Dynamic Linkages among Foreign Exchange, Stock, and Commodity Markets in Northeast Asian Countries: Effects from Two Recent Crises

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Abstract: This paper investigates the interaction among the foreign exchange, stock, and commodity markets of Northeast Asian countries according to the cross-correlation function (CCF) approach. We analyze the impact of the global financial crisis and the European sovereign crisis on the financial market interactions of Japan, South Korea, and Taiwan. The empirical results show that financial markets in different countries show different causality relationships. While interactions in both mean and variance are relatively strong in Japanese financial markets, they are relatively weak in Korean markets. We cannot find any financial market interactions in Taiwan.

Keywords: Financial market, Financial contagion, Hong test, Northeast Asian countries.

1. INTRODUCTION

Numerous econometric methods have been developed to investigate the interaction between asset prices and financial markets—unit root tests (Dickey and Fuller, 1979, 1981), cointegration tests (Engle and Granger, 1987), vector autoregression (VAR) approaches (Sims, 1980), and ARCH (autoregressive conditional heteroskedasticity) approaches (Engle, 1982), for example.

Examining the interaction patterns between the US, Japan, and UK stock markets based on the ARCH approach, Hamao *et al*. (1990) discovered unidirectional information flows from the US stock market to the other two markets. Hamori and Imamura (2000) used the lag-augmented vector autoregression (LA-VAR; Toda and Yamamoto, 1995) method to detect causal relationships among stock prices in the G7 countries. The study of correlations of different markets is of paramount importance as we construct portfolios and manage risk, especially when the correlations are time dependent. Ito (2002) finds evidence of statistically significant high-frequency contagion among Asian countries in both exchange rates and stock prices. He also provides evidence that the spillover effect in stock markets has intensified after the currency crisis in most Asian countries. Chaban (2009) found, by applying the VAR model to analyze the relationship among the prices of natural resources, returns on equity, and nominal exchange rates, that the portfolio-rebalancing motive of Hau and Rey (2006) is weaker for developed countries, such as Australia, Canada, and New Zealand, where primary commodities constitute an important share of exports. Basher, Haug, and Sadorsky (2012) examine a related issue using the structural vector autoregression (SVAR) model. Their results show that positive shocks to oil prices tend to depress emerging market stock prices and US dollar exchange rates in the short run while an increase in emerging market stock prices raises the oil price. Moreover, Akram (2009) examined the relationship among commodity prices, real interest rates, and the US dollar using a SVAR model. He states that commodity prices increase significantly in response to a decrease in real interest rates while a strong dollar depresses commodity prices.

However, financial crises occurring one after another make financial markets sensitive to any information inflow. The contagion phenomenon in financial markets has been extensively discussed in the literature. Here, contagion is broadly defined to be the cross-country transmission of shocks, or the general cross-country spillover effects (World Bank).[1] Mun (2012) investigates the effects of macroeconomic surprise on the foreign exchange and stock markets in both the United States and Japan. Using recent data, he found that these markets respond asymmetrically to information inflows. However, few studies have examined how financial contagion spreads in a domestic financial market consisting of three or more sub-markets.

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[1]http://econ.worldbank.org/WBSITE/EXTERNAL/EXTDEC/EXTRESEARCH/EXTPROGRAMS/EXTMACROECO/0,,contentMDK:20889756~pagePK:64168182~piPK:64168060~theSitePK:477872,00.html

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To the best of our knowledge, no previous empirical studies have analyzed the transformation in the dynamic interactions among financial markets in a certain area during the period spanning the global financial crisis and the European sovereign debt crisis. The global financial crisis was triggered by the sub-prime loan losses of August 7, 2007, while the European sovereign debt crisis resulted from growing concerns about some EU member states' debts following the Dubai sovereign debt crisis of November 5, 2009.

In contrast to previous studies, this paper is characterized by the following three features. First, we investigate the impact of these two financial crises on the financial market interactions of Japan, the South Korea, and Taiwan. Thus, we divide the total sample into the global financial crisis period and the European sovereign debt crisis period. Using the cross-correlation function (CCF) approach proposed by Cheung and Ng (1996), we examine causal relationships in the mean and variance of foreign exchange, stock, and commodity market returns.[2] We then compare the results of the two sub-periods to understand how their interaction patterns differ. Second, Cheung and Ng's test statistics may suffer severe size distortion in the presence of causality in the mean. Therefore, we incorporate a weighted cross-correlation coefficient, introduced by Hong (2001), to detect the interaction changes in Northeast Asian financial markets and identify the direct effects of the two crises in accordance with our research objective. Finally, we investigate the causality effects among domestic financial markets in contrast with other studies trying to find international transmission patterns during a financial crisis. Based on the above procedure, we find that causality in the mean returns of foreign exchange, stock, and commodity markets does not vary between the crisis periods but the causality in variance does vary.

Data and statistical issues are presented in the next section. Section 3 discusses the theoretical framework to examine the interactions among the markets. Section 4 provides the empirical results related to the above issues. Section 5 concludes the paper.

[2]For CCF applications, please see, for example, Hamori (2003), Bhar and Hamori (2005), Bhar and Hamori (2008), Toyoshima and Hamori (2012), Nakajima and Hamri (2012), Xu and Hamori (2012), and Miyazaki and Hamori (2013).

2. DATA

In this paper, we use nominal exchange rates, stock price indexes, and commodity chemical price indexes of Northeast Asian countries to identify causal relationships across markets.[3] Nominal exchange rates in terms of the US dollar are used for comparison across Japan, South Korea, and Taiwan. Stock prices of the respective countries are based on the Tokyo Stock Price Index (TOPIX), Korea Composite Stock Price Index (KOSPI), and Taiwan Stock Exchange Weighted Index (TAIEX). For commodity markets, we use the DataStream commodity chemical price index, which is representative of all domestic commodity prices. All data are obtained from DataStream.

