and is obtained from this relationship:

$$r_{it} = \frac{p_t - p_{t-1}}{p_{t-1}} \tag{3.7}$$

in this way, the concept of ΔCoVaR(α) is the amount of increase in the expected loss of the system in case the conditions of each company become critical. To calculate this measure, the following steps must be performed:

Creating the distribution of research index returns in situations where the situation of each company is critical and obtaining the amount of value at risk.

Creating the return distribution of the research index in the condition that the situation of each company is normal and obtaining the amount of value at risk.

The difference between the value at risk in the first stage and the value at risk in the second stage.

Through the above steps for each company, the amount of systemic risk of each company is obtained.

The page ranking algorithm is actually one of the centrality measures, in which not only the connections between a node and its adjacent and non-adjacent nodes are considered; Rather, the importance of different nodes also plays a role in the importance of each communication. This issue is shown in the following relation:

$$x_i = \alpha \sum_j a_{ji} \frac{x_j}{L(j)} + \frac{1-\alpha}{N} \tag{3.8}$$

in this regard, x_j is the weight of node j, one of the neighbors of node i, whose centrality is measured. L(j) is the number of neighbors of node j in the first level. α is a fixed value and is generally equal to 0.85, and a_{ji} is the corresponding parameter value of the graph adjacency matrix.

Considering the above mentioned, the implementation steps of the research can be summarized as follows: Forming a research database by selecting the companies admitted to the stock exchange from 1394 to 1398 in monthly periods.

Forming the initial variance-covariance matrix to implement the Markov clustering process

Implementation of Markov clustering algorithm and identification of clusters to calculate systemic risk

Calculating systemic risk with the proposed method (using the semi-local centrality criterion adjusted by capital adequacy and banks' size and based on banks' liquidity in the clusters identified in the previous step) in 6-month periods (September and March of each year)

Simulating the crisis in six months and ranking banks based on the SIR index

Calculating systemic risk in six months using $\triangle$CoVaR(α) and PageRank methods

Comparing the systemic risk rating based on the proposed measure with the rating assigned with the SIR index and calculating the linear correlation between the ratings

Calculation of linear correlation of assigned ranks with αCoVaR(α) and PageRank methods

Comparison of linear correlation values calculated between systemic risk by different methods and SIR index

Summary and conclusion regarding the effectiveness of the proposed method to measure systemic risk

4 Research findings

Considering that the issue of systemic risk is generally related to financial institutions, the current research community consists of banks and credit institutions licensed by the Central Bank of Iran. Also, in order to select the sample of the research, the companies admitted to the stock exchange were used, whose shares can be traded on the stock exchange or over-the-counter and whose trading information is available during the research period. In addition, the data used in the research regarding each member of the sample includes the following:

- Basic information such as book value of equity (financial statements), total asset value (financial statements), percentage of free floating shares (annual report of the Securities and Exchange Organization) and capital adequacy ratio (annual report of the Central Bank).
- Trading information related to the stock trading price of the entities in the sample to calculate returns on a daily basis (website of Iran Stock Exchange Technology Company).

In Table 1, the characteristics of the financial institutions selected in the research sample and some related structural characteristics at the end of 2018 are displayed.

Also, the statistical characteristics of the variables used in the research are reviewed in Table 2. It is worth noting that the information related to capital adequacy ratio and size is calculated based on the financial statements and reports of the Central Bank in quarterly periods and for each quarter of the quarterly reports, the same values are considered and the data related to Returns are also entered in the database at monthly and six-month intervals.

Based on Table 2, it can be seen that the skewness of the variables of capital adequacy and size is small and negligible, and their skewness is close to the skewness of the normal distribution. Regarding the variables related to price performance, it can be seen that there is a skew to the right and an excess of normal elongation in the variables, the main reason of which is the significant growth of the stock price in 2018, which causes the weight of the distribution sequence on the right side of it has been.

