2013년 8월

석사학위 논문

Measuring systemic risk through contagion effect of industry sector

조선대학교 대학원

경영학과

김호용

산업의 전염효과를 통한 시스템 위험 측정

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2013년 8월 23일

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이 논문을 경영학 석사학위신청 논문으로 제출함

2013년 4월

조 선 대 학 교 대 학 원

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김호용의 석사학위 논문을 인준함

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2013년 5월

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Table of Contents

ABSTRACT

Measuring systemic risk through contagion effect of industry sector

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시스템 리스크는 한 기업에 대한 부정적인 영향들로 인해서 그 기업과 상호작용이 있는 다른 기업들이 충격을 전이 받는 위험이다. 이 시스템 리스크의 가장 기본적인 개념은 상호작용이다. 따라서 우리는 이 시스템 리스크를 측정 하기 위해 변수들간의 상호작용을 고려 할 수 있는 VAR모형을 이용한 Generalized variance decomposition으로 KOSPI주식시장에 354개 기업들의 표준화된 로그 수익률의 절대값을 이용하여 네트워크를 구성하고 이를 산업 군과 재벌기업들의 관점에서 분석하였다. 한국주식시장에서 가장 큰 위기인 외환 위기(IMF)와 서브 프라임 위기 기간의 특성을 금융산업의 전이 충격의 변화로 밝혀내었고, 한국의 특수한 기업구조인 재벌그룹의 전염효과는 다른 산업 군에 비해서 어떻게 다른지를 비교 분석하였다.

ABSTRACT

Measuring systemic risk through contagion effect of industry sector

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Systemic risk is the risk that negative feedback that is directed at one company is propagated to other companies through a specific relationship channel. To measure systemic risk that is characterized by interconnected features among economic unit, we employ the generalized variance decomposition method (GVDM) with a volatility data set of 354 companies listed on the KOSPI index. Based on the contagion behavior of industry sectors or the chaebol group observed in financial markets, we propose a novel approach to quantify systemic risk and to calculate the extent of systemic risk for the KOSPI market. We find that systemic risk is closely related to financial crises such as the Asian currency crisis and the subprime mortgage crisis. In addition, we analyze whether the chaebol group is related to systemic risk, and find that the chaebol group influences both the contagion effect of real economic sectors, with the exception of construction, and systemic risk.

Ⅰ. Introduction

IT and Internet technologies have undergone revolutionary developments over the last 20 years. The development of these technologies has enabled progressive human achievements using more convenient processes. Consequently, such developments have erased geographic boundaries and facilitated the economic integration of major countries, i.e., globalization. Information that is available in one country now has a rapid and significant impact on others.

During the 1990s, the East Asian currency crisis, the Russian default crisis and the Brazilian financial crisis occurred consecutively, and, as a result, concerns were raised concerning the systemic risk that exists in financial systems.

The concept of systemic risk has not been established as a result of several combined components; it has been studied in the context of financial instability and possible policy responses.

Recent studies of systemic risk in financial systems have provided researcher with deeper insight into the stability of economic systems. A comprehensive concept of systemic risk was introduced by O. D. Bandt and P. Hartmann in a 2000 survey, which states that systemic risk that can be explained by contagion behavior between subjects and is similar to epidemic diseases in an ecosystem. For example, contaminated individuals who transmit their bacteria to others through contact could endanger an entire species once the majority of individuals are contaminated.

From an economic system perspective, systemic risk could be a result of the financial system. While systemic risk also exists in industries because of the systems that are in use, financial systems could be more vulnerable to systemic risk than real economies. For example, a bank that forms the basis of any financial system has significant uncertainty with respect to its financial status, and informed depositors may initiate a bank run that will cause funding to deteriorate, increase the problem of bank illiquidity, and case a cascade effect that will collapse the economy and the financial system.

Systemic risk is risk that is created within a company or market, that is propagated to other companies or markets, and that gradually increases as propagation continues because of domino effect and snowball effects.

The representative case of systemic risk in a financial system is the sub-prime crisis of the US duing the period from 2007 to 2008. The sub-prime crisis occurred because of a complex linkage among the micro- and macro economy, derivatives and human psychology. The first default shock among the sub-prime mortgage banks was propagated to the investment banks, and the default of the investment banks subsequently affected the commercial banks. Consequently, the US economy collapsed because of the systemic risk prevalent in the financial system. This consecutive domino effect caused a liquidity crisis in the global economy that was induced by the aftermath of the sub-prime crisis.

The fact that systemic risk within the financial sector of an economic system is more severe than systemic risk within other industries is an important consideration, but shocks from other economic systems can affect that financial system by the contagion effect of systemic risk generated from the financial sector. The Korean economy has a peculiar business structure organization known as the chaebol group. Collapse of chaebol groups would have a significant impact on the economic and social systems. In this thesis, I study systemic risk in the Korean economic system using contagion effects regarding factors such as the industry sector and the chaebol group.

First, a network model is used to confirm the relationship individual companies because the most important concept in systemic risk is interconnection. The basic network model is an adjacency matrix that is filled with binary information and is characterized by the out-degree and the in-degree of companies. Billio, Monica, et al(2011) use a combined method composed of network and statistical models that is known as the Granger causality network. This method, however, has the weakness that the adjacency matrix of the granger causality network is filled with binary numbers; thus, it is difficult to strictly measure the systemic risk.

This thesis, we employed the VAR model, which is able to analyze the contagion behavior. Contagion behavior is defined by how the shock of one variable affects other variables. We use the VAR model because it can simultaneously consider many endogenous variables. The VAR model can also analyze interactions among variables in VAR systems because it determines the relationships among variables with certain values. Additionally, the VAR model can be extended to the concept of systemic risk by approaching the interactions of variables from a different perspective than that of earlier work[1].

To measure the contagion effect among individual firms in the Korean stock market, a variance decomposition matrix was constructed from 354 individual companies [2] by considering the relationship among individual companies listed on the KOPSI index, which is the primary stock index in Korea.

The benefit of using variance decomposition is that the shock of one company, which cannot be explained by a regression model, is decomposed into shares of other companies. I therefore measure the degree of the system contagion effect and group the individual companies according to their industry to quantify intra-sector, inter-sector and total contagion effects.

I examine how to change the values of the contagion effects according to economic conditions and indicate the comparative riskiness of chaebol groups compared with other real economy sectors.

In Chapter 2, I review earlier research with respective to systemic risk, and I describe the measures used in this study in Chapter 3. Chapter 4 contains an explanation of the data used, the empirical results and interpretation. The conclusions are presented in Chapter 5.

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[1] Diebold, Francis X., and Kamil Yilmaz. “On the network topology of variance decompositions: Measuring the connectedness of financial firms” (2011).

[2] Detailed companies information is in appendix.

Ⅱ. Literature review

Initial studies of systemic risk have focused primarily on banks and financial systems because of the role bonks play as fund providers that distribute their deposits to individuals, institutions and other banks. This study has expanded systemic risk research to include the relationships that affect real economies when banks fail. Allen and Gale(2000) and Freixas, Parigi and Rochet(2000) use a theoretical model to demonstrate that the contagion effect is largely dependent on the magnitude of interbank exposure and the interbank network. Eisenberg and Noe(2001) apply a fixed-point argument and identify a clearing payment vector, i.e., the clearing of member obligations using a clearing system, and the authors develop an algorithm to determine the clearing payment vector. This result implies that non-dissipative shocks to the system will lower the total value of the system and the equity values of certain firms in the system. Furfine(2003) simulates the influence of the failure of one bank under various failure scenarios using interbank payment data, and he finds that the contagion risk of banks is economically small. Additionally, Upper and Worms(2004) simulate the contagion effect of bank failure using the credit relationships of balance sheets. The authors demonstrate that one bank failure can decrease the assets in a banking system by as much as 15%, whereas contagion risk is less when institutional guarantees are applied to saving and cooperative banks that have no guarantees.

The contagion effect measured using simulation methods that consider bank relationships is not sufficient to explain systemic risk because the influence of systemic risk is not sufficient to cause other connected banks to fail. Therefore, studies have been conducted to examine many factors that affect systemic risk, such as the type of payment settlement system, bankruptcy costs, fire sales and liquidity problems. Degryse and Nguyen(2007) demonstrate that contagion risk is decreased by introducing money centers that symmetrically connect other banks within the interbank network. Additionally, Elisinger, Lehar and Summer(2006) find that low bankruptcy costs are crucial for limiting the system-wide impact of contagious event. Cifuentes, Ferruci and Shin(2005) insist that increases in illiquidity through fire sales of distressed institutions strengthen the contagion effect under regulatory solvency constraints. Moreover, bank behaviors, such as holding liquid assets and shortening maturities, can also increase contagion risk[3].

Adrian and Brunnermeier(2009) suggest the CoVaR methodology as a method that is able to measure potential propagation effects through an interbank correlation structure using stock price data. Wong and Fong(2011) utilize CoVaR analysis to study the credit default swaps of Asian-Pacific banks. Zhou(2009) uses extreme value theory(EVT) in place of quantile regression to measure CoVaR.

To identify whether financial institutions are of systemic importance or

[3] Sujit Kapadia, Mathias Drehmann, John Elliott and Gabriel Sterne (2012).

represent vulnerable institutions and to regulate them, recent studies have focused on the allocation methods of systemic risk according the type of financial institution. Gauthier, Lehar and Souissi(2010) maintain that the default rate of individual banks can be decreased and the possibility of systemic crisis can also be decreased by approximately 25% through the use of systemic capital allocation mechanisms that use interbank contractual information, thereby implying that bank regulation is required to manage systemic risk.

Following the 2007 to 2008 sub-prime crisis, many researchers emphasized that all institutions within a financial system, not only banks, should be regulated and prepared for a possible systemic crisis. Certain studies use complex network physics theory combined with economic methods to specifically analyze the connections that are a primary mechanism of contagion risk. Billio and Lo(2011) find that four financial sectors (hedge funds, banks, broker/dealers and insurance companies) are important for systemic risk by using principle component analysis and a Granger causality network. Additionally, Diebold and Yilmaz(2011) demonstrate that significant connectedness is concentrated on depressed institutions using a time-varying network of major US financial institutions that is constructed using variance decomposition methods. This study maintains that a network constructed by variance decomposition is more applicable than a Granger-causality network because a variance decomposition network is weighted.

The methodologies for measuring systemic risk can be classified into probability distribution measures, contingent claims and default measures, illiquidity measures, network analysis measures and macroeconomic measures[4].

Each of these methods has advantages and disadvantages; therefore, it can be difficult to properly measure systemic risk because of the complexity and diversity of the methods. Adopting theories from various fields of academic study and applying them to existing theories in a synergistic manner is therefore considered an effective way to measure systemic risk.

III. Methodology

3-1. Vector autoregression

The vector autoregression (VAR) model is a model that can estimate correlation and causality between variables by combining the features of time series and regression analysis. The purpose of using a VAR model is that economic time series data, such as the money supply, interest rates and the financial returns a company, are affected past trends and fluctuations in other variables.