The global financial crisis began on August 7, 2007, and the European sovereign debt crisis started on November 5, 2009. Therefore, the entire sample period was divided into two sub-periods: August 7, 2007 to November 4, 2009 (587 observations) and November 5, 2009 to 30 November 30, 2012 (802 observations), corresponding to the global financial crisis period and the European sovereign debt crisis period, respectively. In all cases, returns from the market are calculated as first differences of the log of price indexes. Tables **1** and **2** summarize the statistical properties of the data. The results of the Jarque-Bera test show that the null hypothesis of the normal distribution is rejected in all cases, which indirectly support the existence of ARCH effects. Tables **3** and **4** present the unconditional correlation matrixes. Generally, the correlation of the foreign exchange market is negative with the Korean and Taiwanese but positive with the Japanese stock and commodity markets in both sub-periods. In the following section, we apply daily data to analyze how the causal relationship between the markets in these countries differs between the two crises.

3. EMPIRICAL TECHNIQUES

To investigate cross-market correlations in Northeast Asian countries and test for causality in both mean and variance, we incorporate a weighted cross-correlation coefficient into the CCF model proposed by Cheung and Ng (1996) and Hong (2001) according to the following two-step procedure. In the first step, we estimate a set of univariate time-series models to calculate the time-varying conditional mean and variance. In this step, an autoregressive (AR) model

[3]We summarize the empirical results on China in the appendix.

Table 1: Descriptive Statistics for the Global Financial Crisis Period

	Japan			South Korean			Taiwan		
Market	**FX**	**ST**	**CM**	**FX**	**ST**	**CM**	**FX**	**ST**	**CM**
Mean	−0.00044	−0.00109	−0.00133	0.00042	−0.00027	0.0006	−0.00002	−0.00031	−0.00034
Std. Dev.	0.00879	0.02072	0.02530	0.01212	0.02028	0.0308	0.00315	0.01837	0.01985
Skewness	−0.70839	-0.10900	−0.03865	−0.80147	−0.43695	0.06609	−0.50372	−0.16367	0.13327
Kurtosis	6.30682	7.68261	8.16016	18.2173	8.10338	5.41419	9.35082	4.22005	4.66652
Jarque-Bera	316.549	537.457	651.406	5726.63	655.685	142.978	1011.30	39.0275	69.6654
Probability	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00002	0.00031	0.00034

Notes: FX, foreign exchange market; ST, stock market; CM, commodity market. The table values are calculated based on the first differences of logarithmic closing prices.

Table 2: Descriptive Statistics for the European Sovereign Debt Crisis Period

	Japan			South Korean			Taiwan		
Market	**FX**	**ST**	**CM**	**FX**	**ST**	**CM**	**FX**	**ST**	**CM**
Mean	−0.00012	−0.00015	−0.00019	−0.00010	0.00025	0.00055	−0.00014	0.00002	−0.00009
Std. Dev.	0.00602	0.01166	0.01582	0.00574	0.01216	0.02276	0.00251	0.01118	0.01460
Skewness	0.58412	−0.87588	−0.33402	0.75541	−0.52224	−0.38200	0.01756	−0.48391	−0.13501
Kurtosis	6.39189	12.4204	15.0040	8.35346	6.17346	6.50432	6.67096	5.20768	5.17739
Jarque-Bera	430.064	3068.10	4830.14	1033.98	372.990	429.872	450.362	194.169	160.866
Probability	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000

Notes: FX, foreign exchange market; ST, stock market; CM, commodity market. The table values are calculated based on the first differences of the logarithmic closing prices.

Table 3: Unconditional Correlation Matrix for the Global Financial Crisis Period

	Japan			South Korea			Taiwan		
Market	**FX**	**ST**	**CM**	**FX**	**ST**	**CM**	**FX**	**ST**	**CM**
FX	1.00000			1.00000			1.00000		
Stock	0.33856	1.00000		−0.16435	1.00000		−0.41151	1.00000	
Commodity	0.33099	0.91187	1.00000	−0.12451	0.76949	1.00000	−0.32982	0.73584	1.00000

Notes: FX, foreign exchange market; ST, stock market; CM, commodity market. The table values are calculated based on the first differences of the logarithmic closing prices.

Table 4: Unconditional Correlation Matrix for the European Sovereign Debt Crisis Period

	Japan			South Korea			Taiwan		
Market	**FX**	**ST**	**CM**	**FX**	**ST**	**CM**	**FX**	**ST**	**CM**
FX	1.00000			1.00000			1.00000		
Stock	0.21290	1.00000		−0.06127	1.00000		−0.53547	1.00000	
Commodity	0.19293	0.91465	1.00000	−0.07006	0.77570	1.00000	−0.39297	0.67663	1.00000

Notes: FX, foreign exchange market; ST, stock market; CM, commodity market. The table values are calculated based on the first differences of the logarithmic closing prices.

was used for the conditional mean and an exponential generalized autoregressive conditional heterosked-asticity (EGARCH) model (Nelson, 1991) for the conditional variance. The AR(*k*)-EGARCH(*p*, *q*) specification is expressed as follows:

$$x_t = a_0 + \sum_{i=1}^{k} a_i x_{t-i} + \varepsilon_t, E_{t-1}(\varepsilon_t) = 0, E_{t-1}(\varepsilon_t^{\,2}) = \sigma^2 \quad (1)$$

and

$$\text{In}\,(\sigma_t^2) = \omega + \sum_{i=1}^{p} (\alpha_i \left|\varepsilon_{t-1} / \sigma_{t-i}\right| + \gamma_i \varepsilon_{t-i} / \sigma_{t-i}) + \sum_{i=1}^{q} \beta i \,\text{In}(\sigma_{t-i}^2) \quad (2)$$

where E_{t-1} is the conditional information operator based on the information at time *t*-1. Eq. (1), the AR(*k*) model, indicates that the current movement of the variable x_t can be explained by its own past movement $(x_{t-1}, x_{t-2}, \ldots)$. Eq. (2), the EGARCH (*p*,*q*) model, describes the asymmetry of markets, and the sign of past shocks (good news or bad news) has different effects on volatility. We assume the error term follows a generalized error distribution (GED). The maximum likelihood method was used to estimate each model. The Schwarz Bayesian information criterion (SBIC) was used to choose the AR terms. The Ljung-Box Q test was applied to examine the residuals of the AR term. According to the SBIC and residual diagnostics, the values of *k*, *p*, and *q* range as follows: *k*=1,2,…,15; *p*=1,2; and q=1,2. In this step, we try to find the direction and degree of causality between variables.