Table 1: General characteristics of banks and institutions present in the research sample

Bank	symbol	Equity (billion Rials)	Total assets (billion Rials)	Percentage of free floating shares	Capital adequacy ratio
Tejarat Bank	vtejarat	**138,474**	**2,482,054**	**23.89**	**6.1**
Bank Day	Dey	**-112,379**	**249,416**	**62.56**	**-29**
Sarmayeh Bank	Sarmayeh	**-264,734**	**140,551**	**24.56**	**2.1**
Gaedeshgari Bank	vgardesh	**3,943**	**472,916**	**17.06**	**2.5**
Saman Bank	Saman	**18,822**	**554,591**	**57**	**3.2**
Sina Bank	v Sina	**14,707**	**242,467**	**13.58**	**5.1**
Ayandeh Bank	v ayand	**-115,541**	**1,991,359**	**32.06**	**3.3**
Parsian Bank	V pars	**113,602**	**1,630,341**	**18.93**	**4.1**
Pasargad bank	vpasar	**105,732**	**1,563,342**	**39.35**	**9.2**
Saderat Bank of Iran	vbasader	**162,392**	**3,241,358**	**14.16**	**2.3**
Mellat Bank	vbemlat	**360,465**	**4,423,619**	**27.04**	**8.3**
Karafarini Bank	vkar	**16,682**	**220,167**	**28.78**	**7.5**
Eghtesad Novin Bank	vnovin	**32,865**	**636,106**	**31.05**	**1.3**
Khavarmianeh Bank	vkhavar	**21,624**	**207,970**	**90.99**	**8.4**
Bank Shahr	vshahr	**-159,964**	**757,526**	**23.64**	**4.1**

Table 2: General characteristics of banks and institutions present in the research sample

Statistics	Capital adequacy ratio	Value	Monthly yield	Six months return
Minimal	**1.3**	**11.85**	**-0.23**	**-0.67**
Maximum	**9.2**	**15.3**	**0.53**	**2.65**
Average	**4.8**	**13.5**	**0.02**	**0.12**
Middle	**1.4**	**13.6**	**0.01**	**0**
Standard Deviation	**2.6**	**1.12**	**0.004**	**0.03**
Crookedness	**0.45**	**0.12**	**1.52**	**1.81**
Elongation	**2.7**	**2.3**	**3.4**	**4.8**

In order to calculate the initial variance-covariance matrix, which is based on the Markov clustering method, the stock returns of each of the symbols in the above table are calculated in monthly intervals and are placed in the research database for the years 2014-2018. By implementing the Markov clustering algorithm as explained in the previous section, the clustering of banks and credit institutions is obtained as shown in Figure 5.

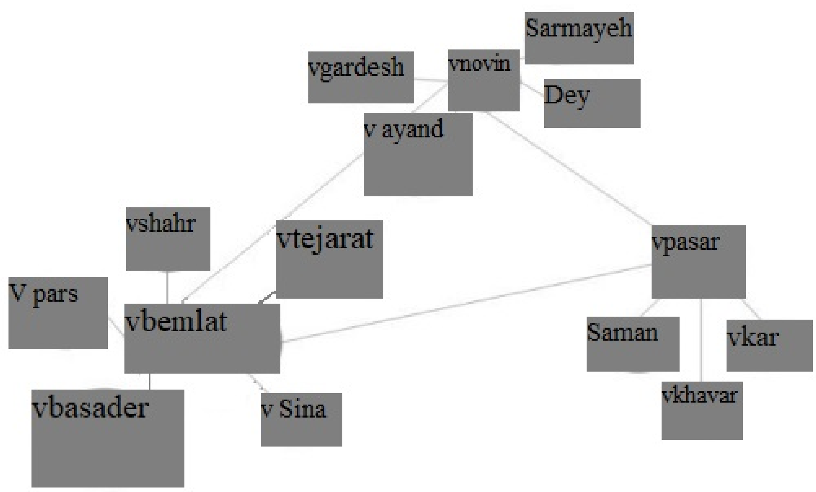

Figure 5: Results of clustering of banks and credit institutions by Markov clustering method As shown in the above figure; Three clusters have been identified and created for financial institutions. The basis for calculating the system risk measure that is semi-local centrality; The clustering done is according to Figure.