[4] Bisias, Flood, Lo and Valavanis(2012).

Therefore, such a model is able to synchronize the analysis of more than one variable.

In an unrestricted VAR system, the basic composition of endogenous variables is $\mathrm{Y}_t = (y_{1t}, y_{2t}, \dots, y_{Kt})'$ for $k = 1, 2, \dots, K$, where $K = 354$ is the number of variables in our study. Thus, y_t is vector $K \times 1$. The VAR(p) system has the form

$$\mathrm{y}_t = c + \mathrm{A}_1 \mathrm{y}_{t-1} + \mathrm{A}_2 \mathrm{y}_{t-2} + \dots + \mathrm{A}_p \mathrm{y}_{t-p} + \epsilon_t \ , \qquad t = 1, \dots., T \qquad (1-1)$$

where A_i *and* c are the $(K \times K)$, *and* $(K \times 1)$ element coefficient matrices, respectively, for $p = 1, \dots, P$ and ϵ_t is a $(K \times 1)$ element white noise forecast error vector that has zero mean and time invariant covariance matrix $E(\epsilon_t \epsilon_t') = \Sigma_\epsilon$.

For a stable VAR, the VAR(p) system can be rewritten by using the companion form of the coefficient matrix to the VAR(1) system:

$$\mathrm{Y}_t = C + \mathrm{A}\mathrm{Y}_{t-1} + V_t \qquad (1-2)$$

$$\mathrm{Y}_t = \begin{bmatrix} y_1 \\ y_2 \\ \vdots \\ y_p \end{bmatrix}, \quad C = \begin{bmatrix} c \\ 0 \\ \vdots \\ 0 \end{bmatrix}, \quad A = \begin{bmatrix} A_1 & A_2 & \cdots & A_{p-1} & A_p \\ I_k & 0 & \cdots & 0 & 0 \\ 0 & I_k & \cdots & 0 & 0 \\ \vdots & \vdots & \ddots & \vdots & \vdots \\ 0 & 0 & \cdots & I_k & 0 \end{bmatrix}, \quad V_t = \begin{bmatrix} \epsilon_t \\ 0 \\ \vdots \\ 0 \end{bmatrix},$$

where y_t, c *and* ϵ_t are $(K \times 1)$ element vectors. Thus, Y_t, C, *and* V_t are $(KP \times 1)$ dimensional column vectors and A is a $(KP \times KP)$ element companion matrix.

Additionally, we can invert this VAR(1) system to an infinite moving average representation.

Consider the following VAR(1):

$$\mathrm{Y}_t = C + \mathrm{AY}_{t-1} + V_t$$

We can recursively solve this system as follows:

$$\mathrm{Y}_t = C + \mathrm{AY}_{t-1} + V_t = C + \mathrm{A}(\mathrm{C} + \mathrm{AY}_{t-2} + V_{t-1}) + V_t$$

$$= C + \mathrm{AC} + \mathrm{A}^2\mathrm{Y}_{t-2} + AV_{t-1} + V_t = C + \mathrm{AC} + \mathrm{A}^2(\mathrm{C} + \mathrm{AY}_{t-3} + V_{t-2}) + AV_{t-1} + V_t$$

$$= C + AC + \mathrm{A}^2 C + \cdots + \mathrm{A}^i C + V_t + \mathrm{A}V_{t-1} + \mathrm{A}^2 V_{t-1} + \cdots$$

$$+\mathrm{A}^i V_{t-i} + \mathrm{A}^{i+1}\mathrm{Y}_{t-i-1}.$$

Finally, we have

$$\mathrm{Y}_t = \gamma + \sum_{j=0}^{\infty} A^i V_{t-j} \qquad (1-3)$$

where $\gamma = (\mathrm{I} - \mathrm{A})^{-1}C$.

To estimate the coefficient of the VAR(p) system, sufficient historical observations satisfying that satisfy the number of lags p of the considered endogenous variables $\mathrm{y}_1, \dots, y_K$, are required. Then, the coefficient can be estimated by ordinary least squares. For example, If we consider the VAR(3) system for a sample of 100 endogenous variables, we require more than 300 pre-sampled data points to estimate efficient estimators.

Although we construct the VAR system without assumptions regarding the relationships among endogenous variables in the sample, we can analyze various dynamic relationships between the variables by using impulse response functions and variance decomposition.

3-2. Impulse response analysis

An impulse response analysis analyzes the effect that one variable has on another variable over time when a particular variable causes a shock in a constructed VAR system.

We consider the following VAR system to analyze the response of variable y_i to the shock of variable y_j:

$$\begin{aligned} y_{1t} &= \alpha_{11}^{1} y_{1,t-1} + \alpha_{12}^{1} y_{2,t-1} + \cdots + \alpha_{1n}^{1} y_{n,t-1} \\ &\quad + \alpha_{11}^{2} y_{1,t-2} + \alpha_{12}^{2} y_{1,t-2} + \cdots + \alpha_{1n}^{2} y_{n,t-2} + \cdots \\ &\quad + \alpha_{11}^{p} y_{1,t-p} + \alpha_{12}^{p} y_{2,t-p} + \cdots + \alpha_{1n}^{p} y_{n,t-p} + \epsilon_t \quad (2-1) \end{aligned}$$

In equation (2-1), the effect that the shock of the second variable y_{2t} affects $y_{1,t+1}$ has on

$$\frac{\partial y_{1,t+1}}{\partial y_{2t}} = \frac{\partial y_{1,t}}{\partial y_{2,t-1}} = \alpha_{12}^{1},$$

and the influence that the shock of the second variable y_{2t} has on the first variable at $t+2\,(= y_{1,t+2})$ is

$$\frac{\partial y_{1,t+2}}{\partial y_{2t}} = \alpha_{12}^{2} + \sum_{j=1}^{K} \alpha_{1j}^{1} \cdot \alpha_{j2}^{1}$$

Thus, the effect that the shock of variable y_{jt} has on variable $y_{i,t+1}$ is

$$\frac{\partial y_{i,t+1}}{\partial y_{jt}} = \alpha_{i2}^{1} \quad for \ \mathrm{i,j} = 1,2,\dots,\mathrm{n}$$

and after 3 times, it is

$$\frac{\partial y_{1,t+3}}{\partial y_{2t}} = \alpha_{12}^{3} + \sum_{j=1}^{K} \left[\frac{\partial y_{j,t+2}}{\partial y_{2t}}\right] \cdot \alpha_{1j}^{1}$$

For the VAR(p) system, we can rewrite the following impulse response function by using an infinite moving average representation, such as (1-3), with $B_j = \mathrm{A}^j$:

$$y_t = \mu + \epsilon_t + \sum_{j=1}^{\infty} B_j \epsilon_{t-j}$$

$$= \mu + \sum_{j=0}^{\infty} B_j \epsilon_{t-j}$$

$$= \mu + \epsilon_t + \mathrm{B}_1\epsilon_{t-1} + \mathrm{B}_2\epsilon_{t-2} + \cdots + \mathrm{B}_h\epsilon_{t-h} + \cdots \quad (2-2)$$

$$\mathrm{B}_h = \frac{\partial y_{t+h}}{\partial \epsilon_t}$$

Therefore, the influence that the impulse ϵ_j on variable y_j has on variable y_{i+h} is $\frac{\partial y_{i,t+h}}{\partial \epsilon_{jt}}$.

However, if correlations among the element of ϵ_t exist, i.e.,

$$\mathrm{E}(\epsilon_t \epsilon_t') = \Sigma \neq I_k ,$$

the response of y_i to a shock in y_j may be uncertain.

To analyze the pure response to a shock, we should eliminate any contemporaneous correlation between disturbances in error terms ϵ_t by orthogonalizing the error term via the Cholesky factorization. By applying the Cholesky method to the covariance matrix of the error vector Σ, we have a Cholesky factor C that satisfies $CC' = \Sigma$ as follows:

$$\Sigma = CC' , C = \begin{pmatrix} c_{11} & 0 & \cdots & 0 \\ c_{21} & c_{22} & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ c_{K1} & c_{K2} & \cdots & c_{KK} \end{pmatrix}$$

According to the characteristics of the covariance matrix of the error vector Σ, which is a positive-definite square matrix, the Cholesky factor C is invertible because

$$\Sigma^{-1} = C'^{-1}C^{-1} \ then, \qquad \Sigma\Sigma^{-1} = C'\Sigma^{-1}C = C^{-1}\Sigma C'^{-1} = I_k$$

Thus, C and C^{-1} are the inverses of each other. We can therefore rewrite (2-2) as an infinite MA that contains Cholesky factor:

$$\begin{aligned} y_t =& \ \mu + CC^{-1}\epsilon_t + B_1 CC^{-1}\epsilon_{t-1} + B_2 CC^{-1}\epsilon_{t-2} + \cdots \\ \equiv& \ \mu + C\epsilon_t + \sum_{j=1}^{\infty} \Xi_j \nu_{t-j} \qquad (2-3) \\ \equiv& \ \mu + \sum_{j=0}^{\infty} \Xi_j \nu_{t-j} \end{aligned}$$

where $\Xi_j \equiv B_j C$ and $\nu_{t-j} \equiv C^{-1}\epsilon_{t-j}$. Thus, we can satisfy $E(\nu_t \nu_t') = I_k$ as follows:

$$E(\nu_t \nu_t') = C^{-1}\epsilon_t \epsilon_t' C'^{-1} = C^{-1}\Sigma C'^{-1} = \Sigma\Sigma^{-1} = I_k$$

and the orthogonalized impulse response function after time h is

$$\Xi_h = \frac{\partial y_{t+h}}{\partial \nu_t'}$$

3-3. Traditional variance decomposition

This method is able to analyze the relative importance of each variable in the VAR system by partitioning the forecast error of one variable into shares of each variables, which is similar to an impulse response function.

