Extreme Risk Spillover in Financial Markets: Evidence from the Recent Financial Crisis

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This paper evaluates the data from the recent financial crisis to examine the risk spillover effects of financial markets value at risk (VaR), which captures the extreme behavior of an asset, is considered a measure of risk in an asset or in a market. We hypothesize that an extreme downside movement of returns in a market measured by a VaR has negative effects on other markets, causing a similar movement of returns in the latter. In particular, we postulate that in the recent crisis, an extreme downside movement in a major market affected other markets, and that these effects intensified. Our empirical results based on the data from several countries with various markets confirm these postulates.

Keywords: Global Financial Crisis, Risk Spillover, Value at Risk

JEL Classification: C11, C14, C2, C3, C5

I. Introduction

We often see that some negative shocks in a financial market have similar effects on other markets with lags of certain length. If markets were perfectly segregated, this kind of effect is not observed. In reality, however, international financial markets have become increasingly inter-dependent because of recent trends of capital liberalization and market

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integration, among other reasons. Kose, Otrok, and Whiteman (2010), for example, report the existence of a common world factor, which is an important source of business cycles in most countries. They also note that the influence of common factors tends to increase during this period of financial globalization.

The recent global financial crisis originated in the world's largest economy: the U.S. (Cheung *et al.* 2010). Recent studies, such as that of Longstaff (2010), examined the effects of the subprime asset-backed CDO (collateralized debt obligation) market on other financial markets. Cheung *et al.* (2010) noted that shocks from the U.S. market promptly spilled over into foreign markets, including both developed and emerging markets. These studies are based on the test of Granger causality in the mean. Engle *et al.* (1990), Ng (2000), and Hong *et al.* (2001), by contrast, used variance as a measure of financial risk for risk spillover analysis. However, analyses based on the mean and variance have clear limitations. That is, analyses based on the mean cannot adequately capture the riskiness of financial assets. In addition, analyses based on the variance cannot investigate asymmetric movements in risks nor the heavy tail properties of financial variables.

In this paper, we study risk spillover based on downside values at risk (VaR). VaR was originally proposed by J.P. Morgan (1994) and has become a standard measure for controlling and monitoring downside market risk. This measure indicates the degree to which the underlying financial asset can lose its profit within a certain period. In terms of statistics, VaR corresponds to the left-tail quantile of a distribution. Our approach to the investigation of risk spillover is to test Granger causality in VaR from one market to other markets. Grangercausality in VaR was introduced by Granger (1980) and further studied by Hong, Liu, and Wang (2009), among a few other researchers.

Our empirical work is based on daily observations from 1 July 2004 to 1 July 2010. We set July 2007 as the starting point of the crisis following Cheung *et al.* (2010). To test the extreme risk spillover effects of the crisis, the downside movement of S&P 500 is used as the benchmark risk. We also analyze the risk spillover effects between the stock market and the currency market of each country under consideration. In addition, we examine whether extreme movements in the value of riskier assets affect demand for safer assets by analyzing effects between the U.S. stock market and the international gold market.

Our result shows that the extreme risk spillover from the U.S. stock market to most Asian stock markets became significant after the global financial crisis. Specifically, downside movement in the U.S. stock market Granger-caused downside movement in Korean stock market at the 1% VaR level after the crisis and the stock markets of China, Hong Kong, Japan and Taiwan, at 5% level. Moreover, downside movement in a U.S. stock index significantly created a Granger-caused depreciation of all Asian currencies under study after the crisis. In addition, downside movement of a U.S. stock index created significant Granger-caused upside movements in international gold prices, which implies that extreme movements in riskier assets increased the demand for safer assets. In our analysis, it is not clear what the world common factor is that is related to the recent financial crisis, as noted in Kose, Otrok, and Whiteman (2010). Shocks in the U.S. market may contain world common factors. Alternatively, shocks in the U.S. market could possibly be transmitted to other markets through world common factors.

The discussion of the paper is as follows. Section II explains how to detect the risk spillover effect in financial markets. Section III provides our empirical results and Section IV concludes the paper.

