Financial Networks: Analysis, Visualization and Interpretation

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学位の種類　博　士（経営学）

学位記番号　経博（経営）第 115 号

学位授与年月日　平成 28 年 9 月 26 日

学位授与の要件　学位規則第 4 条第 1 項該当

研究科、専攻　東北大学大学院経済学研究科（博士課程後期 3 年の課程）
経済経営学専攻

学位論文題目　Financial Networks: Analysis, Visualization and Interpretation
（金融ネットワーク：解析と視覚化および解釈）

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論 文 内 容 の 要 旨

A network is combination of nodes with edges for connectivity in-between. The definition of building blocks of network changes according to field of research, under consideration data and research resolve, as theory of networks is not limited to particular field but applicable across the board. The use of network analysis is increasing in economics and finance, with focus on structure and possibility of contagion. Advanced analytical measures and visualization techniques unlocked the new prospects to understand the social, economic, financial and bilateral relations among different institutions, communities, regions and countries. This dissertation is combination of studies focusing on Eurozone and EU's (European Union) investment, trade and banking networks to understand their structure, resilience and transformations during the last decade.

Theoretical background required for network representation, analysis and visualization process is pooled in chapter 2. We explore the properties of bilateral matrix and simulation process required to simulate external shocks to find contagion within banking network. The chapter also includes the mathematical foundation of centrality measures and conceptual basis of visualization techniques used in subsequent chapters

Topology of different financial networks depends on connectivity patterns and resultant characteristics. Chapter 3 is devoted to explain the technical issues that can arise due to use of identical analytical centrality measures for different types of network, such as trade, investment, banking, capital markets etc. Use of identical analytical measures may change the consequential perception of a particular financial network or may not be able to explain its dynamics in a better way. We analyzed two types of networks - trade and investment – with respect to their local (node level) centrality measure, such as degree, closeness, betweeness, modularity and eigenvector centrality. The similar centrality measures were used to identify their suitability for both networks. EU's trade and Eurozone investment networks for 2007 and 2011 were used. Main findings explain the efficiency of Individualistic centrality measures for partial and complete networks. As different types of measures were used to analyze both networks, we observed that centrality measures can explain less dense and incomplete graphs or networks in much better way. As most of the centrality measures in partial networks such as investment network in our case show the actual position of a node in broad hierarchy. Analysis for multiple years revealed the change, rather improvement or demotion in node's position. While similar centrality measures are not sufficient for complete graphs, EU's trade network in our case. Trade networks are usually complete and the analytical measures at node level are unable to depict the change within network. The only appropriate measure for complete networks is the weighted degrees distribution. For both networks it shows the level of disproportion among nodes, as few large nodes have huge in and out flows while rest of the networks shares small portion of liquidity and other flows.

In chapter 4 we discuss the transformation process of actual networks. The network transformation or evaluation process can enhance our understanding about structure or systemic features of particular micro and macro level systems. The chapter is inspired by Kalyagin et al.,(2014), they discussed network's structural uncertainty for different markets with respect to centrality measures. They used different types of arbitrary network structures to understand the resultant changes in centralities in case of crisis situation. We extended the idea of structural uncertainty for real world financial networks by using similar rather enhanced aggregate level centrality measures. Besides structural uncertainties, tracking the changes within network over certain time span is relatively new concept. This chapter explains the transformations within networks due to external events or due to changes in internal circumstances. The tracking process is not same for all sorts of networks but network analytics can explain it in a much better way compared to simple statistical analysis. Three different networks were used to understand the transformation process for several types of networks mainly partial, complete, small, mid-level, having higher level of liquidity and the ones with fewer strong connections. The actual trade, investment and banking networks of EU and Eurozone were used for different time periods to understand the evolutionary process.

The changes within network can reciprocate the policy shifts and variations at micro and macro levels. Increase or decrease in edges of existing nodes and aggregate centrality measures explained the deviations of liquidity, investment flows and suitable destinations. The transformation process of investment network showed the increase in total density of network with every passing year. Total density explains the increasing volumes and residuals for every node of that particular network. For trade network the phenomena remained the same. There was increase in density due to enhanced volumes. The trade network experienced the dips in total trade due to issues with global economy and reduction in cumulative demand after Global Financial Crisis (GFC). The observed investment and trade networks are gaining more resilience and strength with every passing year. The same networks represented weak connectivity patterns and aggregate centrality measures initially. GFC impacted the whole investment network and every node was exposed to liquidity crunch due to lower volume of flows for few years. The network resorted to domestic connections by increasing the local connectivity level to provide liquidity cushions.

There is a shift in investment behavior of EU investors, as there are more inflow towards domestic and central capital markets such as Germany, France and Luxemburg. EU countries are attracting more investment due to monetary union status and relaxed laws for cross border investment within. Global financial crisis impacted the trade flows of trade network after impacting the investment networks with respect to shock span. This explains the slower and stronger impact on world's trade and relevant networks. Total volumes of trade remained depressed for prolonged time period due to multiple crises at international and domestic fronts. GFC at global level and Eurozone debt crisis at local level impacted the domestic trade flows of connected nodes. The observed banking network shows stronger impact of GFC. The capital levels are decreased significantly as is the connectivity among aggregate banking network. There are few nodes that remained untouched with respect to total value they had, but inflows of every node were reduces by big margins. There is a change in connectivity patterns of aggregate banking networks. There are new connections established by central and major nodes to help the ailing economies. The nodes facing severe reduction of inflows also opted to reduce or even terminate their outflows. The cumulative network represent higher clustering coefficient for weaker nodes due changes in their connectivity and flow configurations.