The h-step-ahead forecast error is

$$e_{t,h} = y_{t+h} - \hat{y}_{t+h} = \epsilon_{t+h} + B_1\epsilon_{t+h-1} + \cdots + B_{h-1}\epsilon_{t+1}$$

and the MSE for the h-step-ahead forecast error is

$$\begin{aligned} MSE(\hat{y}_{t+h}) = MSE(e_{t,h}) &= E[(y_{t+h} - \hat{y}_{t+h})(y_{t+h} - \hat{y}_{t+h})'] \\ &= \epsilon_{t+h}\epsilon_{t+h}{}' + B_1\epsilon_{t+h}\epsilon_{t+h}{}'B_1' + \cdots + B_{h-1}\epsilon_{t+1}\epsilon_{t+1}{}'B_{h-1}' \\ &= \Sigma + B_1\Sigma B_1' + \cdots + B_{h-1}\Sigma B_{h-1}' \end{aligned}$$

For an orthogonal error vector, ϵ_t, it is true

$$\epsilon_t = C\nu_t = \tau_1\nu_{1t} + \tau_2\nu_{1t} + \cdots + \tau_n\nu_{nt}$$

where τ_j is the jth column of the Cholesky factor C. Then, Σ is as follows

$$\begin{aligned} \Sigma = \mathrm{E}(\epsilon_t\epsilon_t') &= \tau_1\tau_1'Var(\nu_{1t}) + \tau_2\tau_2'Var(\nu_{2t}) + \cdots + \tau_K\tau_K'Var(\nu_{Kt}) \\ &= \sum_{k=1}^{K} \tau_K\tau_K'Var(\nu_{Kt}). \end{aligned}$$

Finally, we have the following orthogonal MSE equation:

$$MSE(\hat{y}_{t+h}) = \sum_{k=1}^{K} Var(\nu_{Kt})\,[\tau_k\tau_k' + B_1\tau_k\tau_k'B_1' + \cdots + B_{h-1}\tau_k\tau_k'B_{h-1}']$$

The share of variable y_j in the forecast error of estimator $\hat{y}_{i,t+h}$ is

$$\omega_{ij,h} = \frac{\{Var(\nu_{jt})[\tau_j\tau_j' + B_1\tau_j\tau_j'B_1' + \cdots + B_{h-1}\tau_j\tau_j'B_{h-1}'\}_{ii}}{\{MSE(\hat{y}_{t+h})\}_{ii}} \qquad (2-4)$$

where $\{\cdot\}_{ii}$ is ith diagonal element of matrix $\{\cdot\}$. Because ω_{ij} is the share of $\{MSE(\hat{y}_{t+h})\}_{ii}$, it satisfies $\sum_{j=1}^{K}\omega_{ij} = 1$.

Additionally, because the orthogonalized impulse response function (2-3) is $\Xi_h = \frac{\partial y_{t+h}}{\partial \nu_t'} = B_hC$, we can represent (2-4) as follows

$$\omega_{ij,h} = \frac{\sum_{l=0}^{h-1}(\pi_i'B_lC\pi_j)^2}{\sum_{l=0}^{h-1}(\pi_i'B_l\Sigma B_l'\pi_i)} \qquad (2-5)$$

where π_j is $(K \times 1)$ element selection vector filled with unity for the jth element and zero elsewhere.

3-4. Generalized variance decomposition

The orthogonal impulse response function obtained by Cholesky factorization has the problem that it is sensitive to the order of the variables in the VAR system. Whereas the generalized impulse response function is not affected by the problem, this alternative identification scheme can contain correlated errors and thus lose the advantage of orthogonalization. However, because the problem of reordering variants is quite critical, I apply the generalized variance decomposition method (GVDM) developed by Pesaran and Shin (1998).

The generalized impulse response function for y_t at h, developed by Koop et al. (1996), is

$$GI_y(h, \delta, \psi_{t-1}) = E(y_{t+h}|\epsilon_t = \delta, \psi_{t-1}) - E(y_{t+h}|\psi_{t-1}).$$

By (2-3), we have $GI_y(n, \delta, \psi_{t-1}) = B_h\delta$, and we can consider choosing the jth element of shock vector ϵ_t and then integrate out the contemporaneous effects of other shocks in vector ϵ_t as follows:

$$GI_y(h, \delta_j, \psi_{t-1}) = E(y_{t+h}|\epsilon_{jt} = \delta_j, \psi_{t-1}) - E(y_{t+h}|\psi_{t-1}).$$

In this method, ϵ_t is assumed to obey a multivariate normal distribution. Thus, we can derive the following[5]:

$$E(\epsilon_t|\epsilon_{jt} = \delta_j) = \Sigma\pi_j\sigma_{jj}^{-1}\delta_j.$$

The generalized impulse response of the effect of a shock in the jth error term at time t on y_{t+h} is given by

$$GI_y(h, \delta_{jt}, \psi_{t-1}) = \left(\frac{B_h\Sigma\pi_j}{\sqrt{\sigma_{jj}}}\right)\left(\frac{\delta_{jt}}{\sqrt{\sigma_{jj}}}\right).$$

We obtain a scaled generalized impulse response function divided by $\frac{\delta_{jt}}{\sqrt{\sigma_{jj}}}$ that gives the effect of a 'unit' shock. Then, the scaled generalized impulse

[5] See in Koop et al. (1996) and Pesaran et al. (1998) for details.

response function is $\sigma_{jj}^{-\frac{1}{2}} B_h \Sigma \pi_j$.

Finally, the share of variable y_j in the forecast error of estimator $\hat{y}_{i,t+h}$ using the GVDM is

$$\omega^g{}_{ij,h} = \frac{\sigma_{jj}^{-1} \sum_{l=0}^{h-1} (\pi_i' B_l \Sigma \pi_j)^2}{\sum_{l=0}^{h-1} (\pi_i' B_l \Sigma B_l' \pi_i)}$$

where σ_{jj} is the jth diagonal element of the forecast error covariance matrix.

The traditional variance decomposition satisfies $\sum_{j=1}^{K} \omega_{ij} = 1$, but GVDM has $\sum_{j=1}^{K} \omega^g{}_{ij,h} \neq 1$. Therefore, we follow the normalized GVDM of Diebold and Yilmaz (2011) and Greenwood-Nimmo et al. (2012):

$$\tilde{\eta}_{ij} = \frac{\omega^g{}_{ij}}{\sum_{j=1}^{K} \omega^g{}_{ij}}$$

The normalized GVD satisfies

$$\sum_{j=1}^{K} \tilde{\eta}_{ij} = 1$$

$$\sum_{i=1}^{K} \sum_{j=1}^{K} \tilde{\eta}_{ij} = K.$$

3-5. Average outflow shock and contagion effect of shocks

We obtain the following matrix via the normalized GVD:

	y_1	y_2	⋯	y_j	From other
y_1	$\tilde{\eta}_{11}$	$\tilde{\eta}_{12}$	⋯	$\tilde{\eta}_{1j}$	$\sum_{j=1}^{K} \tilde{\eta}_{1j} = 1$
y_2	$\tilde{\eta}_{21}$	$\tilde{\eta}_{22}$	⋯	$\tilde{\eta}_{2j}$	$\sum_{j=1}^{K} \tilde{\eta}_{2j} = 1$
⋮	⋮	⋮	⋱	⋮	⋮
y_i	$\tilde{\eta}_{i1}$	$\tilde{\eta}_{i2}$	⋯	$\tilde{\eta}_{ij}$	$\sum_{j=1}^{K} \tilde{\eta}_{ij} = 1$
To other	$\sum_{i=1}^{K} \tilde{\eta}_{i1} \neq 1$	$\sum_{i=1}^{K} \tilde{\eta}_{i2} \neq 1$	⋯	$\sum_{i=1}^{K} \tilde{\eta}_{ij} \neq 1$	$\sum_{i=1}^{K} \sum_{j=1}^{K} \tilde{\eta}_{ij} = K$

where $i, j = 1, 2, \ldots, K$.

From the perspective of network theory, the NGVD matrix is an adjacency matrix filled with weights and not with the logical numbers 1 or 0. These weights are interpreted by Diebold and Yilmaz (2011) as connectedness. Because variance decomposition is a method that manages the forecast error extracted by the VAR system, these outputs are therefore the shocks that are unexplained by the relationships among the selected variables in the VAR system. We can also interpret these weights as the shocks.

Therefore, from this point on, we interpret each element of the normalized GVD matrix (NGVD matrix) $\tilde{\eta}_{ij}$ as the shock from company (variable) j company i. Because the diagonal term in the normalized GVD matrix (NGVD matrix) is the shock from the company onto itself and the row sum of the NGVD matrix is 1, the diagonal values in the results are ingnored[6]. I also focus on the outflows of each company to confirm the contagion effect of shocks.

On an individual level, the outflow of a shock to another company from company y_j is the columned sum of company y_j as follows:

$$Out_{j,t} = \sum_{i=1}^{K} \tilde{\eta}_{ij,t} \, .$$

and the average outflow shock (AOS)[7] is

$$\mathrm{AOS}_t = \frac{\sum_j^K Out_{jt}}{K}$$

$$for\ t = 1,2, \dots T.$$

AOS indicates the average outflow shock for all companies, which is equal to $\frac{\sum_{i=1}^{K}\sum_{j=1}^{K}\tilde{\eta}_{ij,t}}{K}$ $for\ i \neq j$. The dynamics of AOS is determined using a rolling-window method with a window of one day.

On the sector level, I group and average the shock of companies by the different number of companies in a sector. Then, I redefine the NGVD matrix as follows:

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6 i.e., the values of the diagonal terms are filled with zeros.

7 AOS is equal to "Total connectedness", Diebold and Yilmaz (2011).

	S_1	S_2	…	S_j	From other sectors
S_1	$\tilde{\eta}(S_{11})$	$\tilde{\eta}(S_{12})$	…	$\tilde{\eta}(S_{1j})$	$\sum_{j=1}^{G}\tilde{\eta}(S_{1j}) \neq 1$
S_2	$\tilde{\eta}(S_{21})$	$\tilde{\eta}(S_{22})$	…	$\tilde{\eta}(S_{2j})$	$\sum_{j=1}^{G}\tilde{\eta}(S_{2j}) \neq 1$
⋮	⋮	⋮	⋱	⋮	⋮
S_i	$\tilde{\eta}(S_{i1})$	$\tilde{\eta}(S_{i2})$	…	$\tilde{\eta}(S_{ij})$	$\sum_{j=1}^{G}\tilde{\eta}(S_{ij}) \neq 1$
To other sectors	$\sum_{i=1}^{G}\tilde{\eta}(S_{i1}) \neq 1$	$\sum_{i=1}^{G}\tilde{\eta}(S_{i2}) \neq 1$	…	$\sum_{i=1}^{G}\tilde{\eta}(S_{i3}) \neq 1$	$\sum_{i=1}^{G}\sum_{j=1}^{G}\tilde{\eta}(S_{ij}) \neq K$

where $i, j = 1,2,\ldots,G$, G = the number of sectors, and $\tilde{\eta}(S_{ij})$ is the average shock on S_i from S_j. Additionally, $\sum_{i=1}^{G}\sum_{j=1}^{G}\tilde{\eta}(S_{ij})$ is not equal to K and should be less than K because, as mentioned earlier, the sum of diagonal elements in the NGVD matrix of individual companies is zero.

The outflow of an average shock to other sectors from sector S_j at time t is

$$Out(S_{j,t}) = \sum_{i=1}^{G}\tilde{\eta}(S_{ij,t}).$$

I then separate $Out(S_{j,t})$ into two parts, the intra-shock and inter-shock of sector j. The intra-shock of S_j is the average outflow shock (AOS) on the sector itself, but an inter-shock of S_j is an AOS that affects other sectors except the companies of sector j. I define inter- and intra-shocks as follows:

$$Out(S_{j,t})_{intra} = \tilde{\eta}\left(S_{jj,t}\right)$$

$$Out(S_{j,t})_{inter} = \frac{Out(S_{j,t}) - \tilde{\eta}\left(S_{jj,t}\right)}{G-1}$$

I insist that an outflow shock, which eliminates self-influence, could be interpreted as a contagion effect of shocks because the contagion effect is that the shock of a depressed company affects other companies in the sector. Therefore, I define $Out(S_{j,t})_{intra}$ as the intra-sector contagion effect, $Out(S_{j,t})_{inter}$ as the inter-sector contagion effect and $Out(S_{j,t})$ as the total contagion effect.