II. Extreme Risk Spillover and Econometric Inference

A. A Measure of Extreme Market Movements: Value at Risk

We consider the following model for a stochastic process $\{X_t,\ t \geq 1\}$:

$$X_t = \mu_t + \varepsilon_t\, h_t^{1/2} \tag{1}$$

where ε_t is an independent and identically (iid) distributed random variable. We let $F_t(x) = Prob[X_t \leq x \mid \Omega_{t-1}]$ be the conditional distribution of ε_t conditioned on $\Omega_{t-1} = \{X_{t-1},\ X_{t-2},\ \ldots\}$, the set of all relevant information available at $t-1$. We then let $V_t \equiv V(\Omega_{t-1},\ \alpha)$ be the negative α-quantile of the conditional distribution of X_t:

$$P(X_t < V_t \mid \Omega_{t-1}) = \alpha \tag{2}$$

Then, VaR at level α of X_t, $V_t(\alpha)$, is determined as:

$$V_t(\alpha) = \mu_t - h_t^{1/2} z(\alpha) \tag{3}$$

where $z(\alpha)$ denotes the left-tail critical value of α-level of $F_t(\cdot)$.

B. Method of Testing for Granger Causality in Value at Risk

We let Ω_{it} be the information set available in market i for $i=1, 2$ at time t, $\Omega_{it}=\{X_{it}, \ldots, X_{i1}\}$. Then, we let:

$$\Omega_{t-1}\equiv\{\Omega_{1(t-1)},\ \Omega_{2(t-1)}\}.$$

The Granger causality between two processes in its most general form is defined as follows:

Definition (Granger causality) The process $\{X_{2t}\}_{t=1}^{\infty}$ Granger-causes $\{X_1\}_{t=1}^{\infty}$ if $P(X_{1t}<x\,|\,\Omega_{1(t-1)}\neq P(X_{1t}<x\,|\,\Omega_{t-1})$ is satisfied for all $x\in(-\infty,\ \infty)$.

This general version of Granger causality can be applied naturally to the above VaR between two processes, as studied by Hong *et al.* (2009).

Definition (Granger causality in VaR level α) The time series $\{X_{2t}\}_{t=1}^{\infty}$ Grangercauses the time series $\{X_{1t}\}_{t=1}^{\infty}$ in VaR if $P(X_{1t}<-V_{1t}\,|\,\Omega_{1(t-1)}\neq P(X_{1t}<-V_{1t}\,|\,\Omega_{t-1})$.

Hong *et al.* (2009) proposed a procedure for testing Granger causality in VaRs. We let $Z_{lt}=1[X_{1t}\leq -V_{1t}]$. Then, the above hypothesis is equal to:

$$\begin{aligned} H_0 &: E[Z_{1t}\,|\,\Omega_{1(t-1)}]=E[Z_{1t}\,|\,\Omega_{t-1}] \\ H_1 &: E[Z_{1t}\,|\,\Omega_{1(t-1)}]\neq E[Z_{1t}\,|\,\Omega_{t-1}] \end{aligned} \tag{4}$$

Heuristically, the existence of Granger causality from X_2 to X_1 means that the cross covariance between Z_{1t} and $Z_{2t(t-j)}$ is not equal to zero for some $j>0$. The sample cross-covariance function between $\hat{Z}_{1t}$ and $\hat{Z}_{2t}$, denoted by $\hat{C}(j)$, is defined as:

$$\hat{C}(j)=\begin{cases} T^{-1}\sum_{t=1+j}^{T}(\hat{Z}_{1t}-\hat{\alpha}_1)(\hat{Z}_{2t-j}-\hat{\alpha}_2), & 0\leq j\leq T-1 \\ T^{-1}\sum_{t=1-j}^{T}(\hat{Z}_{1t+j}-\hat{\alpha}_1)(\hat{Z}_{2t}-\hat{\alpha}_2), & 1-T\leq j<0 \end{cases} \tag{5}$$

where $\hat{\alpha}_l\equiv T^{-1}\sum_{t=1}^{T}\hat{Z}_{lt}$.