In the second step, we applied the Cheung-Ng (1996) testto examine the causality in both mean and variance based on the standardized residuals from the first step. Consider two stationary time series, X_t and Y_t. Let H_t, I_t, and J_t be three information sets defined by $H_t = (X_{t-j};\, j \geq 0)$, $I_t = (Y_{t-j};\, j \geq 0)$, and $J_t = (X_{t-j}, Y_{t-j};\, j \geq 0)$. Y_t is said to cause X_t in mean if

$$E\left[X_t \middle| H_{t-1}\right] \neq E\left[X_t \middle| J_{t-1}\right] \quad (3)$$

Similarly, X_t is said to cause Y_t in mean if

$$E\left[Y_t \middle| H_{t-1}\right] \neq E\left[Y_t \middle| J_{t-1}\right] \quad (4)$$

Feedback in mean occurs if X_t causes Y_t and Y_t causes X_t. In the same way, Y_t causes X_t in variance if

$$E\left[(X_t - \mu_{x,t})^2 \middle| H_{t-1}\right] \neq E\left[(X_t - \mu_{x,t})^2 \middle| J_{t-1}\right] \quad (5)$$

where $\mu_{x,t}$ is the mean of X_t conditional on H_{t-1}. Similarly, Y_t causes X_t in variance if

$$E\left[(Y_t - \mu_{y,t})^2 \middle| I_{t-1}\right] \neq E\left[(Y_t - \mu_{y,t})^2 \middle| J_{t-1}\right] \quad (6)$$

where $\mu_{y,t}$ is the mean of Y_t conditional on I_{t-1}. Feedback in mean occurs if X_t causes Y_t or vice versa. These kinds of causality in variance provide a method to investigate a directional relationship with volatility spillover across different assets or markets.

Suppose X_t and Y_t are defined as follows:

$$X_t = \mu_{x,t} + h_{x,t}^{0.5} \varepsilon_t \quad (7)$$

and

$$Y_t = \mu_{y,t} + h_{y,t}^{0.5} \zeta_t \quad (8)$$

where ε_t and ζ_t are two independent white-noise processes with zero mean and unit variance. For the causality-in-mean test, the following standardized innovations were used:

$$\varepsilon_t = (X_t - \mu_{x,t}) / h_{x,t}^{0.5} \quad (9)$$

and

$$\zeta_t = (Y_t - \mu_{y,t}) / h_{y,t}^{0.5} \quad (10)$$

Since both ε_t and ζ_t are unobservable, their estimations $\hat{\varepsilon}_t$ and $\hat{\zeta}_t$ were used to evaluate Eqs. (3)−(4).Subsequently, the cross-correlation coefficient at lag *k*, $\hat{r}_{\varepsilon,\zeta}(k)$, can be estimated from the consistent estimates of the conditional mean and variance of X_t and Y_t. This computation yields

$$\hat{r}_{\varepsilon,\zeta}(k) = c_{\varepsilon,\zeta}(k) / \sqrt{c_{\varepsilon,\varepsilon}(0)\, c_{\zeta,\zeta}(0)} \quad (11)$$

where $c_{\varepsilon,\zeta}(k)$ is the *k*th lag sample cross-covariance given by

$$c_{\varepsilon,\zeta}(k) = T^{-1} \sum (\hat{\varepsilon}_t - \bar{\varepsilon})(\hat{\zeta}_t - \bar{\zeta}), k = 0, \pm 1, \pm 2, \ldots, \quad (12)$$

and $c_{\varepsilon,\varepsilon}(0)$ and $c_{\zeta,\zeta}$ are the sample variances of $\hat{\varepsilon}_t$ and $\hat{\zeta}$, respectively. Given the asymptotic behavior of $\hat{r}_{\varepsilon,\zeta}(k)$, a normal test statistic or a chi-square test statistic can be constructed to test the null hypothesis of no causality. To test for a causal relationship at a specified lag *k*, we defined the following chi-square test statistic to exam the squared standardized residual CCF:

$$S_1 = \sum_{i=j}^{k} \hat{r}_{\varepsilon\beta}^2(i) \quad (13)$$

which has a chi-square distribution with *k*−*j*+1 degrees of freedom and can be used to test the null hypothesis of no causality in mean from lag *j* to lag *k*.

For the test of causality in variance, let u_t and v_t be the squares of standardized innovations,

$$u_t = (X_t - \mu_{x,t})^2 / h_{x,t} = \varepsilon_t^2 \quad (14)$$

and

$$v_t = (Y_t - \mu_{x,t})^2 / h_{y,t} = \varepsilon_t^2 \quad (15)$$

Since both u_t and v_t are unobservable, their estimations $\hat{\varepsilon}_t$ and $\hat{\zeta}_t$ were used to evaluate Eqs. (5)−(6). Subsequently, the cross-correlation coefficient at lag *k*, $\hat{r}_{u,v}(k)$ can be estimated from the consistent estimates of the conditional mean and variance of X_t and Y_t. This computation yields

$$\hat{r}_{u,v}(k) = c_{u,v}(k) / \sqrt{c_{u,u}(0)\, c_{v,v}(0)} \quad (16)$$

where $c_{\varepsilon,\zeta}(k)$ is the *k*th lag sample cross-covariance given by

$$c_{u,v}(k) = T^{-1} \sum (\hat{u}_t - \overline{u})(\hat{v}_t - \overline{v}),\ k = 0, \pm 1, \pm 2, \ldots, \quad (17)$$

and $c_{u,u}(0)$ and $c_{v,v}(0)$ are the sample variances of $\hat{u}_t$ and $\hat{v}_t$, respectively. Given the asymptotic behavior of $\hat{r}_{u,v}(k)$, a normal test statistic or a chi-square test statistic can be constructed to test the null hypothesis of no causality. To test for a causal relationship at a specified lag *k*, we defined following chi-square test statistic to exam the squared standardized residual CCF:

$$S_2 = \sum_{i=j}^{k} \hat{r}_{uv}^2(i) \quad (18)$$

which has a chi-square distribution with *k*−*j*+1 degrees of freedom and can be used to test the null hypothesis of no causality in mean from lag *j* to lag *k*.