Finally, I set the parameters, which are the number of lags p and the predictive horizon h, in the following manner. The selection problem of p is related to the number of observations applied to the VAR system. If the number of lags is greater than 3, we require greater than $3\,times\,K$(the number of variables) observations to sufficiently estimate the forecast error.

Therefore, although there are AIC and BIC methods to select p, I manually choose the number of lags as to be 3 because the considered variable size is too large and third-order VAR is frequently used for daily data.

The second selection problem is that of the predictive horizon, h. Because the number of predictive horizons does not significantly affect both the AOS and CES results, as detailed in Diebold and Yilmaz (2011), I manually set $h = 12$.

Ⅳ. Empirical results

4-1. Data

To calculate the primary result, I use the daily closing price for individual companies that are listed on the KOSPI stock index, Table 1 presents additional details.

I use the mean and standard deviation of the normalized absolute log-return as a proxy of volatility from April 1 from April 1, 1991 to December 31, 2010. The volatility is defined as follows:

$$Vol_i(t) = \left|\frac{R_i\,(t) - \bar{R}_i}{\sigma_i}\right|,\ \ i = 1, 2, \ldots., N$$

$$R_i(\mathrm{t}) = \ln\big(\mathrm{p(t)}\big) - \ln(\mathrm{p(t-1)})$$

$Vol_i = normalized\ volatility$

$P(t) = closing - price - on\ day\ t$

$\bar{R}_i = average\ return\ of\ company\ i\ for\ entire\ period$

$\sigma_i = standard\ deviation\ of\ company\ i\ for\ entire\ period,$

where N is the number of companies.

Because the GVDM assumes that the forecast error obeys a multivariate normal distribution, the data must be appropriate for the nature of the normal distribution. Diebold and Yilmaz (2011) used the log-realized volatility for two reasons: volatility is valuable as a fear indicator and volatility is especially sensitive to crises. I therefore apply volatility data instead of a return time series. Because the realized daily volatility is difficult to collect for many companies, I use the absolute standardized log-return as a proxy of daily volatility. Absolute return is more suitable for daily volatility than squared return[8], and the natural logarithm often obeys approximate normality.

For the entire period, I select 354 among all stocks listed on the KOSPI index and categorize these companies according to their industry sector and chaebol group[9] to analyze the contagion behavior of information flows calculated using a volatility time series.

[8] Forsberg et al (2004).

[9] Detailed information of industry sectors and Chaebol groups is in appendix.

4-2. Results

Part 1. Contagion effects of the KOSPI system

(Figure 1-A)[10]

Figure 1-A shows the AOS for all companies. I adapt training sample data with 1400 points spanning approximately five years because the sample captures a broader range of changes and secures the statistical significance of the results[11]. We consider whether the novel measurement proposed in this thesis can capture the stability of the economy, particularly with respect to two major events, an International Monetary Fund (IMF) event on November 21, 1997, in South Korea and the Lehman Brothers bankruptcy event (sub-prime crisis) on

[10] The red line represents the randomized AOS, which is calculated using the average random normal returns of 130 random sets following the mean and variance of each company.

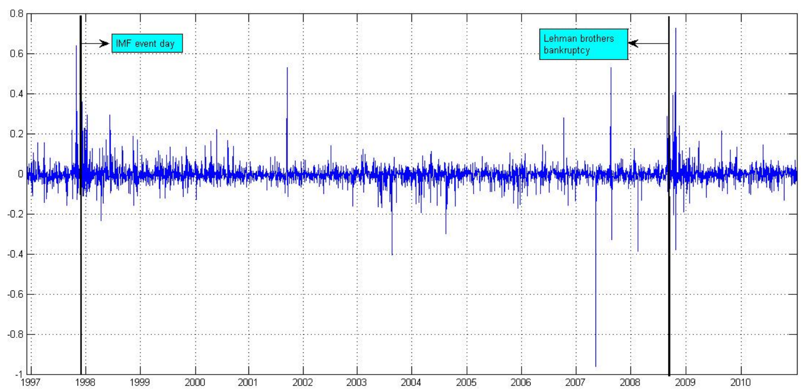
[11] If I reduce the training sample size, I can reveal more subtle change over time.

September 16, 2008, in the US. The IMF event, which is known as the Asian currency crisis, was triggered by the bankruptcy of the Hanbo Steel, which was a major company with liabilities of approximately 5.7 trillion won on January 23, 1997. Other major companies, including SAM MI, JIN RO, Hanshin Engineering & Construction, the Tea-il Precision Company, the Dea-nong and the SBW, also fell into bankruptcy in March 1997, and the Korean economy rapidly collapsed. The Korean government eventually requested international relief loans from the IMF on November 21, 1997. The Asian currency crisis lasted from November 21, 1997, when the relief loans were requested from the IMF, to August 23, 2001, when the repayments on the loans, which totaled 195 billion dollars, were completed.

Figure 1-A illustrates that the AOS is dynamic and detects between 88% and 95% of AOS variation, which increases significantly during financial crisis periods such as the Korean IMF event, the September 11th terror event and the subprime crisis. The AOS value increased from 92% to 94.5% following the first day of the IMF event because the negative effect of the news reported by the mass media the government request for a relief loan from the IMF should have influenced the Korean stock market before the date of the event, November 21, 1997. The AOS had high values of 94-95% after this date until early 2003, and the AOS of 94.5% sharply decreases in a day by the shock of 9.11 terror in US, and then AOS is continuously decreases in one day following the shock of the September 11th terror attack on the US. The AOS then continuously decreased from 94% in early 2003 to 90% in May 2007 because of stabilization in the

Korean stock market and decreased sharply in May 2007. It increased again by 1% from 88.3% to 89.3% in August 2007 because of the effect of shocks in response to sub-prime crisis, such as the bankruptcy of the American Home Mortgage company and the US governments supplying funds of approximately 115 billion dollars to the Countrywide Financial Corporation and reducing the FRB rediscount rate by 0.5%. Despite the aftereffects of the events lasting for five months, the Korean stock market (KOSPI) became stable and reached the lowest record of 87.8% at the end of August 2008. From early September 2008, however, negative effects associated with the incremental risk factors of immense financial companies, such as Fanny Mae and Freddie Mac the acquisition of Merrill Lynch, and the bankruptcy of Lehman Brothers, influenced major companies in the US, such as AIG and Wachovia. These financial shocks influenced not only the US economy but also the global financial market. We find that during this period, the AOS increased to 90% for two months. Consequently, the outflow shock of the Korean stock market is significantly associated with the financial stability of the US. In fact, the AOS explains the financial market stability over the financial crisis, which was rapidly improve compared with all other periods.

We also estimate the difference in the AOS values from Figure 1. Figure 1-B displays the difference in the AOS during entire period. The AOS increased during times of financial crisis, such as the Korean IMF event, the September 11 terror attacks and the sub-prime period. Differences in the AOS following the aftermath of the shocks caused by the IMF event, the September 11th terror attacks and the subprime event were greatest near the day of the event. Consequently, the contagion effects between companies should increase sharply in a financial crisis, whereas the systemic risk of a financial system will increase because of a number of events.



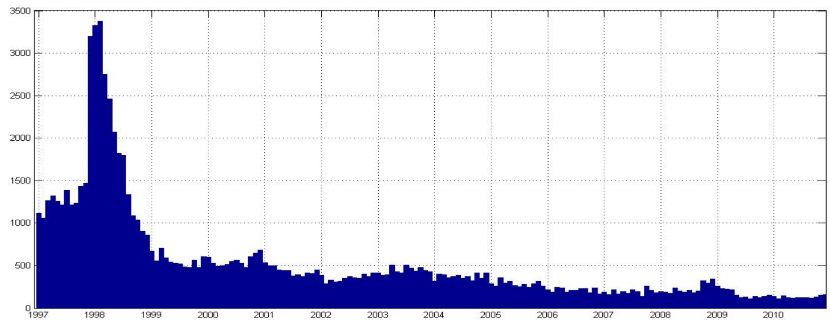
(Figure 1-B, Difference of AOS)

Additionally, although the variation in the difference of the AOS values exhibits clustering around both the IMF event and the Lehman Brother's bankruptcy, there is a difference between the two major events. There is a variation in the difference of the AOS values, which is illustrated by the rapid increase before the IMF event that was not evident in the case of the Lehman Brother's bankruptcy. This variation is because of fundamental features of the two major events. Whereas the IMF event was a domestic event, endogenous shock and the negative sentiments of market members because of defaults of major companies were instantly reflected in the Korean stock market. There is no precursor behavior in the Lehman Brother's event because it is an event of a major exogenous shock.

Consequently, dynamical changes caused by major events, such as the IMF event, the September 11th terror attack and the American Home Mortgage company bankruptcy, confirmed more definitively the differences observed in the AOS than in Figure 1-A.

According to the results, the IMF event, which was a financial crisis created by a domestic problem, was greatly exposed to the overall risk in both the financial and real economic system, whereas financial crises induced by exogenous shocks, such as the September 11th terror attack and subprime events, had an influence on the financial market.

To support the above results, I observe a number of defaulted companies (NDC) over time from 1997 to 2010. Figure 1-C indicates that the NDC increased from the beginning of 1997, peaked at approximately 3400 in 1998 during the IMF crisis, and subsequently decreased. Our results indicate that the Korean economy suffered more during the foreign currency crisis than during any other sub-period.



(Figure 1-C. The number of defaulted companies)[12]

Following the official request from the Korean government for a relief loan from the IMF, the number of defaulted companies increased and was more than double the number in any other period. During the Lehman Brother's bankruptcy event, there was a slight increase followed by a subsequent decline from 2009 to 2010. The reasons for this result are two-fold.

First, the foreign currency crisis was triggered by the problem of a lack of foreign exchange holdings, which originated some years earlier but became more critical following the default of several major companies, which resulted in the withdrawal of foreign investment. This crisis caused major, robust companies to restructure. Because the most significant companies in Korea belong to a chaebol group, a bankruptcy of one major company in a certain chaebol will cause defaults by its subcontractors and other connected companies. Many companies experienced default during the foreign currency crisis period. The sharp increase in AOS during the foreign currency crisis period is related to shocks that affected the Korean stock market because of overall economic

[12] Source in Bank of Korea (BOK).

problems in the Korean economy. These conditions were induced through a cascade of bankruptcies following a default by one chaebol group. With respect to the sub-prime crisis period, the negative effect caused by the numerous interconnections between South Korea and other countries was less than the effect cause by the IMF event that occurred because of problems related to both finance and the real economy. The impacts generated by the IMF event affected the AOS of the Korean stock market more than the sub-prime effect.