We extended our analytical approach to evaluate the characteristics of individual nodes to establish the relationship between portfolio investment flows and economic indicators in Chapter 5. The concept of this chapter is influenced by Joseph & Chen (2014b), they used composite centrality framework to understand the relationship between economy and network statistics of OECD (Organization for Economic Cooperation and Development) countries. Our findings explain that being incomplete graph, investment network's connectivity patterns are different for every node. Some nodes have central position with higher connectivity levels compared to others. We divided the countries into different groups or tiers based on the resultant centrality and analytical measures. The classification of countries into different groups explains the differences in connectivity patterns for nodes. We divided the nodes into three tires based on their closeness centrality. The general conclusion confirmed our assumptions about central nodes. More central a country is, or more prominent position it has within investment network, there more relationships or correlations with economic indicators it holds. It can also have implications for countries with less connectivity to improve their network position and capture more economic benefits. The countries must strive to connect with all nodes to fully capitalize the opportunities for market efficiency and improvements on economic front. European Union is an example, the case for other investment networks and individual countries to establish strong linkages to increase the connectivity patterns.

In chapter 6 we explore the possibility of contagion with Eurozone's aggregate bilateral banking network. Most empirical studies are based on partial information on bilateral exposures between banks, due to data limitations. A common feature among most of the previous studies is that they focus on interbank network of one country only, to measure the strength and interconnectedness. Our focus was on interbank network of European Union instead of single country. Although data limitations remained same, but new approach enhance the understanding of financial network of whole region to study the contagion and systemic risk. The issue of systematic risk or contagion is highlighted by GFC and it's after effects. It can worsen things for already weak financial network, besides posing default threat to different nodes.

The pre and post crisis networks are different in terms of their bilateral obligations and capital structures. Pre-crisis network nodes had higher level of interconnectedness and are more dependent on bilateral obligations. Besides higher level of exposures, their capital buffers are not that large. On the other hand post-crisis network had smaller volume of bilateral obligations, and higher level of capital and reserves. All nodes are interconnected to other nodes within network. Level of interconnectedness can be determined by analyzing the volume of bilateral obligations. Higher level of interconnectedness for small nodes can be hazardous, while for large nodes, appears to increase their overall strength.

Contagion plays an important role in transferring default risk. If large node faces difficult conditions, as a result different other nodes would face problems afterwards because of their bilateral obligations. While this phenomenon would not be effective if small nodes are in trouble after idiosyncratic shock. Different intensities of shocks show the resilience level of network. It appears that banking systems were not prepared for even small shocks during pre-crisis period, with few exceptions of large nodes. We witnessed that they faced lots of trouble and consumed taxpayer's money as bailouts. Post-crisis network seems stronger and resilient, as they accumulated capital and reduced bilateral obligations.

Clearing scenarios for network's bilateral obligations indicated that banking systems can sustain shocks, if bankruptcy system is efficient and cost effective. As there is a trend of lower default probabilities for long term scenarios compared to short term scenarios. An efficient, reliable and cost effective bankruptcy system can save the country's resources, and bailouts can be reduced or even eliminated.

Keywords: Banking Network, Bilateral Matrix, Centrality, Closeness, Clusters, Connectivity, Contagion, Correlation Matrices, Default Probability, Domino Effect, Dynamic Graph, European Union, Eurozone, Financial Crisis, Financial Network, Graph Theory, Investment Network, Liquidity Flow, Macroeconomic Indicators, Modularity, Network Analytics, Network Transformation, Network, Systemic Risk, Trade Network, Visualization,

論文審査結果の要旨

本論文は，投資や貿易，金融機関の資金貸借などに見られる資金のフローを金融ネットワークとして捉え，ネットワークの構造と経済現象の相互関連について分析を行っている．

全体では6章の構成である．第1章で研究の目的や概要を示した後，第2章では一般的なネットワーク理論を簡潔にまとめて，次章以降の分析枠組の準備としている．第3章では本研究で重要な役割を果たす概念であるネットワークの中心性(centrality)が導入されている．ネットワークの中心性はネットワーク全体の構造から導かれ，個別のノードの全体に対する相対的な関係性を表す尺度である．第4章と第5章は，上記の中心性尺度を実際のネットワークに適用した分析を行っている．著者は，EU諸国をノードとした貿易ネットワークおよび投資ネットワークを実データに基づき構築し，それらのネットワークにおける様々な中心性尺度を計算した．第4章では，ネットワーク全体の中心性にもとづいて，ネットワークの構造変化を調査している．そこでは，例えば貿易ネットワークと比較して，投資ネットワークの変動が激しいこと，リーマン・ショックの影響が後者ではより早い時期に出現し，回復していることなどが見出された．第5章では，同じネットワークにおける個別ノードを対象として中心性尺度を評価している．個別のノード（国）を中心性尺度の値により3つの階層に分類した場合，それらの階層間では異なる時系列的な変化が生じていることを見出している．第6章においては，銀行間の資金貸借から構築されるネットワークが扱われている．著者は，銀行ネットワークを国ごとに集約した貸借ネットワークを構築し，デフォルトリスクがネットワーク上でいかにして伝播するかを分析している．

近年のネットワーク分析の手法を金融ネットワークに適用した本研究によって，いくつかの興味深い知見が得られた．それらに対するより深みのある経済学的な解釈が望まれるところではあるものの，既存研究において実データに基づくネットワークの分析が限られている状況において，本研究の貢献は少なくない．以上より，本論文は博士（経営学）として「合格」と判断する．