To test for Granger causality in VaR, as defined in Equation (4), Hong *et al.* (2009) suggested the following test statistic:

TABLE 1
SUMMARY DESCRIPTIVE STATISTICS FOR DAILY STOCK PRICE, EXCHANGE RATE, AND GOLD COMMODITY PRICE CHANGES

Indices	Sample Size	Mean	Std.Dev.	Skewness	Kurtosis
United States S&P 500 Index	1566	-0.0067	1.4204	-0.2505	13.9369
Korean Kospi200	1566	0.04876	1.5147	-0.5839	10.5500
Japanese Nikkei225	1566	-0.0163	1.6219	-0.4417	12.6262
Hong Kong Hangseng Index	1566	0.0315	1.7730	0.0904	12.2820
Chinese Shanghai Composite	1566	0.0337	1.8872	-0.3042	5.9648
Taiwan SE Index	1566	0.0139	1.3685	-0.3674	6.0914
Exchange Rates	**Sample Size**	**Mean**	**Std.Dev.**	**Skewness**	**Kurtosis**
Dollar/Euro	1566	0.0007	0.2772	0.2428	7.6654
Dollar/Yen	1566	0.0063	0.3039	0.6559	7.2478
Dollar/Won	1566	-0.0017	0.3947	0.8439	47.8650
Dollar/Hong Kong Dollar	1566	0.0000	0.0190	10.5144	117.8842
Dollar/Taiwan Dollar	1566	0.0012	0.1314	0.3060	6.8653
Commodity Prices	**Sample Size**	**Mean**	**Std.Dev.**	**Skewness**	**Kurtosis**
Gold Future Price (CMX-GOLD 100 OZ)	1566	0.0719	1.3223	-0.3159	6.5230

Notes: The starting date is July 1, 2004, and the ending date is July 1, 2010. All data are obtained from Datastream.

$$Q_1(M) \equiv \{T\sum_{j=1}^{T-1} k^2(j / M)\hat{\rho}^2(j) - C_{1T}(M)\} / D_{1T}(M)^{1/2}, \tag{6}$$

where $\hat{\rho}^2(j)$, $C_{1T}(M)$, and $D_{1T}(M)$ are defined, respectively, as follows:

$$\hat{\rho}^2(j) = \hat{C}(j)/\hat{S}_1\hat{S}_2, \ ...j = 0, \pm 1, \ldots, \pm(T-1).$$

$$\hat{S}_l = \hat{\alpha}_l(1-\hat{\alpha}_l) \text{ for each } l = 1, 2,$$

$$C_{1T}(M) = \sum_{j=1}^{T-1}\left(1-\frac{j}{T}\right) k^2\left(\frac{j}{M}\right)$$

$$D_{1T}(M) = 2\sum_{j=1}^{T-1}\left(1-\frac{j}{T}\right)\left\{1-\frac{j+1}{T}\right\} k^4(j / M)$$

Clearly, the above statistics depend on the choice of the kernel $k(\cdot)$. In our work a non-uniform Daniell kernel $k_T(z) = \sin(\pi z)/\pi$ is used, which

TABLE 2
MAXIMUM LIKELIHOOD ESTIMATION OF UNIVARIATE GARCH MODELS FOR DAILY STOCK PRICE CHANGES

Parameter	S&P 500	Kospi200	Nikkei225	Hangseng	Shanghai	Taiwan SE
β_0	0.0050 (0.0210)	0.04945 (0.0305)	0.0144 (0.0283)	0.0439 (0.0274)	0.0503 (0.0394)	0.0270 (0.0290)
β_1	-0.0656 (0.0278)	0.04423 (0.0286)	-0.0145 (0.0299)	-0.0031 (0.0281)	0.0012 (0.0262)	0.04548 (0.0282)
β_2	-0.0401 (0.0263)	-0.0245 (0.0253)	-0.0215 (0.0258)	-0.0261 (0.0273)	-0.0215 (0.0265)	0.0069 (0.0258)
β_3	-0.0196 (0.0265)	0.0383 (0.0256)	0.0278 (0.0261)	0.0444 (0.0238)	0.0616 (0.0260)	0.0308 (0.0262)
α_0	0.0085 (0.0012)	0.0738 (0.0106)	0.0337 (0.0062)	0.0175 (0.0039)	0.0457 (0.009)	0.0248 (0.0050)
γ_1	-0.0332 (0.0078)	-0.0164 (0.0107)	0.0151 (0.0110)	0.0332 (0.0119)	0.0466 (0.0095)	0.0229 (0.0095)
γ_2	0.1310 (0.0127)	0.1847 (0.0226)	0.1313 (0.0169)	0.0791 (0.0153)	0.0291 (0.0111)	0.0652 (0.0127)
α_1	0.9572 (0.0063)	0.8799 (0.0127)	0.9000 (0.0116)	0.9189 (0.0098)	0.926763 (0.007296)	0.9276 (0.0087)
Sample Size	1566	1566	1566	1566	1566	1566
log-likelihood	-2169.32	-2595.48	-2585.497	-2628.425	-3072.625	-2508.185