Second, the previous crisis yielded experience that was useful for overcoming subsequent crises. In the foreign currency crisis, the Korean government supported public funding of financial markets. The merchant banks were expelled from the market as part of the financial sector restructuring. Thus, the government was the most significant cause of financial market stability through the rigorous restructuring of weak financial companies. Therefore, despite a strengthened Korean financial market being affected by the US financial market, which was impacted by the Lehman Brothers bankruptcy, the spread of this effect across financial and economic sectors was limited.

However, because globalization continues and dependence upon foreign trade is a characteristic of Korea, the economy will exhibit a significant and rapid response to shocks in major countries around the world. According to a report by the Bank of Korea, Korean financial institutions are relatively stable. But if the chaebol groups suffer from shocks from overseas markets, there is the risk that a second IMF event could result because the risk faced by chaebol groups is still high and their influence is substantial. It is therefore important to be prepared for unexpected risks by analyzing the degree of risk of chaebol groups.

Part 2. Contagion effects of industry sectors

This study has analyzed the contagion effect between individual companies in the KOSPI index by an analysis of the AOS.

To rigorously analyze the impact of contagion effects among the various economic institutions, we consider industry sectors that have specific economic functions and that constitute the economic system. It is important to note the dynamic change of the contagion effects between industry sectors over time according to market status. I define contagion behavior of the industry sector level by classifying individual companies according to their related industry because the contagion effect in terms of the stability of an economy system can be analyzed from the industry perspective.

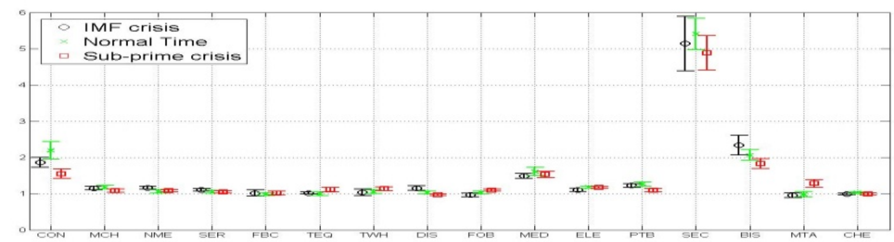
The contagion effect of each industry sector is calculated using Equation mentioned in Section 3. Additionally, we explore the total contagion effect according to the intra- and inter-sector contagion effects defined in Sector 3. To determine whether the contagion behavior for industry sectors is related to the economic situation, I analyze the contagion effect in three periods, which are 1995 to 2001(the IMF period), 2002 to 2007(a normal period)[13] and 2008 to

[13] Technically, several events, such as the credit card crisis and the economic shocks caused by the chaebol group regulation, occurred during the normal period, but the impacts of these events were not

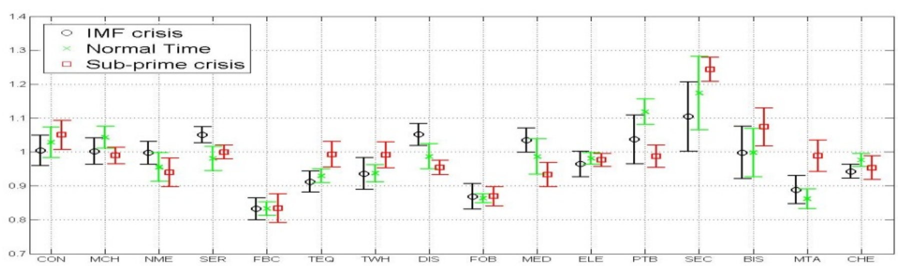
2011 (the sub-prime period).

(Figure 2. The contagion effect for 16 industry sectors)

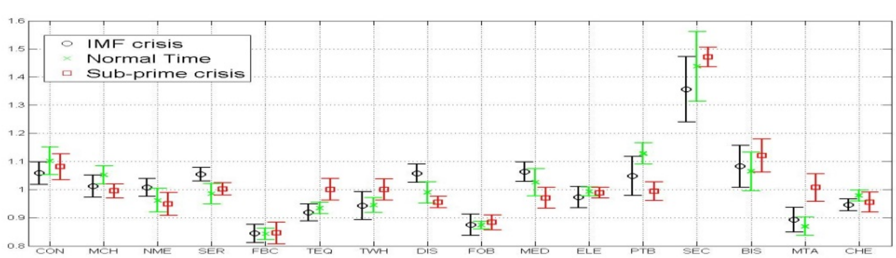
A. Intra-sector contagion effect



B. Inter-sector contagion effect



C. Total contagion effect



as significant as those of the IMF event and the sub-prime crisis and their boundaries are not clearly identified. Thus, I define period 2002 to 2007 as a normal period.

Figure 2-A, 2-B and 2-C illustrates the contagion effects for the intra-sector, inter-sector and total data sets of the KOSPI market index. The contagion effects for the IMF period (black circles), the normal economy status (green crosses) and the sub-prime period (red squares) are shown in the error-bar plot.

Figure 2-A illustrates that there are dominant industry sectors with respect to contagion behavior in the intra-sector data set: SEC, BIS, CON and MED are larger than those for other industry sectors. The above results indicate that interactions among individual companies that belong to the specific industry sector such as the financial sector, the construction sector and the medical sector are significant in comparison with other sectors. In particular, the contagion effect for the security sector, regardless of the economic situation, has the highest value. These results indicate that most companies in the security sector substantially influence other companies in the same sector. This is the case because companies that belong to the security sector have a sensitive reaction in response to the aggregate economic situation.

The BIS sector is similar to the SEC sector; however, the influence is less than that of the SEC sector. Additionally, the CON and MED sectors are politically dependent sectors because their sectors are more substantially affected by government economic policy rather than the actions of market players. Therefore, individual companies from the CON and MED sectors have more significant strong interactions than other sectors except the financial sector, whereas other sectors that are more related to the real economy have less significant interactions. The intra-sector contagion effects in these sectors exhibit average contagion values that are similar to the value for the whole system. This result suggests that the deterioration of individual companies in a sector does not have a significant influence on their sector, with the exception of the financial, construction and medical sectors.

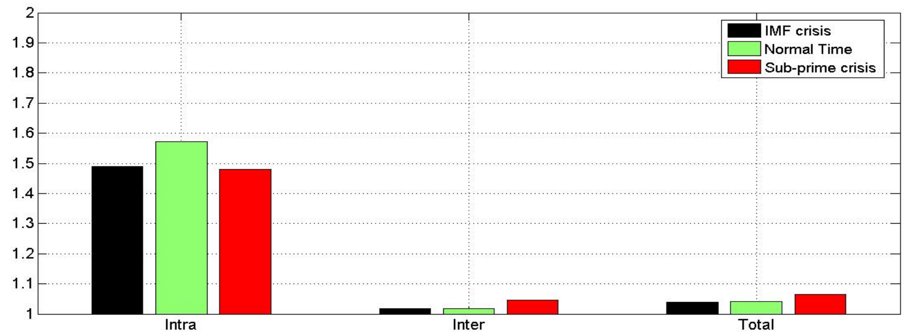
Figure 2-B illustrates that inter-sector contagion effects exhibit values similar to the system average contagion value, which is approximately 1. However, the SEC has the largest value of inter-sector contagion effect. Thus, the SEC sector has not only a strong interaction effect but also a substantial impact on other dominant sectors in the KOPSI index.

The total contagion effect in figure 2-C depicts that the industry sectors, except for the financial sectors (SEC and BIS), have comparable influence on the system average contagion effect level, whereas the CON and MED sectors have relatively significant interactions among their own companies compared with other real economy sectors in terms of the intra-sector contagion effect.

In summary, financial sectors (SEC and BIS) and politically dependent sectors (CON and MED) have considerably larger intra-sector contagion effects. In contrast, the inter-sector contagion effect is not clearer than the intra-sector contagion effect. However, the financial sectors also have a significant inter-sector contagion effect. Accordingly, this study posits that financial sectors and politically dependent sectors significantly contribute to the contagion effect of overall system. Specifically, these sectors have a significant influence on the stability of economic systems in terms of contagion behavior. Consequently, financial sectors and politically dependent sectors are greatly exposed to the contagion effects of the system. However, real economic sectors exhibit minimal contagion effect of approximately 1.

In comparison with the contagion effects of certain sectors in the normal and crisis economic conditions with respect to financial stability, intra-sector contagion effects are relatively more significant larger in a normal state than in a crisis state, whereas inter-sector contagion effects are more dominant in a crisis state than in a normal state for many sectors. This is, especially, apparent for the financial and politically dependent sectors. This result suggests that the degree of contagion effects among sectors for the financial, construction and medical sectors is greather during financial crisis periods than normal periods because a company from one of these sectors may react sensitively to both endogenous and exogenous events. Accordingly, I suggest that the contagion effect of economic sectors is closely related to financial stability, which is negatively affected by contagion behavior.

To confirm the above results, I compare the average value of intra-sector, inter-sector and total contagion effects for each sub-period.



(Figure 3. Average value of contagion effects in each period)

Figure 3 illustrates the average contagion effect of all industry sectors for intra-sector, inter-sector and total sectors, calculated based on the equation in section 3.

The results indicate that the intra-sector contagion effect in normal periods is more significant than that of financial crisis periods such as the IMF crisis and the sub-prime crisis, whereas during the subprime crisis, the average contagion effect of industry sectors had significantly greater values than for other periods. The results imply that each of the industry sectors typically interact well internally during normal periods, whereas when anticipating a significant negative event, their connections are broken by protective behaviors that may affect other industry sectors.

The explanation for why the contagion effects among industry sectors during the sub-prime crisis period were more significant than during the IMF crisis period is that the industry sectors that react sensitively react to conditions of world trade and financial markets are more sensitive to recent events than to past evetns because of globalization by rapidly developing interconnected economics.

In particular, the sub-prime crisis period is the period that caused an illiquidity crisis in global financial markets and the collapse of US financial market. According to market conditions, the sensitive industry sectors should react more dramatically to the sub-prime crisis than the IMF crisis.

With respect to the IMF crisis, because the shock of the real economy collapse caused by the default of major companies and an unstable foreign exchange propagated to the financial and real economy arena, and because these shocks were also inhomogeneous, the standard deviations of contagion effects among companies in a specific sector were significant; however, their average values during the IMF crisis were less than those of the sub-prime crisis[14] .

In the case of sub-prime crisis, because the sub-prime crisis occurred in the US, the shock was first propagated through the globalized financial system. Moreover, because the origin of the shock was the collapse of financial companies in the US, the financial market of Korea was affected more quickly than real economic sectors. Therefore, inter-sector contagion effects of financial sectors are the greatest. Because of the relatively stabilized financial market of Korea that was established following experienced gained from a previous crisis, this shock caused the Korean stock market index to decline significantly but did affect the real economy.

[14] Several real economy sectors had greater inter-sector contagion effects during the IMF crisis than the sub-prime crisis because their real economy sectors were sources of shocks.

However, if this large event were related to a major Korean company, we could not exclude the possibility of a significant crisis arising from the shock of systemic risk in the US market. Such systemic risk would have a significant influence on financial markets in Korea and the country's real economy.