As described, the semi-local centrality measure is used to calculate the systemic risk of financial institutions. In Table 3, the calculation statistics using this measure and the amount of calculated systemic risk are displayed.

Table 3: Calculations of systemic risk by the proposed research metrics

Raws	Bank	$M^w(j)$	S	A	G	Q^w	DDSC(v)
1	Tejarat Bank	**1.41**	**0.83**	**0.6**	**0.13**	**2.19**	**4.16**
2	Bank Day	**0.51**	**0.16**	**0.05**	**0.63**	**0.42**	**1.42**
3	Sarmayeh Bank	**0.43**	**0.11**	**0.1**	**0.14**	**0.15**	**1.84**
4	Gaedeshgari Bank	**0.47**	**0.35**	**0.15**	**0.04**	**0.25**	**1.37**
5	Saman Bank	**1.08**	**0.39**	**0.24**	**0.56**	**1.28**	**2.16**
6	Sina Bank	**0.61**	**0.16**	**0.48**	**0.11**	**0.46**	**1.65**
7	Ayandeh Bank	**0.65**	**0.77**	**0.25**	**0.23**	**0.81**	**1.72**
8	Parsian Bank	**1.49**	**0.71**	**0.35**	**0.07**	**1.68**	**3.42**
9	Pasargad bank	**1.17**	**0.7**	**0.95**	**0.33**	**0.64**	**3.38**
10	Saderat Bank of Iran	**1.38**	**0.91**	**0.13**	**1.01**	**1.49**	**3.78**
11	Mellat Bank	**1.58**	**0.96**	**0.87**	**0.17**	**3.16**	**4.81**
12	Karafarini Bank	**0.83**	**0.13**	**0.78**	**0.2**	**0.93**	**1.96**
13	Eghtesad Novin Bank	**1.41**	**0.44**	**0.07**	**0.22**	**1.03**	**2.24**
14	Khavarmianeh Bank	**0.94**	**0.11**	**0.9**	**0.65**	**1.56**	**2.08**
15	Bank Shahr	**0.73**	**0.49**	**0.35**	**0.13**	**0.71**	**1.82**

Based on this, the results obtained from measuring the systemic risk by the proposed research method with the results obtained from the ΔCoVaR measure and the PageRank measure have been compared in Table 4.

Table 4: Systemic risk ratings assigned by different methods

Bank	Assigned Rank		
	Suggested	ΔCoVaR	PageRank
Tejarat Bank	**2**	**3**	**2**
Bank Day	**13**	**12**	**13**
Sarmayeh Bank	**15**	**15**	**9**
Gardeshgari Bank	**14**	**16**	**14**
Saman Bank	**7**	**10**	**6**
Sina Bank	**12**	**14**	**8**
Ayandeh Bank	**11**	**7**	**12**
Parsian Bank	**4**	**4**	**3**
Pasargad bank	**5**	**6**	**5**
Saderat Bank of Iran	**3**	**2**	**4**
Mellat Bank	**1**	**1**	**1**
Karafarini Bank	**9**	**11**	**7**
Eghtesad Novin Bank	**6**	**5**	**10**
KhavarmianehBank	**8**	**8**	**11**
Bank Shahr	**10**	**9**	**15**

Based on the ranking done by the proposed method, the highest systemic risk is related to Mellat, Trade and Export Banks, which are all located in the same cluster. On the other hand, the lowest systemic risk is related to finance, capital and tourism, which despite the unfavorable financial and credit situation, due to not being in a wide network of communications, their systemic risk is estimated to be lower.

The interesting thing about the results of the proposed method is that, based on the ratings made with this method, most of the banks in the same cluster have received systemic risk ratings close to each other, and this shows that The clustering performed can well justify the differences in the systemic risk of banks and credit institutions.