Notes: The estimated model is $s_t = \beta_0 + \sum_{j=1}^{3} \beta_j s_{(t-j)} + \varepsilon_t$, $\varepsilon_t = \upsilon_{it} h_t^{1/2}$, $\upsilon_t \sim N(0, 1)$,
$h_t = \alpha_0 + \gamma_1 \varepsilon_{(t-1)}^2 + \gamma_2 \varepsilon_{(t-1)}^2 1(\varepsilon_{(t-1)} < 0) + \alpha_1 h_{(t-1)}$.
Numbers in parentheses are standard errors for the estimates.

maximizes the power of the test. Hong *et al.* (2009) have shown that:

$$Q_1(M) \xrightarrow{d} N(0, 1)$$

C. Models for Conditional Heteroscedasticity

The test statistic defined in Equation (6) depends on VaRs. Because VaR is an unobserved value, we need to estimate it. In practice, J.P. Morgan's (1997) Risk Metrics uses the following model that is widely use (Hong *et al.* 2004):

TABLE 3
MAXIMUM LIKELIHOOD ESTIMATION OF UNIVARIATE GARCH MODELS FOR DAILY EXCHANGE RATE AND GOLD FUTURE PRICE CHANGES

Dollar to	Euro	Yen	Won	HK Dollar	Taiwan Dollar	Gold Future
β_0	0.0169	0.0033	0.0150	0.0005	0.0035	0.0654
	(0.0130)	(0.0069)	(0.0099)	(0.0003)	(0.0073)	(0.0271)
β_1	-	-	0.1333	-	-	-
	-	-	(0.0269)	-	-	-
α_0	0.0010	0.0006	0.0036	0.0000	0.0010	0.0090
	(0.0005)	(0.0002)	(0.0006)	(0.0000)	(0.0002)	(0.0031)
γ	0.0325	0.0301	0.1296	0.2467	0.0558	0.0381
	(0.0049)	(0.0042)	(0.0101)	(0.0084)	(0.0062)	(0.0060)
α_1	0.9652	0.9633	0.8677	0.8351	0.9365	0.9567
	(0.0047)	(0.0049)	(0.0083)	(0.0044)	(0.0057)	(0.0069)
Sample Size	1566	1566	1566	1566	1566	1566
log-likelihood	-1342.505	-247.6221	-1047.037	3582.144	-289.6563	-2485.252

Notes: For the estimated model for each exchange rate and gold future prices, we choose GARCH(1, 1), $s_t=\beta_0+\varepsilon_t$, $\varepsilon_t=\upsilon_{it}\,h_t^{1/2}$, $\upsilon_t\sim N(0,1)$, $h_t=\alpha_0+\gamma\varepsilon^2_{(t-1)}+\alpha_1 h_{(t-1)}$.
Especially, for dollar/won exchange rate, we select AR(1)-GARCH(1, 1) model: $s_t=\beta_0+\beta s_{t-1}+\varepsilon_t$, $\varepsilon_t=\upsilon_{it}\,h_t^{1/2}$, $\upsilon_t\sim N(0,1)$, $h_t=\alpha_0+\gamma\varepsilon^2_{(t-1)}+\alpha_1 h_{(t-1)}$, according to Akaike and Schwarz criterion and significance of coefficient parameters.
Numbers in parentheses are standard errors for the estimates.

$$X_t=\sigma_t\varepsilon_t\sim i.i.d.\ N(0,1) \tag{7}$$

$$\sigma_t^2=(1-\lambda)\sum_{j=1}^{\infty}\lambda^j X_{t-j}^2 \tag{8}$$

As in Equation (8), the daily return of financial assets is set to be a GARCH (1, 1) model, which is known to capture most of volatility clustering phenomena of financial assets (*e.g.*, Engle 1986 and Engle *et al.* 1993). Furthermore, according to Glosten, Jaganathan, and Runkle (1993), an interesting feature of financial asset movements known as the “leverage effect” exists. This effect is about the asymmetric effects of “good” and “bad” news on asset returns. To capture such an asymmetric effect, the above conditional variance is modified as the following:

TABLE 4
TESTING FOR RISK SPILLOVER FROM THE U.S. TO THE KOREAN STOCK MARKET

				BEFORE CRISIS		
1% VaR	M	5	10	20	30	40
S&P⇒KOSPI	Q_{1DAN}	3.3590	1.7410	0.3111	-0.1445	-0.4551
(p-values)		(0.0004)***	(0.0408)**	(0.3778)	(0.5575)	(0.6755)
5% VaR	M	5	10	20	30	40
S&P⇒KOSPI	Q_{1DAN}	16.4110	12.5750	8.8624	7.3389	6.2459
(p-values)		(0.0000)***	(0.0000)***	(0.0000)***	(0.0000)***	(0.0000)***
10% VaR	M	5	10	20	30	40
S&P⇒KOSPI	Q_{1DAN}	13.2856	10.9383	8.0410	6.1927	5.0005
(p-values)		(0.0000)***	(0.0000)***	(0.0000)***	(0.0000)***	(0.0000)***
				AFTER CRISIS		
1% VaR	M	5	10	20	30	40
S&P⇒KOSPI	Q_{1DAN}	4.988	4.0430	3.0830	4.5070	4.9360
(p-values)		(0.0000)***	(0.0000)***	(0.0000)***	(0.0000)***	(0.0000)***
5% VaR	M	5	10	20	30	40
S&P⇒KOSPI	Q_{1DAN}	15.7785	15.0640	13.2190	11.5485	10.3740
(p-values)		(0.0000)***	(0.0000)***	(0.0000)***	(0.0000)***	(0.0000)***
10% VaR	M	5	10	20	30	40
S&P⇒KOSPI	Q_{1DAN}	28.1447	21.5553	16.1087	12.9388	10.9703
(p-values)		(0.0000)***	(0.0000)***	(0.0000)***	(0.0000)***	(0.0000)***

Notes: ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively.

$$\begin{cases} s_{it} = \beta_{i0} + \sum_{j=1}^{p} \beta_{ij} s_{i(t-j)} + \varepsilon_{it} \\ \varepsilon_{it} = \upsilon_{it} h_{it}^{1/2}, \upsilon_{it} \sim N(0,1) \\ h_{it} = \alpha_{i0} + \alpha_{i1} h_{i(t-1)} + \gamma_{i1} \varepsilon_{i(t-1)}^2 + \gamma_{i2} \varepsilon_{i(t-1)}^2 1(\varepsilon_{i(t-1)} < 0) \\ \textit{where } s_{it} \textit{ is the daily return on the stock price.} \end{cases} \tag{9}$$

If $e_{i(t-1)}<0$, its effect on h_{it} is $(\gamma_{i1}+\gamma_{i2})e_{i(t-1)}$ and if $e_{i(t-1)}\geq 0$, its effect on h_{it} is $\gamma_{i1}e_{i(t-1)}$. This threshold-GARCH (TGARCH) allows for leverage effects. Specifically, in the case of one-period-ahead positive shock, the effect on the log of the conditional variance is $\alpha_1+\lambda$, and in the case of negative shock, the effect is $-\alpha_1+\lambda$. By contrast, we use the AR(p)-GARCH model for estimation of conditional heteroscedasticity for exchange rates and gold commodity prices, where the order of autoregression is