Part 3. Contagion effect of industry sectors within the chaebol group

To further analyze the contagion effect in the scope of the real economy, we consider the chaebol group of the Korean economy, which has a unique firm structure and contains many individual companies that belong to various industry sectors. The influence of chabeol groups in the Korean economy is substantial. The Korean government has announced regulatory policies regarding chaebol groups with each change of regime. The influence of the Samsung Group has been sufficiently significant to shake the Korean economy.

To analyze the contagion effect of chaebol groups, I reclassify 41 companies in the data set and group them according to the eight chaebol group[15]. I then consider each of the chaebol groups as a sector to analyze their contagion effects.

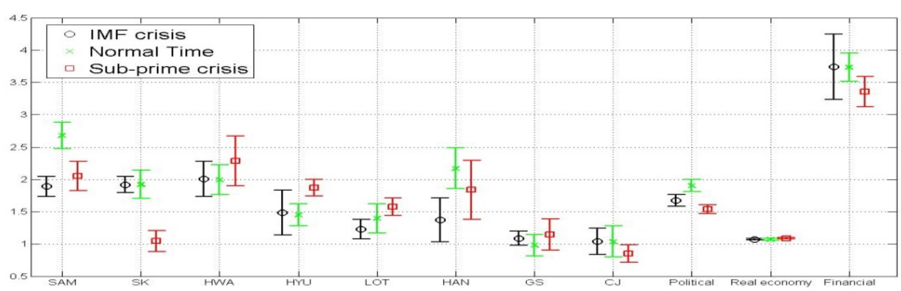
I classify the industry sectors into three groups to easily compare their

[15] Samsung, SK, Hanwha, Hyundai motors, Lotte, Hanjin, GS and CJ (A detailed description of the chaebol groups is reported in the chaebol group table in the appendix).

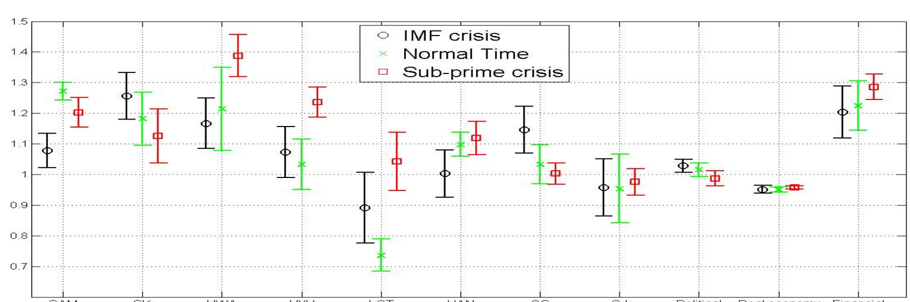
contagion effects with those of the chaebol groups. The construction and medical sectors are defined as political sectors because they are dependent on the economic policy of the government and will not be significantly affected by the chaebol group. The security and BIS sectors are defined as financial sectors, and the remaining sectors are defined as real economy sectors. To accurately strictly estimate the contagion behavior, I compare the contagion effects of the chaebol groups with the average values of the contagion effects for the three groups.

(Figure 4. Contagion effects of the 3 sector groups with the 8 chaebol groups)

A. Intra-sector contagion effect



B. Inter-sector contagion effect



C. Total contagion effect

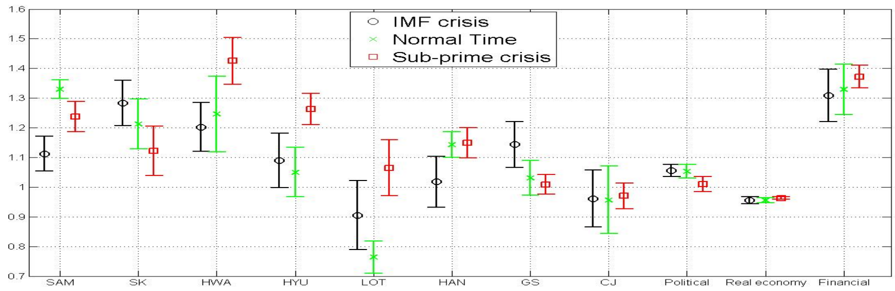
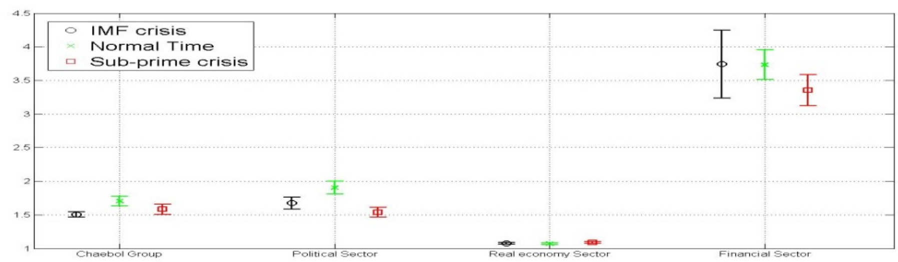


Figure 4-A, 4-B and 4-C illustrate the contagion effect of each group, the chaebol, finance, political and real economy sectors. The majority of the chaebol sectors, regardless of whether we consider the intra-sector, inter-sector or total effects, have relatively more significant values than those for the real economy sector. Furthermore, the contagion effects among companies in the chaebol groups exhibits greater variation because the contagion shocks of individual companies that belonging to the chaebol groups exhibit heterogeneous features. Similarly, for the chaebol groups, the contagion effect between sectors are more significant that the real economy sector and have a significant standard deviation, which implies that they affect other sectors heterogeneously, except for the LOT, GS and CJ groups.

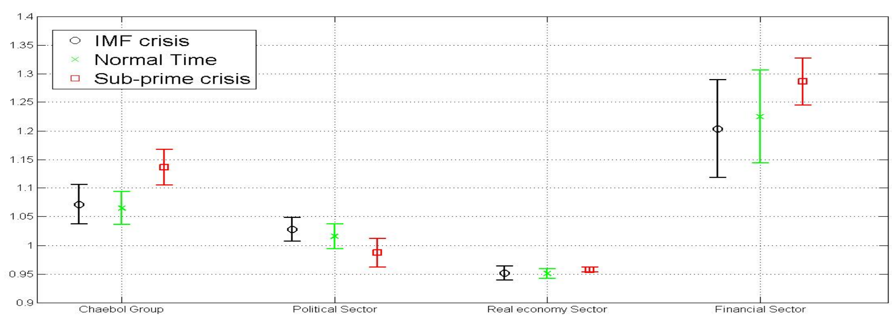
Because each of the chaebol groups has a specific character, it is difficult to analyze individual values. Therefore, the eight chaebol groups are grouped into one large chaebol group, and value of their contagion effects are averaged.

(Figure 5. Contagion effects of 4 sector groups)

A. Intra-sector contagion effect



B. Inter-sector contagion effect



C. Total contagion effect

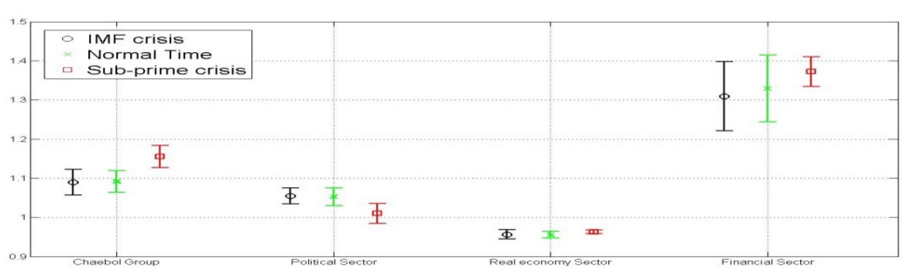


Figure 5 depicts the average contagion effects for the four different groups.

The Figure 5-A illustrates that for all periods, the contagion value of financial sector in intra-sectors is approximately 4 times larger than the system average value and that the political and chaebol sectors have 1.5 to 2 times greater values, whereas there is no effect on the real economy sectors.

Consequently, individual companies of chaebol group have more significant interactions than companies from the real economy sector, although one chaebol group has many companies in various industry sectors.

Individual companies in a chaebol group, which are also contained in the real economy sector, have to be bound to the chaebol group rather than a real economy sector to achieve system stability. Bankruptcy of such a chaebol group may cause a worsening of the Korean economy because it would affect the industry sectors of the companies in the chaebol group and its subcontractors. Furthermore, individual companies in a chaebol group in our sample are relatively robust because they are the companies that survivied during our sample period and they do not constitue all of the chaebol group's individual companies. Therefore, these results should underestimate the influence of chaebol group in terms of the stability of the financial system.

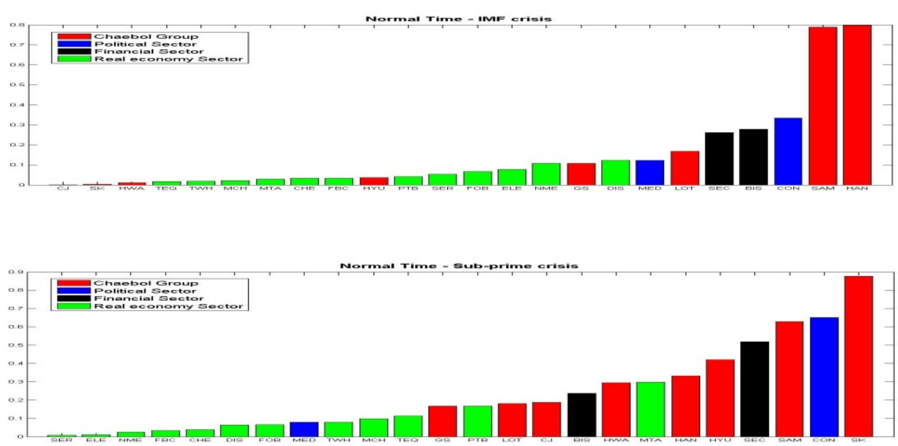
In fact, because bankruptcies of many chaebol groups whould cause the default of numerous subcontractors and increase unemployment, the Korean economy would deteriorate substantially.

Figure 5-B illustrates that the contagion effect between sectors for the

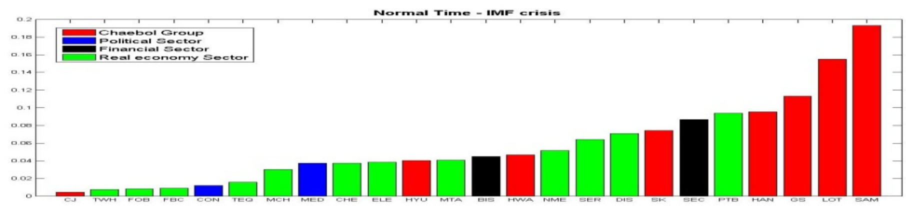
chaebol group is the second largest value, following the financial sector. Because its volatility is large, we posit that the chaebol group generates a heterogeneous inter-sector contagion effect and that it exhibited a greater inter-sector contagion effect during the sub-prime crisis period than the IMF crisis period. Additionally, the contagion effect of the real economy sector is not significant level in the Korea economy because that sector has the least inter-sector contagion effect and the least intra-sector contagion effect.