But in the final step, a decision should be made regarding the performance of the proposed method. For this purpose, the time period of the research which is considered from 2014 to 2018; It is divided into 10 6-month periods, and systemic risk values are calculated with the aforementioned three metrics in each period. In addition, by using the crisis simulation technique, creating a crisis in each of the selected financial institutions in the stock exchange and investigating its spread in the communication network has been used. The final result, which is displayed with the SIR index; It shows the number of financial institutions to which the crisis has spread. The more the number of institutions; The rank assigned by the SIR index will be lower. In this way, it is possible to make a decision about their efficiency by calculating the linear correlation between the ratings assigned by the aforementioned three methods and the SIR method. Figure 6 shows the linear correlation changes of each of the three indicators of systemic risk assessment.

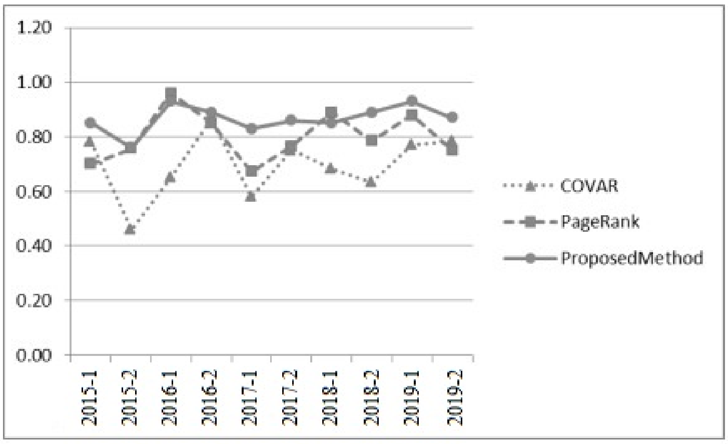

Figure 6: Comparison of linear correlation of different systems risk assessment methods with SIR index Based on the above figure, it can be seen that the performance of the proposed method is always higher than the ΔCoVaR measure and in most cases compared to the PageRank measure, and this indicates the appropriate efficiency of the hybrid method based on communication graph clustering and the use of the semi-centrality criterion. It is a place to measure systemic risk.

5 Results and suggestions

Measuring the systemic risk of financial institutions in an economy as accurately as possible can have a significant effect in preventing the occurrence of financial crises and their spread. This has caused that in many of the top economies of the world, the assigned risk ratings and the requirements imposed on different banks are affected by their systemic risk.

The metrics developed so far are in three categories: size (based on the structural characteristics of financial institutions such as the size of assets), connections (based on direct connections between financial institutions) and centrality (based on all direct and indirect connections between financial institutions with each other) are placed. Most of the researches conducted in recent years have confirmed that the efficiency of centrality-based metrics is higher than other methods. However, in the present research, this issue has been challenged and a model has been developed that combines the positive features of risk assessment using structural features and communication features. The proposed method includes clustering the communication graph using the Markov clustering algorithm and then using the adjusted systemic risk measure (with structural features including size, free floating shares and capital adequacy ratio).

The results obtained from the research show that the difference between the systemic risk ratings of financial institutions is well justified by the clustering done, and in fact, the shape of the communication network of each communication cluster is a more suitable ability to estimate the systemic risk. It creates a network of general direct and indirect communication of each financial institution. In addition, the results of measuring the accuracy of the estimated systemic risk (by comparing the linear correlation between the estimated systemic risk with the proposed method, the ΔCoVaR measure and the PageRank measure) show the proper performance of the proposed method and its high accuracy. It is worth mentioning that the mentioned results were obtained in the period of 2014 to 2018 in 6 months.

It is worth noting that based on the results of this research, Mellat, Trade and Export Banks create the most systemic risk for the banking network, which is due to the potential of creating a crisis due to high credit, liquidity and market risks and the severity of the crisis. It is because of their large size on one hand and their wide communication network with other banks of the country on the other hand. On the other hand, the lowest systemic risk has been related to capital, tourism and D banks, which despite the high credit, liquidity and market risks regarding them, due to their smaller size and much smaller communication network, there is little systemic risk for They create a banking network.