TABLE 5
TESTING FOR RISK SPILLOVER FROM THE KOREAN TO THE U.S. STOCK MARKET

		BEFORE CRISIS				
1% VaR	M	5	10	20	30	40
KOSPI ⇒ S&P	Q_{1DAN}	0.1600	0.7868	-0.1522	-0.8679	-1.57
(p-values)		(0.4364)	(0.2157)	(0.5605)	(0.8073)	(0.9418)
5% VaR	M	5	10	20	30	40
KOSPI ⇒ S&P	Q_{1DAN}	-0.8975	-0.7779	-0.986	-1.353	-1.444
(p-values)		(0.8153)	(0.7817)	(0.8379)	(0.912)	(0.9256)
10% VaR	M	5	10	20	30	40
KOSPI ⇒ S&P	Q_{1DAN}	-0.8767	-1.288	-1.475	-1.47	-1.198
(p-values)		(0.8097)	(0.9011)	(0.9299)	(0.9292)	(0.8845)
		AFTER CRISIS				
1% VaR	M	5	10	20	30	40
KOSPI ⇒ S&P	Q_{1DAN}	-0.7196	-0.9521	-0.8363	-0.7455	-0.8549
(p-values)		(0.7641)	(0.8295)	(0.7985)	(0.772)	(0.8037)
5% VaR	M	5	10	20	30	40
KOSPI ⇒ S&P	Q_{1DAN}	-0.787	-0.4336	-0.2173	-0.2105	-0.3405
(p-values)		(0.7844)	(0.6677)	(0.586)	(0.5833)	(0.6332)
10% VaR	M	5	10	20	30	40
KOSPI ⇒ S&P	Q_{1DAN}	-0.3585	-0.5478	0.3129	0.8003	0.9768
(p-values)		(0.6400)	(0.7081)	(0.3772)	(0.2118)	(0.1643)

Notes: ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively.

selected based on Akaike and Schwarz criteria. In addition, VaR at level α is determined as:

$$V_t(\alpha)=\hat{\mu}_t-\hat{h}_t^{1/2}z(\alpha) \tag{10}$$

where $z(\alpha)$ denotes the α-quantile of the standard normal distribution.

III. Empirical Results

A. Data

Data are obtained from daily observations from 1 July 2004 to 1 July 2010. We define July 2007 as the starting point of the crisis, in accordance with Cheung *et al.* (2010).[1] To test the extreme risk spillover

TABLE 6
TESTING FOR RISK SPILLOVER FROM THE U.S. TO THE TAIWANESE STOCK MARKET

		BEFORE CRISIS				
1% VaR	M	5	10	20	30	40
S&P⇒TAIWAN	Q_{1DAN}	1.9133	2.7987	3.1714	3.4039	3.0980
(p-values)		(0.0279)**	(0.0026)***	(0.0008)***	(0.0003)***	(0.0010)***
5% VaR	M	5	10	20	30	40
S&P⇒TAIWAN	Q_{1DAN}	1.8107	2.1387	1.4354	1.2	1.3341
(p-values)		(0.0351)**	(0.0162)**	(0.0756)*	(0.1150)	(0.0911)*
10% VaR	M	5	10	20	30	40
S&P⇒TAIWAN	Q_{1DAN}	12.2747	9.4256	6.7174	5.4363	4.8551
(p-values)		(0.0000)***	(0.0000)***	(0.0000)***	(0.0000)***	(0.0000)***
		AFTER CRISIS				
1% VaR	M	5	10	20	30	40
S&P⇒TAIWAN	Q_{1DAN}	36.0741	25.6255	17.5259	13.9582	11.7078
(p-values)		(0.0000)***	(0.0000)***	(0.0000)***	(0.0000)***	(0.0000)***
5% VaR	M	5	10	20	30	40
S&P⇒TAIWAN	Q_{1DAN}	21.2537	15.3124	10.5493	8.8112	7.9469
(p-values)		(0.0000)***	(0.0000)***	(0.0000)***	(0.0000)***	(0.0000)***
10% VaR	M	5	10	20	30	40
S&P⇒TAIWAN	Q_{1DAN}	24.8435	18.6125	13.1120	10.5678	9.0197
(p-values)		(0.0000)***	(0.0000)***	(0.0000)***	(0.0000)***	(0.0000)***

Notes: ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively.

effects of the crisis, the downside movement of the S&P 500 is used as the "benchmark" risk. We examined risk spillover effects between the US stock market and each of Asian markets, between the stock market and the currency market of each economy, and between the stock market and the gold market. Tables 4 to 20 show the results of our test. Values of the test statistic (6) and their p-values are reported under the null hypothesis that there exists no Granger causality in the VaR at $\alpha=1\%$, $\alpha=5\%$, and $\alpha=10\%$. Table 1, on the other hand, contains summary statistics for rates of returns of stock indices and exchange rates.

[1] AAA CDOs were first downgraded in July 2007 (Cheung *et al.* 2010).

