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Time-varying causal network of the Korean financial system based on firm-specific risk premiums

Jae Wook Song, Bonggyun Ko, Poongjin Cho, Woojin Chang *

Department of Industrial Engineering, Seoul National University, 151-742, Seoul, Republic of Korea

HIGHLIGHTS

- Time-varying causal network of the Korean financial system is studied.
- Causal direction is measured based on the firm-specific risk premiums.
- Aspects of risk-spillovers and co-movements are discovered.
- Topology of causal network is analyzed.
- Relations to the long-term future direction and stability of KOSPI is revealed.

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ABSTRACT

The aim of this paper is to investigate the Korean financial system based on time-varying causal network. We discover many stylized facts by utilizing the firm-specific risk premiums for measuring the causality direction from a firm to firm. At first, we discover that the interconnectedness of causal network is affected by the outbreak of financial events; the co-movement of firm-specific risk premium is strengthened after each positive event, and vice versa. Secondly, we find that the major sector of the Korean financial system is the Depositories, and the financial reform in June-2011 achieves its purpose by weakening the power of risk-spillovers of Broker-Dealers. Thirdly, we identify that the causal network is a small-world network with scale-free topology where the power-law exponents of out-Degree and negative event are more significant than those of in-Degree and positive event. Lastly, we discuss that the current aspects of causal network are closely related to the long-term future scenario of the KOSPI Composite index where the direction and stability are significantly affected by the power of risk-spillovers and the power-law exponents of degree distributions, respectively.

1. Introduction

The financial crisis in 2007–2009 has brought a rigorous attention from both academia and policy-related field that a collapse of financial systems, also known as *systemic risk*, is highly probable in reality. Based on this notion, many researchers have studied the financial system to discover the sources of the crisis, contagion paths, and stylized facts.

It is now well-known that traditional models are not fully adequate to measure systemic risk and financial stability [1]. Therefore, previous literatures have focused on developing advanced and intuitive risk measures of financial system. Specifically, studies based on transaction data have revealed numerous topological characteristics of financial system in

* Corresponding author.
E-mail address: changw@snu.ac.kr (W. Chang).

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various countries, including the United States [2–4], the United Kingdom [5], Italy [6–8], Austria [9,10], Brazil [11], the Netherlands [12], the Czech Republic [13], Russia [14], Turkey [15], and Australia [16]. The above literatures have discovered how risks of firm are interconnected in perspective of complex system. Although the data-driven network can directly explain the financial system, a drawback of such network arises when a country legally prohibits an access to the transaction data. In this case, an alternative approach should be used to investigate a financial network.

Two types of alternative methods are popularly used in previous studies: *agent-based simulations* and *econometric methods*. In the *agent-based modeling*, the logical behaviors of firms and market determine the formation of financial network, transaction rules, and simulation procedures [17–22]. Once the network is simulated, the resilience and stability in different network topology are evaluated for extreme scenarios (e.g. defaults, bankruptcy cascades, and liquidity shocks). The *econometric* relations are used to find a meaningful relationship among financial firms on the basis of publicly offered data such as stock prices and credit default swap (CDS) premiums. Especially, a stock price is known to reflect the current and future values of a firm. Hence, the evolution of price series and its impact on the value of other firm can provide a substantial evidence of interconnectedness. Popular *econometric* measures include correlation [23,24], cointegration [25,26], and causality [27–30].

In this paper, we employ the Granger causality to investigate causal directions among the financial firms in the Republic of Korea whose transaction data are not publicly available. A causal network is widely used to analyze the dynamics of information transfer in bio-informatics fields, including gene networks, cell mitigation, and neurology [31–34]. To the best of our knowledge, our research is the first attempt to analyze the Korean financial system using the causal network based on firm-specific risk premiums. Some of previous studies related to the systemic risk of Korean financial system are limited to non-network-based measures such as marginal expected shortfall and conditional value-at-risk [35–37].

Our study is novel for following reasons. At first, we construct the time-varying causal network based on the firm-specific risk premiums. The firm-specific risk premium is computed by filtering the systematic (exogenous) risk of the capital market from the stock price. Secondly, we discover many stylized facts of Korean financial system based on moving window method. For example, we find that the connectivities of causal network are closely related to the major events where the positive event increases the co-movement among the firm-specific risk premiums, and vice versa; the major sector of the Korean financial system is the Depositories, whereas the leading sector of risk-spillovers during bullish market is the Broker-Dealers (BD); and the financial reform in June-2011 changes the regime of interconnectedness by lowering the magnitude of overall connectivity and weakening the power of BD sector. Also, we find that the causal network of the Korean financial system is a small-world network with scale-free topology. Lastly, we find that the connectivity and topology of current causal network are closely related to the long-term future scenario of KOSPI Composite Index than short-term one. The power of risk-spillovers affects the direction of the market, whereas the power-law exponents of degree distribution affect market stability in the future.

The rest of paper is organized as follows. Section 2 defines the mathematical realization of the causal network and the connectivity measures. Section 3 explains the data used in this study, including the financial firms, sectors, and major events. Section 4 discusses the major findings of our paper, and Section 5 concludes.

2. Methods

A causal network is a diagraph composed of financial firms as vertices and causality directions as directed edges. A causality direction can be measured via Granger causality test, the most popular method for evaluating a statistical cause-and-effect direction from one time series to another [38]. In this study, we select a firm-specific risk premium as a proxy for risk of a financial firm. As discussed in many previous literatures, the presence of Granger causality can be considered as risk-spillover among the market participants given that the causality should not be detected in the efficient market [27,39–41]. Specifically, the risk-spillover indicates the co-movements of idiosyncratic risk (valuation) among financial firms.

2.1. Causal network structures

To create the causal network, a set of time-series of each firm is required. The series must be stationary, which implies that the mean, variance, and auto-correlations can be approximated based on a single set of realizations [42]. In this study, we decide to use the time-series of stock price. However, a price series of an individual stock is known to be non-stationary process. A simple method for ensuring the stationary process is converting the price to the logarithmic return. Let $P_{i,t}$ denote the price dynamics of stock i at time t. Then, the log return, $R_{i,t}$, can be described as follows.

$$R_{i,t} = \ln(P_{i,t}) - \ln(P_{i,t-1}). \tag{1}$$

We ensure the stationary condition of $R_{i,t}$ via various unit root tests (see Appendix A for more details) [43,44].

In this paper, we apply the concept of moving window in creating the time-varying causal network whose size of moving window is set to be 500 dates (approximately two years). It means that the Granger-causality test at time t uses the data from the past 500 days, $I_t = \{t-499, t-498, \ldots, t-1, t\}$. The window moves to $t+1$ when the analysis of causal network is completed at time t.