Cheung and Ng (1996) pointed out that the test statistic may be subject to severe size distortion in the presence of causality in mean. Hence, we incorporated the weighted cross-correlation suggested by Hong (2001) into the CCF approach. Then, the test statistics for causality in mean and causality in variance can be rearranged as follows:

$$M_1 = (S_1 - k) / \sqrt{2k} \quad (19)$$

and

$$M_2 = (S_2 - k) / \sqrt{2k} \quad (20)$$

which follow a normal distribution with zero mean and unit variance. Since M_1 and M_2 are one-sided tests, upper-tailed *N*(0,1) critical values must be used. For example, the asymptotic critical value at the 1% level is 2.326. If the test statistic is larger than the critical value of the normal distribution, the null hypothesis is rejected. In the following section, we use M_1 and M_2 to test for causality in mean and causality in variance, respectively, across the markets of Northeast Asian countries in both financial crisis periods.

4. EMPIRICAL RESULTS

4.1. The Global Financial Crisis Period

This section summarizes the results from the AR-EGARCH models for the global financial crisis period. Table **5** presents the empirical results of the foreign exchange, stock, and commodity markets for all the countries. As indicated in this table, all coefficients of the GARCH term (β) with values less than one are statistically significant at the 1% level. The coefficients of asymmetric effect (γ) are statistically significant at the 1% level with negative values expect for the Korean foreign exchange market. In addition, they are statistically significant at the 1% level for Chinese and Taiwanese stock markets and at the 5% level for the Chinese commodity market. No other markets show asymmetry. Moreover, the GED parameters in both tables are statistically significant at the 1% level with values less than two, suggesting that the tails of the error terms are heavier than those of the normal distribution and that ARCH effects are present.

Table **5** also shows $Q(s)$ and $Q^2(s)$ statistics to justify the empirical results of the AR-EGARCH models. The $Q(s)$ statistic at lag *s* is a test statistic, which has an asymptotic chi-square distribution with degrees of freedom equal to the number of autocorrelations less the number of parameters. Its null hypothesis assumes that there is no autocorrelation up to lag *s* for standardized residuals. The $Q^2(s)$ statistic at lag *s* proposes a null hypothesis of no autocorrelation up to order *s* for standardized squared residuals. According to Table **5**, the null hypothesis of no autocorrelation up to order 20 for standardized residuals and standardized squared residuals is accepted for all countries, supporting our model specifications.

The sample cross-correlations of standardized residuals and standardized squared residuals are presented in Table **6**. In particular, we set *k* equal to 5 for our analysis. Table **6** presents the empirical results of causality among the markets in these countries. M_1 and M_2, if statistically significant at the 1% level, show

Table 5: Empirical Results of the AR-EGARCH Models for the Global Financial Crisis Period

	Japan			South Korea			Taiwan		
Market	**FX**	**ST**	**CM**	**FX**	**ST**	**CM**	**FX**	**ST**	**CM**
model	**G(1, 1, 1)**	**G(4, 1, 1)**	**G(7, 1, 1)**	**G(4, 1, 1)**	**G(8, 1, 1)**	**G(1, 1, 1)**	**G(1, 1, 1)**	**G(13, 1, 1)**	**G(1, 1, 1)**
Mean equation									
a_0	−0.000	−0.000	−0.001	0.000	−0.000	0.000	0.000	0.001	−0.000
	(0.000)	(0.000)	(0.001)	(0.000)	(0.000)	(0.001)	(0.000)	(0.001)	(0.001)
a_1	−0.078**	−0.021	0.007	0.053	0.030	0.077***	0.073***	0.012	0.077*
	(0.040)	(0.043)	(0.044)	(0.041)	(0.041)	(0.034)	(0.028)	(0.037)	(0.042)
a_2		0.001	−0.035	0.065	0.009			0.045	
		(0.040)	(0.044)	(0.039)	(0.038)			(0.036)	
a_3		−0.054	−0.051	−0.019	0.044			0.027	
		(0.040)	(0.043)	(0.040)	(0.039)			(0.036)	
a_4		0.064*	0.030	0.064*	0.008			−0.023	
		(0.039)	(0.041)	(0.038)	(0.036)			(0.034)	
a_5			0.036		0.010			−0.029	
			(0.041)		(0.035)			(0.033)	
a_6			−0.024		0.010			−0.002	
			(0.043)		(0.037)			(0.034)	
a_7			−0.070**		0.063			0.047	
			(0.043)		(0.038)			(0.032)	
a_8					0.061*			0.036	
					(0.037)			(0.032)	
a_9								−0.020	
								(0.034)	
a_{10}								0.013	
								(0.032)	
a_{11}								−0.042	
								(0.032)	
a_{12}								−0.009	
								(0.033)	
a_{13}								0.111***	
								(0.021)	
Variance equation									
ω	−0.351*	−0.252***	−0.353***	−0.459***	−0.280***	−0.755***	−1.099***	−0.326***	−4.062***
	(0.211)	(0.093)	(0.129)	(0.112)	(0.079)	(0.222)	(0.340)	(0.092)	(0.129)
α_1	0.087**	0.097***	0.199***	0.361**	0.086**	0.132**	0.472***	0.090*	0.390***
	(0.043)	(0.036)	(0.055)	(0.067)	(0.037)	(0.062)	(0.097)	(0.049)	(0.121)
γ_1	−0.055**	−0.109***	−0.068***	0.063**	−0.192***	−0.235**	0.016	−0.081***	−0.064
	(0.023)	(0.023)	(0.022)	(0.032)	(0.036)	(0.058)	(0.057)	(0.032)	(0.080)
β_1	0.970***	0.979***	0.975***	0.980***	0.974***	0.908***	0.933***	0.968***	0.521***
	(0.021)	(0.010)	(0.013)	(0.009)	(0.008)	(0.029)	(0.058)	(0.015)	(0.172)
GED parameter	1.361***	1.507***	1.726***	1.147***	1.353***	1.104***	0.951***	1.147***	1.191***
	(0.085)	(0.131)	(0.164)	(0.091)	(0.120)	(0.079)	(0.027)	(0.113)	(0.099)
Diagnostic									
Q(20)	23.660	8.2329	14.344	26.196	10.648	13.287	25.237	21.696	22.953
	[0.258]	[0.990]	[0.813]	[0.159]	[0.955]	[0.865]	[0.193]	[0.357]	[0.291]
$Q^2(20)$	23.112	33.429	26.402	17.248	13.804	20.517	12.954	24.060	15.334
	[0.283]	[0.300]	[0.153]	[0.637]	[0.840]	[0.426]	[0.879]	[0.240]	[0.757]