TABLE 7
TESTING FOR RISK SPILLOVER FROM THE TAIWANESE TO THE U.S. STOCK MARKET

		BEFORE CRISIS				
1% VaR	M	5	10	20	30	40
TAIWAN ⇒ S&P	Q_{1DAN}	1.4440	0.9134	-0.2145	-0.9645	-1.5120
(p-values)		(0.0744)*	(0.1805)	(0.5849)	(0.8326)	(0.9347)
5% VaR	M	5	10	20	30	40
TAIWAN ⇒ S&P	Q_{1DAN}	0.3845	0.04612	-0.4730	-0.8567	-1.2230
(p-values)		(0.3503)	(0.4816)	(0.6819)	(0.8042)	(0.8894)
10% VaR	M	5	10	20	30	40
TAIWAN ⇒ S&P	Q_{1DAN}	-0.0504	0.7209	1.4510	1.2590	1.0450
(p-values)		(0.5201)	(0.2355)	(0.07343)	(0.1041)	(0.1481)
		AFTER CRISIS				
1% VaR	M	5	10	20	30	40
TAIWAN ⇒ S&P	Q_{1DAN}	0.0983	-0.3262	-0.7791	-0.8992	-0.9450
(p-values)		(0.4609)	(0.6279)	(0.7820)	(0.8157)	(0.8277)
5% VaR	M	5	10	20	30	40
TAIWAN ⇒ S&P	Q_{1DAN}	1.9440	1.2460	0.5331	0.08137	0.0566
(p-values)		(0.0259)**	(0.1063)	(0.2970)	(0.4676)	(0.4774)
10% VaR	M	5	10	20	30	40
TAIWAN ⇒ S&P	Q_{1DAN}	1.6240	0.9635	1.2883	1.6350	1.7390
(p-values)		(0.0522)**	(0.1677)	(0.0989)*	(0.0510)*	(0.0410)**

Notes: ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively.

B. Estimation Results for Conditional Heteroscedasticity

Estimation results of parameters in (9) are reported in Table 2 and Table 3. In all six stock indices of S&P 500, KOSPI 200, Nikkei 225, Hang Seng, Shanghai, and Taiwan SE, there is a highly significant leverage effect (γ_2).

C. Extreme Risk Spillover: Global Stock Markets

1. S&P 500 and Korean KOSPI 200
   The test results in Table 4 show a significant extreme risk spillover effect from the U.S. to Korean stock markets in both periods of before and after July 2007. However, in both periods, causality in the opposite direction (Korea ⇒ U.S.) was not confirmed at any level

TABLE 8
TESTING FOR RISK SPILLOVER FROM THE U.S. TO THE CHINESE STOCK MARKET

				BEFORE CRISIS		
1% VaR	M	5	10	20	30	40
S&P⇒Sanghai	Q_{1DAN}	0.0003	0.5458	0.6159	1.2670	1.3670
(p-values)		(0.4999)	(0.2926)	(0.2690)	(0.1025)	(0.0858)
5% VaR	M	5	10	20	30	40
S&P⇒Sanghai	Q_{1DAN}	-0.4084	-0.0833	-0.2174	-0.6501	-0.6087
(p-values)		(0.6585)	(0.5332)	(0.5860)	(0.7422)	(0.7286)
10% VaR	M	5	10	20	30	40
S&P⇒Sanghai	Q_{1DAN}	0.5620	2.2456	2.3399	2.425	2.4022
(p-values)		(0.2871)	(0.0124)**	(0.0096)***	(0.0077)***	(0.0081)**
				AFTER CRISIS		
1% VaR	M	5	10	20	30	40
S&P⇒Sanghai	Q_{1DAN}	0.9584	0.4848	0.3681	0.5038	0.4315
(p-values)		(0.1689)	(0.3139)	(0.3564)	(0.3072)	(0.3330)
5% VaR	M	5	10	20	30	40
S&P⇒Sanghai	Q_{1DAN}	1.8690	1.5380	0.6536	0.2829	0.0051
(p-values)		(0.0308)**	(0.0620)*	(0.2567)	(0.3886)	(0.4979)
10% VaR	M	5	10	20	30	40
S&P⇒Sanghai	Q_{1DAN}	9.0590	7.0220	4.6082	3.5254	2.8000
(p-values)		(0.0000)***	(0.0000)***	(0.0000)***	(0.0000)***	(0.0000)***

Notes: ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively.

of the VaR under consideration (Table 5). Effects of risk spillover from the U.S. to Korean markets intensified during the global financial crisis. Downside movement in S&P500 during the crisis Granger-caused a downside movement in KOSPI200 at $\alpha=1\%$, which was not significant before the crisis. Finally, in both periods, causality in the opposite direction (Korea ⇒ U.S.) was not confirmed at any level of VaR.