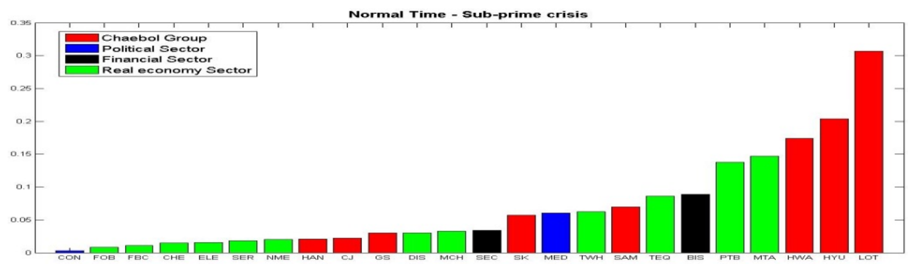
(Figure 6. Sorting absolute value of the difference of the average contagion effect)

A. Intra-sector contagion effect

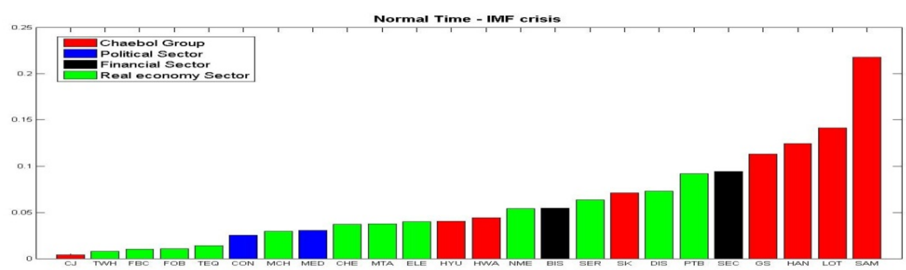


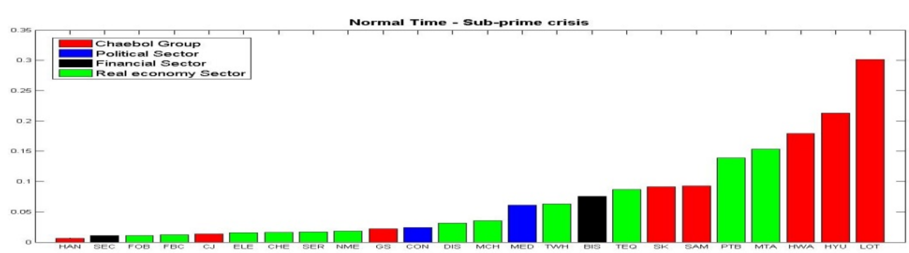
B. Inter-sector contagion effect





C. Total contagion effect





To analyze subtle changes in the contagion effects of industry sector according to market status for intra-sector, inter-sector and total effects, we calculate the difference of the contagion effects between normal and market crisis periods such as the IMF event and the subprime event . Figure 6 demonstrates that absolute values of the difference between average values of each contagion effect during the normal period and crisis periods are sorted according to those industry sectors that are sensitive to crisis.

In these results, certain chaebol groups rank the highest in terms of Intra- and inter-sector contagion effects, and most of the chaebol groups rank highly. This implies that chaebol groups react sensitively to substantial negative events. Moreover, whereas there are no significant changes in the inter-sector contagion effect, there are significant changes in the intra-sector contagion effect, and many chaebol groups were ranked highly during the sub-prime crisis in comparsion with the IMF crisis. This reason is that the influence of chaebol groups in our study during the IMF crisis differed from their influence during the sub-prime crisis[16]. Furthermore, most chaebol groups have a significant tendency to depending on international trade and markets. Therefore, connections among individual companies in a chaebol group were more substantially affected by the exogenous shock of the sub-prime crisis, which was crisis of international risk, rather than the IMF crisis, which was an endogenous shock.

[16] The chaebol groups in our paper are in the top 10 groups based on 2010 data but not in the top 10 groups based on 1997 data.

Ⅴ. Conclusions

There are various channels that are associated with one company: lending channels that are connected to banks, industrial channels that are connected to other companies in the same industry and structural channels that are connected to subsidiaries. Systemic risk propagates the risk of one company to other companies through such channels. The most important concept of systemic risk is connections (interactions) that are linked to other groups. Irrespective of the origins of negative feedback, a default of one company affects other industry sectors thourgh its connections. Many researchers have recognized the potentially serious impacts associated with systemic risk, and studies regarding this subject are ongoing. Most previous studies are related to the construction of networks of a certain system to analyze connections in that system. Recent studies have measured systemic risk using incorporative methods such as the Granger causality network and variance decomposition network.

This study quantifies the contagion behavior among financial objects, such as an individual company and an industry sector, using a VAR model and a GVDM, which is regarded as an adjacency matrix in network theory. Thismethod is used to measure the contagion effects of systemic risk and uses absolute normalized log-returns as a proxy of daily volatility for 354 survival companies listed on the KOSPI index.

The study demonstrates that shares values of other companies are of more significance when a significant financial event occurs and that for the Korean stock market, the deterioration of markets was sustained longer during the IMF crisis than the sub-prime crisis.

From the perspective of contagion effects, this study analyzes each of the industry sectors and determines their characteristics by separating contagion effects into intra-sector and inter-sector contagion effects.

The study demonstrates that individual companies that belong to industry sectors such as the financial sector, the political sector and chaebol groups have the most significant interactions, whereas other real economy sectors have the least significant interactions.

The intra-sector contagion effect between companies is significant because the ndividual companies have strong interactions.

Because the individual companies in an industry sector have strong interactions, the intra-sector contagion effect is large. The financial sector has the most significant interactions among the constituent companies and is followed by the political sector and the chaebol groups. Because other real economy sectors have the least interactions, the collapse of an individual company from a real economy sector should not significantly affect other related companies from the same industry sector.

Whereas the intra-sector contagion effect is also important, the contagion effect among sectors based on contagion behavior to other industry sectors is quite important as a concept of systemic risk. The sector that most affects other industry sectors is the financial sector, followed by the chaebol groups, which have significant influence on other industry sectors. However, because the chaebol groups in our paper have an influence that tends to be underestimated, it is expected that the real influence of chaebol groups in the Korean economy is considerably larger.

The intra-sector contagion effect is decreased and the inter-sector contagion effect is increased when a sugstantial negative event regarding a major sector, such as the financial or chaebol groups, occurs. Such an event implies that the connections of individual companies in a sector are weakened when a crisis occurs and that they are more significantly affected by other industry sectors through the shock of the crisis. The period of greastest inter-sector contagion effect during the sub-prime crisis. The reason for this result is that the influences of the financial sector and the chaebol groups, which are sensitive to global economic conditions, are dominant in the Korea economy.

Our results indicate that the real economy sectors do not significantly affect other sectors; however, the financial sector and the chaebol groups have serious negative impacts. Global economic system are closely connected because of the globalization of economics and rapid deregulation. Stringent regulation and monitoring of financial institutions are needed because financial markets are at the center of all risk. Although there have been attempts to regulate the chaebol groups in Korea, these actions have not been effective. Many concerns the potential collapse of the Korea economy because of the default of a large chaebol group are evident. From the perspective of systemic risk, it is necessary to strictly measure the risk of the chaebol groups and to monitor their financial health along with the health of financial institutions because the default of a chaebol group could cause huge impacts and contagion effects.

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Appendix

Table 1, Contagion effect of 16 industry sectors[17]

Intra sector contagion effect of 16 Industry sectors																	
	Sector	CON	MCH	NME	SER	FBC	TEQ	TWH	DIS	FOB	MED	ELE	PTB	SEC	BIS	MTA	CHE
IMF crisis	Mean	1.86	1.15	1.17	1.10	1.02	1.02	1.04	1.15	0.97	1.49	1.10	1.22	5.14	2.34	0.95	0.99
	Std	0.13	0.05	0.04	0.03	0.08	0.03	0.09	0.06	0.05	0.07	0.04	0.05	0.76	0.27	0.07	0.02
Normal Time	Mean	2.20	1.18	1.06	1.05	0.98	1.00	1.05	1.03	1.03	1.61	1.18	1.26	5.40	2.06	0.98	1.02
	Std	0.24	0.05	0.05	0.04	0.04	0.05	0.05	0.04	0.04	0.11	0.03	0.06	0.43	0.15	0.08	0.02
Sub-prime crisis	Mean	1.55	1.08	1.08	1.04	1.02	1.11	1.13	0.97	1.10	1.53	1.17	1.10	4.88	1.83	1.28	0.99
	Std	0.13	0.04	0.04	0.03	0.05	0.06	0.05	0.02	0.03	0.08	0.02	0.05	0.48	0.13	0.11	0.03

Inter sector contagion effect of 16 Industry sectors																	
	Sector	CON	MCH	NME	SER	FBC	TEQ	TWH	DIS	FOB	MED	ELE	PTB	SEC	BIS	MTA	CHE
IMF crisis	Mean	1.00	1.00	1.00	1.05	0.83	0.91	0.94	1.05	0.87	1.03	0.96	1.04	1.10	1.00	0.89	0.94
	Std	0.04	0.04	0.03	0.02	0.03	0.03	0.05	0.03	0.04	0.04	0.04	0.07	0.10	0.08	0.04	0.02
Normal Time	Mean	1.03	1.04	0.96	0.98	0.83	0.93	0.94	0.99	0.86	0.99	0.98	1.12	1.17	1.00	0.86	0.98
	Std	0.05	0.03	0.04	0.04	0.02	0.02	0.03	0.04	0.01	0.05	0.02	0.04	0.11	0.07	0.03	0.02
Sub-prime crisis	Mean	1.05	0.99	0.94	1.00	0.83	0.99	0.99	0.95	0.87	0.93	0.98	0.99	1.24	1.07	0.99	0.95
	Std	0.04	0.02	0.04	0.02	0.04	0.04	0.04	0.02	0.03	0.04	0.02	0.03	0.04	0.06	0.05	0.03

Total contagion effect of 16 Industry sectors																	
	Sector	CON	MCH	NME	SER	FBC	TEQ	TWH	DIS	FOB	MED	ELE	PTB	SEC	BIS	MTA	CHE
IMF crisis	Mean	1.06	1.01	1.01	1.05	0.84	0.92	0.94	1.06	0.87	1.06	0.97	1.05	1.36	1.08	0.89	0.95
	Std	0.04	0.04	0.03	0.02	0.03	0.03	0.05	0.03	0.04	0.03	0.04	0.07	0.12	0.07	0.04	0.02
Normal Time	Mean	1.10	1.05	0.96	0.99	0.84	0.93	0.94	0.99	0.87	1.03	0.99	1.13	1.44	1.06	0.87	0.98
	Std	0.05	0.03	0.04	0.04	0.02	0.02	0.03	0.04	0.01	0.05	0.02	0.04	0.12	0.07	0.03	0.02
Sub-prime crisis	Mean	1.08	0.99	0.95	1.00	0.85	1.00	1.00	0.96	0.88	0.97	0.99	0.99	1.47	1.12	1.01	0.96
	Std	0.05	0.02	0.04	0.02	0.04	0.04	0.04	0.02	0.03	0.04	0.02	0.03	0.03	0.06	0.05	0.03

[17] Pointed values with red color are larger than overall average value (over 1).