Notes: FX, foreign exchange market; ST, stock market; CM, commodity market; G (k, p, q), AR (k)-GARCH (p, q). The numbers given in parentheses are standard errors. The numbers given in square brackets are p-values. *Q*(20) is the Ljung-Box *Q* statistic for the null hypothesis of no autocorrelation up to order 20 for standardized residuals. $Q^2(20)$ is the Ljung-Box *Q* statistic for the null hypothesis of no autocorrelation up to order 20 for standardized squared residuals.
*Significant at the 10% level.
**Significant at the 5% level.
***Significant at the 1% level.

Table 6: Test Statistics for Causality in Mean and Causality in Variance for the Global Financial Crisis Period

	M_1 (causality in mean)			M_2 (causality in variance)		
Market	**FX→ST**	**ST→CM**	**FX→CM**	**FX→ST**	**ST→CM**	**FX→CM**
Panel A						
South Korea	0.1342	−0.6538	−0.8193	7.5176***	−0.7904	0.9329
Japan	18.304***	−1.2724	15.060***	3.5584***	0.0715	5.3819***
Taiwan	1.0434	−0.0882	0.4219	−1.0946	1.3503	0.3604
Market	**FX←ST**	**ST←CM**	**FX←CM**	**FX←ST**	**ST←CM**	**FX←CM**
Panel B						
South Korea	30.244***	−0.8804	11.547***	31.540***	−0.9457	10.543***
Japan	13.572***	−1.1319	0.0205	−1.2710	2.8222***	−0.6639
Taiwan	0.8593	−0.3159	−0.6830	−0.0395	1.0692	0.0286

Notes: FX, foreign exchange market; ST, stock market; CM, commodity market. This table reports test statistics for causality in mean and causality in variance for X⇔Y. For example, FX→ST indicates that the foreign exchange market Granger-causes the stock market, while FX←ST indicates that the stock market Granger-causes the foreign exchange market.
***Significant at the 1% level.

causality in mean and variance, respectively, among the markets in these countries. Table **6**, shows no causality in mean or variance in Taiwanese financial markets. Likewise, Korean financial markets do not show a close relationship in either meanor variance. The table shows, for example, one-way causality in mean and variance from the stock and commodity markets to the foreign exchange market. Moreover, the causality-in-variance test indicates that volatility in the foreign exchange market causes volatility in the stock market as well. In the case of Japan, we find interactions between the stock and foreign exchange markets as well as one-way causality in mean and variance from the foreign exchange market to the commodity market. Moreover, we detect causality in mean and variance from the commodity market to the stock market.

4.2. The European Sovereign Debt Crisis Period

This section summarizes the empirical results based on the European sovereign debt crisis subsample. Table **7** presents the empirical results for the Chinese and Japanese financial markets. As indicated in this table, all coefficients of the GARCH term (β) with values less than one are statistically significant at the 1% level. Likewise, coefficients of asymmetric effect (γ) with negative values are statistically significant at the 5% level in the Taiwanese and Japanese foreign exchange markets and at the 1% level in other markets.

Moreover, GED parameter values less than twoare statistically significant at the 1% level in both tables, suggesting that the tails of the error terms are heavier than those of the normal distribution and that ARCH effects are present.

Table **8** presents empirical results for causality among the markets in Japan, South Korea, and Taiwan. For South Korea, the results show one-way causality in mean and variance from the stock and commodity markets to the foreign exchange market. The global financial crisis influenced the South Korean stock market more than the European sovereign debt crisis did because the causality in variance from the foreign exchange market to the stock market disappeared during the European sovereign debt crisis.

Japan shows interactions between the stock market and foreign exchange market as well as one-way causality in mean and variance from the foreign exchange market to the commodity market. Moreover, we detect causality in variance from the commodity market to the stock and foreign exchange markets. Comparing the results for both periods, we observe that the higher the degree of interaction among financial markets in Japan, the greater the causality in variance; however, causality in mean remains unchanged. The results reflect the fact that Japanese investors hold more European sovereign bonds than subprime securities, since the causality in variance of financial markets increases even though the causality in mean does not change. For a better comparison, we

Table 7: Empirical Results of the AR-EGARCH Models for the European Sovereign Debt Crisis Period