According to the results of the present research, it seems that conducting further investigations on the effect of the clusters in the communication graph on the systemic risk of financial institutions can be a suitable topic for conducting further research in the field of systemic risk. Also, studying the function of other methods of measuring systemic risk in early formed clusters (such as other measures based on centrality with a focus on the cluster) and using other methods of graph clustering to determine the optimal methods and parameters in the proposed method of this research , can help improve the performance of the proposed method and increase the accuracy of systemic risk measurement.

References

[1] T. Adrian and M.K. Brunnermeier, *CoVaR (No. w17454)*, National Bureau of Economic Research, 2011.

[2] A.M. Andries and E. Galasan, *Measuring financial contagion and spillover effects with a state-dependent sensitivity value-at-risk model*, Risks **8** (2020), no. 1, 5.

[3] S. Benoit, G. Colletaz, C. Hurlin, and C. Pérignon, *A theoretical and empirical comparison of systemic risk measures*, HEC Paris Research Paper No.1030 FIN(204), Available at SSRN: https://ssrn.com/abstract=1973950, (2013).

[4] M. Bhattacharya, J.N. Inekwe, and M.R. Valenzuela, *Credit risk and financial integration: An application of network analysis*, Int. Rev. Financ. Ana. **72** (2020), 101588.

[5] D. Bianchi, M. Billio, R. Casarin, and M. Guidolin, *Modeling systemic risk with Markov switching graphical SUR models*, J. Economet. 210 (2019), no. 1, 58–74.

[6] Financial Stability Board, *Financial Stability Implications from Fintech: Supervisory and Regulatory Issues that Merit Authorities' Attention*, Washington, DC: International Monetary Fund and World Bank, 2018.

[7] M.K. Brunnermeier and L.H. Pedersen, *Market liquidity and funding liquidity*, Rev. Financ. Stud. **22** (2009), no. 6, 2201–2238.

[8] O. De Bandt and P. Hartmann, *Systemic risk: A survey*, Available at SSRN 258430, (2000).

[9] M. Hatef Vahid and A. Saleh Ardestani, *Systemic risk evaluation of banks and financial institutions applying Markov clustering method and centrality measures of risk*, Islamic Economics & Banking, 9 (2020), no. 30, 115–140.

[10] X. Jin, *How Much Does Book Value Data Tell us About Systemic Risk and its Interactions with the Macroeconomy? A Luxembourg Empirical Evaluation*, Central Bank of Luxembourg, 2018.

[11] M.E. Kaukab, *The urgency of foreign direct investment in micro, small, and medium enterprises financing framework: The case of Indonesia*, Verslas: teorija ir praktika **24** (2023), no. 1, 47–57.

[12] E. Nier, J. Yang, T. Yorulmazer, and A. Alentorn, *Network models and financial stability*, J. Econ. Dyn. Control **31** (2007), no. 6, 2033–2060.

[13] X. Sun, X. Yao and J. Wang, *Dynamic interaction between economic policy uncertainty and financial stress: A multi-scale correlation framework*, Finance Res. Lett. **21** (2017), 214–221.

[14] N. Tarashev, *Measuring portfolio credit risk correctly: Why parameter uncertainty matters*, J. Bank. Finance **34** (2010), no. 9, 2065–2076.

[15] A.K. Tiwari, N. Trabelsi, F. Alqahtani, and S. Hammoudeh, *Analysing systemic risk and time-frequency quantile dependence between crude oil prices and BRICS equity markets indices: A new look*, Energy Econ. **83** (2019), 445–466.

[16] G.-J. Wang, Z.-Q. Jiang, M. Lin, C. Xie, and H.E. Stanley, *Interconnectedness and systemic risk of China's financial institutions*, Emerg. Markets Rev. **35** (2018), 1–18.