Table 2, Contagion effect of 16 industry sectors with Chaebol Groups

Intra sector contagion effect of 16 Industry sectors with Chaebol Groups

	Sector	SAM	SK	HWA	HYU	LOT	HAN	GS	CJ	CON	MCH	NME	SER	FBC	TEQ	TWH	DIS	FOB	MED	ELE	PTB	SEC	BIS	MTA	CHE
IMF crisis	Mean	1.89	1.92	2.01	1.49	1.23	1.37	1.09	1.04	1.83	1.15	1.17	1.11	1.02	1.02	0.97	1.15	0.99	1.49	1.10	1.22	5.19	2.11	0.94	0.98
	Std	0.15	0.12	0.27	0.35	0.15	0.34	0.11	0.21	0.15	0.05	0.04	0.03	0.08	0.05	0.08	0.07	0.03	0.07	0.06	0.05	0.76	0.21	0.06	0.03
Normal Time	Mean	2.68	1.92	1.99	1.45	1.40	2.17	0.98	1.04	2.17	1.18	1.06	1.04	0.98	0.99	0.99	1.03	1.06	1.61	1.14	1.26	5.23	2.36	0.98	1.00
	Std	0.21	0.22	0.23	0.17	0.23	0.32	0.17	0.24	0.24	0.05	0.05	0.04	0.04	0.08	0.09	0.05	0.02	0.11	0.02	0.06	0.38	0.15	0.06	0.02
Sub-prime crisis	Mean	2.05	1.04	2.29	1.87	1.58	1.84	1.15	0.85	1.52	1.08	1.08	1.03	1.02	1.08	1.16	0.95	1.07	1.53	1.17	1.10	4.43	1.98	1.20	0.96
	Std	0.23	0.16	0.38	0.13	0.14	0.46	0.24	0.13	0.13	0.04	0.04	0.02	0.05	0.08	0.13	0.04	0.03	0.08	0.03	0.05	0.40	0.13	0.08	0.03

Inter sector contagion effect of 16 Industry sectors with Chaebol Groups

	Sector	SAM	SK	HWA	HYU	LOT	HAN	GS	CJ	CON	MCH	NME	SER	FBC	TEQ	TWH	DIS	FOB	MED	ELE	PTB	SEC	BIS	MTA	CHE
IMF crisis	Mean	1.05	1.23	1.16	1.05	0.89	0.99	1.14	0.95	1.04	0.99	1.00	1.07	0.82	0.91	0.84	1.05	0.88	1.01	0.94	1.02	1.30	1.11	0.87	0.91
	Std	0.05	0.07	0.08	0.08	0.12	0.07	0.08	0.09	0.04	0.04	0.03	0.02	0.03	0.03	0.05	0.04	0.03	0.04	0.04	0.07	0.11	0.07	0.04	0.03
Normal Time	Mean	1.24	1.16	1.20	1.01	0.73	1.08	1.03	0.95	1.06	1.02	0.95	0.98	0.81	0.92	0.87	0.97	0.90	0.97	0.97	1.11	1.37	1.09	0.85	0.94
	Std	0.03	0.08	0.14	0.08	0.05	0.04	0.06	0.11	0.05	0.03	0.05	0.03	0.02	0.03	0.03	0.04	0.02	0.05	0.01	0.03	0.12	0.07	0.03	0.02
Sub-prime crisis	Mean	1.18	1.12	1.37	1.21	1.03	1.11	1.00	0.97	1.05	0.98	0.93	1.00	0.82	0.99	0.98	0.93	0.86	0.91	0.97	0.97	1.38	1.13	0.97	0.92
	Std	0.05	0.09	0.06	0.05	0.09	0.06	0.03	0.04	0.04	0.03	0.05	0.02	0.05	0.06	0.06	0.04	0.03	0.03	0.02	0.04	0.03	0.05	0.04	0.04

Total contagion effect of 16 Industry sectors with Chaebol Groups

	Sector	SAM	SK	HWA	HYU	LOT	HAN	GS	CJ	CON	MCH	NME	SER	FBC	TEQ	TWH	DIS	FOB	MED	ELE	PTB	SEC	BIS	MTA	CHE
IMF crisis	Mean	1.09	1.26	1.19	1.07	0.90	1.00	1.14	0.95	1.07	0.99	1.01	1.07	0.82	0.92	0.85	1.05	0.89	1.03	0.95	1.03	1.46	1.15	0.87	0.91
	Std	0.06	0.07	0.08	0.09	0.12	0.08	0.08	0.09	0.04	0.04	0.03	0.02	0.03	0.03	0.05	0.04	0.03	0.03	0.04	0.07	0.13	0.07	0.04	0.03
Normal Time	Mean	1.30	1.19	1.24	1.03	0.76	1.12	1.03	0.95	1.10	1.02	0.95	0.98	0.82	0.92	0.88	0.97	0.90	1.00	0.98	1.12	1.53	1.15	0.85	0.94
	Std	0.03	0.08	0.13	0.08	0.06	0.04	0.06	0.11	0.05	0.03	0.05	0.03	0.02	0.03	0.03	0.04	0.02	0.05	0.01	0.03	0.12	0.07	0.03	0.02
Sub-prime crisis	Mean	1.21	1.11	1.40	1.24	1.06	1.14	1.00	0.97	1.07	0.98	0.94	1.00	0.83	1.00	0.99	0.93	0.87	0.94	0.98	0.98	1.51	1.16	0.98	0.93
	Std	0.05	0.08	0.07	0.05	0.09	0.05	0.03	0.04	0.05	0.03	0.05	0.02	0.04	0.06	0.06	0.04	0.03	0.04	0.02	0.04	0.04	0.05	0.05	0.04

Table 3, Contagion effect of 4 sector groups

Intra sector contagion effect of 16 Industry sectors					
	Sector	Conglomerates	Political	Real economy	Financial
IMF crisis	Mean	1.50	1.66	1.07	3.65
	Std	0.04	0.09	0.01	0.47
Normal Time	Mean	1.70	1.89	1.06	3.80
	Std	0.07	0.09	0.02	0.23
Sub-prime crisis	Mean	1.58	1.52	1.07	3.20
	Std	0.07	0.07	0.02	0.25

Inter sector contagion effect of 16 Industry sectors					
	Sector	Conglomerates	Political	Real economy	Financial
IMF crisis	Mean	1.06	1.03	0.94	1.21
	Std	0.03	0.02	0.02	0.09
Normal Time	Mean	1.05	1.01	0.94	1.23
	Std	0.03	0.02	0.01	0.09
Sub-prime crisis	Mean	1.12	0.98	0.94	1.26
	Std	0.03	0.02	0.01	0.03

Total contagion effect of 16 Industry sectors					
	Sector	Conglomerates	Political	Real economy	Financial
IMF crisis	Mean	1.08	1.05	0.95	1.31
	Std	0.03	0.02	0.02	0.09
Normal Time	Mean	1.08	1.05	0.95	1.34
	Std	0.03	0.02	0.01	0.09
Sub-prime crisis	Mean	1.14	1.01	0.95	1.34
	Std	0.03	0.02	0.01	0.03

Table 4, Industry sectors and Chaebol Groups information

	Sector name	Company symbol code in KOSPI								
Chaebol Groups	Samsung	810	830	1300	4000	5930	6400	9150	12450	16360
	SK	1510	1740	3600	6120					
	Hanhwa	370	880	3530	9830					
	Hyundai motors	270	1500	4020	4560	5380	10520	12330	720	
	Lotte	400	2270	4010	4990	5300				
	Hanjin	700	2320	3490	5430					
	GS	1250	5070	5420	6360					
	CJ	120	1040	11150						
Industries	Construction	210	360	800	1260	1470	1880	2410	2460	2530
		2780	2990	3070	4200	4960	5450	5900	5960	9410
		13360	13700	14350	720	6360				
	Machinery	490	2900	4380	4450	6570	8720	9160	9310	10660
		10820	11700	12200	12600	15590				
	Nonmetalic minerals	480	1520	2000	2030	3300	3410	4090	4870	4980
		6390	7110	7210	8870	10780	11390			
	Service	70	140	150	180	320	590	1940	2020	2790
		3090	3480	3550	3560	5250	5620	5810	6200	6260
		8930	9280	9970	10770	11420	12510	15020	15540	15860
		3600	700	1040						
	Fiber Clothes	50	950	1070	1460	1530	2070	3200	3610	5800
		5820	7700	9270	11000	14990	16090			
	Transportation equip	300	430	1420	1620	2920	3570	3620	4100	5030
		5850	6660	7860	10100	10620	12280	13570	15230	270
		5380	12330							
	Transportation warehousing	650	1140	3280	4140	4360	9070	9180	14130	5430
		2320	3490	120						
	Distribution	1120	2700	2810	3010	4060	4170	4270	4920	5110
		5360	5390	5440	6370	6490	8600	9810	10420	11760

		11810	12410	13000	830	1740	4010	1250		
	Food Beverage	890	1130	1680	1790	1800	2600	3230	3680	3920
		3940	3960	4370	4410	5180	5610	6980	7540	8040
		2270	4990	5300	11150					
	Drug medicine	20	100	220	230	520	640	1060	1360	1630
		2210	2250	2390	2620	2630	2720	3000	3060	3120
		3190	3520	3850	4310	4720	5500	5690	6280	7570
		9290	9420	16570	19170					
	Electric	4690	990	1210	1440	1820	4130	4490	4710	4770
		5680	6340	7610	7630	7810	8060	8110	8700	8900
		9140	9320	9470	11230	12170	14910	15260	17040	12450
		5930	6400	9150						
	Paper Timber	1020	2200	2300	2310	2820	2870	4150	4540	7190
		8250	9200	9460	11280	12690	14160			
	Security	1200	1270	1720	1750	3450	3460	3470	3540	5940
		6800	16420	16610	16360	1510	3530	1500		
	Bank Insurance	10050	10460	6350	60	540	1450	2550	3690	5830
		810	370	400						
	Metal	670	970	1080	1230	1770	2220	2240	2710	3030
		3640	5010	5490	6110	7280	8260	8350	8970	10130
		12800	14280	16380	18470	4020	4560	10520		
	Chemistry	240	860	1340	1390	1550	1570	2100	2350	2360
		2380	2760	2840	2960	3080	3240	3350	3650	3720
		3780	3830	4250	4430	4800	4830	4840	4910	5190
		5720	5950	6380	7340	7590	7690	8000	8490	8730
		10060	10640	10950	11720	11780	14680	1300	4000	6120
		880	9830	5070	5420					

* Red codes are individual companies also contained in Chaebol groups.