	Japan			South Korea			Taiwan		
Market	**FX**	**ST**	**CM**	**FX**	**ST**	**CM**	**FX**	**ST**	**CM**
Model	**G(1, 1, 1)**	**G(5, 1, 1)**	**G(1, 1, 1)**	**G(1, 1, 1)**	**G(7, 1, 1)**	**G(14, 1, 1)**	**G(14, 1, 1)**	**G(6, 1, 1)**	**G(7, 1, 1)**
Mean Equation									
a_0	−0.000	−0.000	−0.000	−0.000	0.000	0.001	−0.000	0.001	0.000
	(0.000)	(0.000)	(0.001)	(0.000)	(0.000)	(0.001)	(0.000)	(0.000)	(0.000)
a_1	−0.084***	0.020	0.062	0.065*	−0.030	0.018	0.005	0.043	−0.003
	(0.032)	(0.038)	(0.035)	(0.036)	(0.035)	(0.036)	(0.032)	(0.033)	(0.032)
a_2		0.037			0.006	0.046	0.034	−0.005	0.015
		(0.034)			(0.035)	(0.035)	(0.032)	(0.037)	(0.031)
a_3		0.062			0.045	−0.0432	−0.035	−0.006	0.032
		(0.037)			(0.034)	(0.036)	(0.031)	(0.031)	(0.030)
a_4		−0.015			−0.018	−0.033	−0.011	−0.021	−0.021
		(0.033)			(0.034)	(0.034)	(0.029)	(0.030)	(0.031)
a_5		−0.066**			−0.016	0.035	−0.019	0.037	−0.004
		(0.033)			(0.033)	(0.034)	(0.028)	(0.030)	(0.029)
a_6					−0.051	−0.044	−0.002	−0.081***	−0.044
					(0.032)	(0.033)	(0.029)	(0.029)	(0.030)
a_7					0.054*	−0.000	0.039		0.064**
					(0.032)	(0.034)	(0.028)		(0.023)
a_8						−0.004	−0.032		
						(0.034)	(0.027)		
a_9						0.011	0.018		
						(0.034)	(0.027)		
a_{10}						0.020	−0.003		
						(0.035)	(0.026)		
a_{11}						0.039	−0.032		
						(0.033)	(0.026)		
a_{12}						−0.012	−0.014		
						(0.033)	(0.026)		
a_{13}						0.002	0.024		
						(0.034)	(0.024)		
a_{14}						0.106***	0.044*		
						(0.034)	(0.025)		
Variance Equation									
ω	−0.579*	−1.171***	−0.923***	−0.324***	−0.407***	−0.280***	−1.189***	−1.144***	−0.783***
	(0.337)	(0.268)	(0.182)	(0.105)	(0.103)	(0.104)	(0.382)	(0.297)	(0.247)
α_1	0.122***	0.056	0.101**	0.173***	0.069*	0.127***	0.346***	0.077*	0.172***
	(0.047)	(0.042)	(0.041)	(0.035)	(0.040)	(0.038)	(0.061)	(0.049)	(0.051)
γ_1	−0.045**	−0.219***	−0.226***	0.070***	−0.191***	−0.061***	−0.048	−0.222***	−0.148***
	(0.028)	(0.033)	(0.034)	(0.023)	(0.035)	(0.0267)	(0.037)	(0.043)	(0.039)
β_1	0.952***	0.876***	0.901***	0.982***	0.961***	0.977***	0.923***	0.883***	0.924***
	(0.031)	(0.030)	(0.021)	(0.009)	(0.010)	(0.012)	(0.029)	(0.032)	(0.027)
GED parameter	1.198***	1.741***	1.659***	0.818***	1.396***	1.416***	1.040***	1.226***	1.168***
	(0.075)	(0.103)	(0.112)	(0.040)	(0.092)	(0.112)	(0.067)	(0.095)	(0.077)
Diagnostic									
Q(20)	17.720	12.060	8.9381	27.383	11.249	5.9377	27.383	11.249	5.9377
	[0.606]	[0.914]	[0.984]	[0.125]	[0.940]	[0.999]	[0.125]	[0.940]	[0.999]
$Q^2(20)$	10.361	27.291	28.257	17.961	16.206	25.760	17.961	16.206	25.760
	[0.961]	[0.127]	[0.103]	[0.590]	[0.704]	[0.174]	[0.590]	[0.704]	[0.174]

Notes: FX, foreign exchange market; ST, stock market; CM, commodity market; G (k, p, q), AR (k)-GARCH (p, q). The numbers given in parentheses are standard errors. The numbers given in square brackets are p-values. *Q*(20) is the Ljung-Box *Q* statistic for the null hypothesis of no autocorrelation up to order 20 for standardized residuals. $Q^2(20)$ is the Ljung-Box *Q* statistic for the null hypothesis of no autocorrelation up to order 20 for standardized squared residuals.
*Significant at the 10% level.
**Significant at the 5% level.
***Significant at the 1% level.

Table 8: Test Statistics for Causality in Mean and Causality in Variance for the European Sovereign Debt Crisis Period

	M_1 (causality in mean)			M_2 (causality in variance)		
Market	**FX→ST**	**ST→CM**	**FX→CM**	**FX→ST**	**ST→CM**	**FX→CM**
Panel A						
South Korea	−0.8374	−0.6389	−0.9001	−0.8812	−0.1834	0.9911
Japan	8.5463***	−0.8081	6.1604***	2.9632***	1.5373	2.9632***
Taiwan	1.4857	−0.1269	−0.0472	0.8219	−0.7405	0.0679
Market	**FX←ST**	**ST←CM**	**FX←CM**	**FX←ST**	**ST←CM**	**FX←CM**
Panel B						
South Korea	82.070***	−0.5994	27.397***	27.660***	−0.5850	156.45***
Japan	2.2298**	−0.9174	−0.8081	6.0946***	2.9598***	3.4151***
Taiwan	1.5605	−0.3242	0.3341	0.8336	−0.8880	−0.8132

Notes: FX, foreign exchange market; ST, stock market; CM, commodity market. This table reports test statistics for causality in mean and causality in variance for X⇔Y. For example, FX→ST indicates that the foreign exchange marketGranger-causes the stock market, while FX←ST indicates that the stock market Granger-causesthe foreign exchange market.
**Significant at the 5% level.
***Significant at the 1% level.

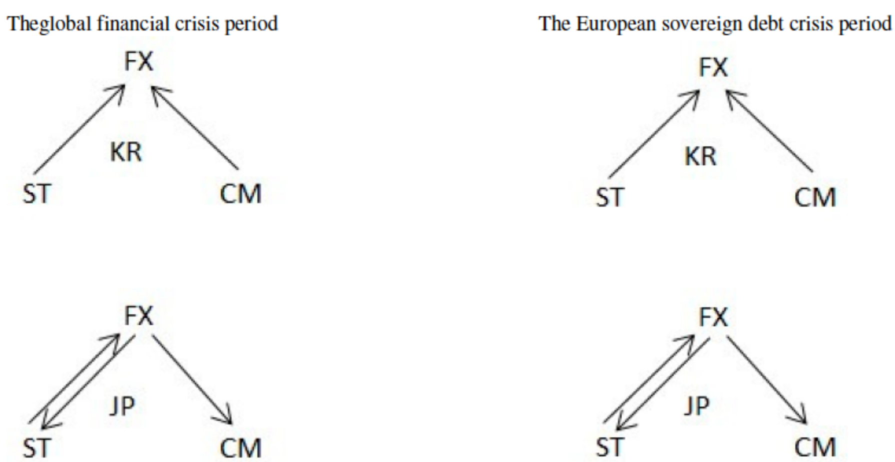

Figure 1: Causality in mean among markets in Northeast Asian countries.

Notes: CN, China; KR, Korea; JP, Japan. X→Y indicates X Granger-causes Y.

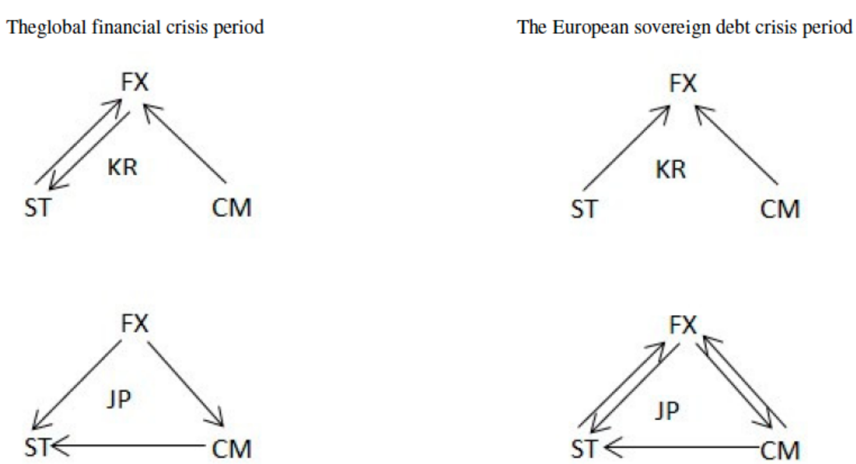

Figure 2: Causality in variance among markets in Northeast Asian countries.

Notes: CN, China; KR, Korea; JP, Japan. X→Y indicates X Granger-causes Y.

illustrate these types of causality relationships in both Figures **1** and **2**. Since the Taiwanese markets show no causality in mean or variance for both periods, we do not illustrate the results here.

To summarize our findings, the causality in mean for foreign exchange, stock, and commodity market returns in Northeast Asian countries do not change, indicating that we do not need to consider the influence of returns from other financial markets while designing investment portfolios for these countries during crisis periods. However, to serve the best interests of investors, portfolio managers should optimize investment portfolios by reducing the risk of volatility during crisis periods with due consideration to the influence of changes in the variance of returns from other financial markets.

5. CONCLUSION

In this paper, we examine causality relationships in mean and variance among the foreign exchange, stock, and commodity markets in Northeast Asian countries based on a test proposed by Hong (2001). This paper aimed to investigate the effects of two different financial crises on the domestic financial markets. Our empirical results indicate a high degree of interaction among the Japanese financial markets during the European sovereign crisis. However, South Korean financial markets show a low degree of interaction during the European sovereign crisis based on causality in variance. Finally, no interaction pattern changes are detected in the Taiwanese financial markets during both crises.

An examination of causality in the mean and variance of financial market returns in Northeast Asian countries would provide insights into the risk-return trade-offer investment portfolio optimization with movement of returns in a single market as well as co-movement of returns in multiple markets. Moreover, we still notice spillover effects not just in a single financial market but across multiple markets in Northeast Asian financial countries.

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APPENDIX

The Chinese government, through its 2005 currency reform, changed the U.S. dollar-pegged foreign

Table A1: Descriptive Statistics

China	The global financial crisis period			The European sovereign debt crisis period		
Market	**FX**	**ST**	**CM**	**FX**	**ST**	**CM**
Mean	−0.000174	−0.000667	−0.000750	−0.000118	−0.000573	−0.000963
Std. dev.	0.000914	0.023433	0.026062	0.001116	0.001116	0.017078
Skewness	−0.045977	−0.108458	−0.159995	−0.189894	−0.189894	−0.276286
Kurtosis	6.568991	4.495788	3.381287	9.171581	9.171581	3.569091
Jarque-Bera	311.7496	55.87348	6.060130	1277.608	1277.608	21.02578
Probability	0.000000	0.000000	0.048312	0.000000	0.000000	0.000027

Notes: FX, foreign exchange market; ST, stock market; CM, commodity market. The table values are calculated using the first differences of the logarithmic closing prices.

Table A2: Unconditional Correlation Matrix

China	The global financial crisis period			The European sovereign debt crisis period		
Market	**FX**	**ST**	**CM**	**FX**	**ST**	**CM**
FX	1.000000			1.000000		
Stock	−0.017782	1.000000		−0.120694	1.000000	
Commodity	0.011599	0.818872	1.000000	−0.091230	0.830703	1.000000

Notes: FX, foreign exchange market; ST, stock market; CM, commodity market. The table values are calculated using the first differences of the logarithmic closing prices.

exchange system to a floating rate regime. Arguably, fluctuations of the yuan in the foreign exchange market not only reflect comparative advantages of the United States and China but also offer potential benefits for the domestic economy of China. However, the reason we illustrate the empirical results of China in this appendix is that, although the foreign exchange market is still subject to strong intervention by the Chinese government, the market does reflect economic prospects. Thus, the causality relationships disclosed by our econometric approach can hardly determine whether government behaviors are market driven. We summarize our findings on Chinese markets here because the country is the biggest economy in Asia and our major research concern. Furthermore, we use similar data types and the same analytical approach to investigate the interaction among Chinese financial markets as we did for other countries to allow comparison of our results across countries. To put it simply, our empirical results on the European sovereign debt crisis show that the interaction among the Chinese financial markets increase in both mean and variance.

Table A3: Empirical Results of the AR-EGARCH Models

China	The global financial crisis period			The European sovereign debt crisis period		
Market	FX	ST	CM	FX	ST	CM
Model	G(12, 1, 1)	G(3, 1, 1)	G(1, 1, 1)	G(5, 1, 1)	G(4, 1, 1)	G(6, 1, 1)
Mean equation						
a_0	0.0000 (0.0000)	0.0007 (0.0008)	0.0010 (0.0008)	0.0000 (0.0000)	−0.0005 (0.0004)	−0.0005 (0.0006)
a_1	−0.0193 (0.0400)	−0.0137 (0.0381)	0.1523*** (0.0372)	−0.0803*** (0.0249)	−0.0241 (0.0258)	0.0393 (0.0369)
a_2	−0.0060 (0.0308)	0.0005 (0.0372)		−0.0009 (0.0182)	−0.0117 (0.0277)	−0.0114 (0.0352)
a_3	0.0368 (0.0305)	0.0751** (0.0366)		−0.0033 (0.0208)	0.0402 (0.0281)	0.0186 (0.0341)
a_4	0.0461 (0.0303)			−0.0030 (0.0206)	−0.0887*** (0.0273)	−0.0266 (0.0329)
a_5	0.0492 (0.0302)			−0.0359* (0.0213)		0.0096 (0.0338)
a_6	0.0435 (0.0300)					−0.0560* (0.0323)
a_7	0.0110 (0.0297)					
a_8	0.0204 (0.0303)					
a_9	−0.0046 (0.0292)					
a_{10}	0.0112 (0.0292)					
a_{11}	0.0224 (0.0288)					
a_{12}	−0.0544* (0.0287)					
Variance equation						
ω	−0.1809** (0.1116)	−0.6737*** (0.0791)	−0.9242*** (0.2221)	−0.4013*** (0.0841)	−4.6517** (2.0151)	−2.7937** (1.2339)

α_1	0.1859** (0.0540)	0.1248** (0.0553)	0.2208*** (0.0711)	0.3656*** (0.0499)	−0.1033 (0.1008)	0.2099** (0.0929)
γ_1	0.1226 (0.0566)	−0.1270*** (0.0410)	−0.1226** (0.0566)	0.0381 (0.0388)	−0.2012*** (0.0652)	−0.0928* (0.0547)
β_1	0.9973*** (0.0045)	0.9241*** (0.0290)	0.8962*** (0.0439)	0.9881*** (0.0051)	0.0922 (0.0699)	0.6772*** (0.1466)
β_2					0.4605** (0.2326)	
GED parameter	0.9514*** (0.0555)	1.1980*** (0.1095)	1.1467*** (0.1105)	0.9514*** (0.0265)	1.1471*** (0.1125)	1.1914*** (0.0989)
Diagnostic						
Q(20)	9.0029 [0.983]	22.123 [0.334]	21.748 [0.354]	25.237 [0.193]	21.696 [0.357]	22.953 [0.291]
$Q^2(20)$	1.4702 [1.000]	16.753 [0.669]	13.877 [0.837]	12.954 [0.879]	24.060 [0.240]	15.334 [0.757]

Notes: FX, foreign exchange market; ST, stock market; CM, commodity market; G (k, p, q), AR (k)-GARCH (p, q). The numbers given in parentheses are standard errors. The numbers given in square brackets are the p-values. *Q*(20) is the Ljung-Box *Q* statistic for the null hypothesis of no autocorrelation up to order 20 for standardized residuals. $Q^2(20)$ is the Ljung-Box *Q* statistic for the null hypothesis of is no autocorrelation up to order 20 for standardized squared residuals.
*Significant at the 10% level.
**Significant at the 5% level.
***Significant at the 1% level.

Table A4: Test Statistics for Causality in Mean and Causality in Variance for the Global Financial Crisis Period

China	M_1 (causality in mean)			M_2 (causality in variance)		
Market	**FX→ST**	**ST→CM**	**FX→CM**	**FX→ST**	**ST→CM**	**FX→CM**
Panel A						
The global financial crisis period	0.6568	1.5831	−0.4059	−0.6510	−1.3838	−1.0885
The European sovereign debt crisis period	−1.0660	4.6392***	2.7146***	−1.4945	38.508***	−0.9328
Market	**FX←ST**	**ST←CM**	**FX←CM**	**FX←ST**	**ST←CM**	**FX←CM**
Panel B						
The global financial crisis period	0.1506	−0.1931	0.1149	0.4750	−0.6727	0.0589
The European sovereign debt crisis period	−0.7828	−0.0901	2.6714***	−1.3490	−0.2232	1.9755**

Notes: FX, foreign exchange market; ST, stock market; CM, commodity market. This table reports test statistics for causality in mean and variance for X⇔Y. For example, FX→ST indicates that foreign exchange market Granger-causes the stock market, while FX←ST indicates that the stock market Granger-causesthe foreign exchange market.
**Significant at the 5% level.
***Significant at the 1% level.

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