2. S&P 500 and Taiwan SE Indices

Table 6 and 7 present the results of the Taiwanese markets. We find evidence of Granger causality in VaRs from S&P 500 to the Taiwan SE index in both periods. There is a stronger evidence of risk spillover from the U.S. to Taiwanese stock market during the crisis at the 5% VaR level. In addition, we can see evidence of Granger caus-

TABLE 9
TESTING FOR RISK SPILLOVER FROM THE CHINESE TO THE U.S. STOCK MARKET

				BEFORE CRISIS		
1% VaR	M	5	10	20	30	40
Shanghai⇒S&P	Q_{1DAN}	0.0307	1.1380	0.9472	1.1850	1.2363
(p-values)		(0.4878)	(0.1276)	(0.1718)	(0.1179)	(0.1083)
5% VaR	M	5	10	20	30	40
Shanghai⇒S&P	Q_{1DAN}	-0.3199	-0.6681	0.1438	0.1353	0.2939
(p-values)		(0.6255)	(0.7480)	(0.4428)	(0.4462)	(0.3844)
10% VaR	M	5	10	20	30	40
Shanghai⇒S&P	Q_{1DAN}	-0.1389	0.2522	0.5258	0.3354	0.9667
(p-values)		(0.5552)	(0.4004)	(0.2995)	(0.3687)	(0.1669)
				AFTER CRISIS		
1% VaR	M	5	10	20	30	40
Shanghai⇒S&P	Q_{1DAN}	0.7071	0.9176	1.7760	2.1750	2.0094
(p-values)		(0.2397)	(0.1794)	(0.0378)**	(0.0148)**	(0.0223)**
5% VaR	M	5	10	20	30	40
Shanghai⇒S&P	Q_{1DAN}	4.6180	3.3884	2.5333	2.1694	1.584
(p-values)		(0.0000)***	(0.0000)***	(0.0057)***	(0.0151)**	(0.0566)*
10% VaR	M	5	10	20	30	40
Shanghai⇒S&P	Q_{1DAN}	1.6810	0.7792	-0.2751	-0.8992	-1.0660
(p-values)		(0.0464)**	(0.2179)	(0.6084)	(0.8157)	(0.8568)

Notes: ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively.

ality at the 10% VaR level from Taiwan to the U.S. stock markets.

3. S&P 500 and Shanghai Commodity Indices
Table 8 and 9 show the results of between S&P 500 and Shanghai Commodity indices. Granger causality from the former to the latter intensified during the crisis at the 10% VaR level. Moreover, there is evidence of risk spillover from the Shanghai Commodity to the S&P 500 during the crisis, at the 5% VaR level.

4. S&P 500 and Hang Seng Indices
S&P 500 significantly Granger-caused the Hang Seng Index at all VaR levels in both periods (Tables 10 and 11). In addition, the Hang Seng Index had some spillover effects on S&P 500 at the 10% level of VaR, before and during the crisis.

TABLE 10
TESTING FOR RISK SPILLOVER FROM THE U.S. TO THE HONG KONG STOCK MARKET

		BEFORE CRISIS				
1% VaR	M	5	10	20	30	40
S&P⇒Hangseng	Q_{1DAN}	16.0112	12.4926	8.9382	6.8345	5.0727
(p-values)		(0.0000)***	(0.0000)***	(0.0000)***	(0.0000)***	(0.0000)***
5% VaR	M	5	10	20	30	40
S&P⇒Hangseng	Q_{1DAN}	41.3532	30.1205	21.6353	17.6785	15.1858
(p-values)		(0.0000)***	(0.0000)***	(0.0000)***	(0.0000)***	(0.0000)***
10% VaR	M	5	10	20	30	40
S&P⇒Hangseng	Q_{1DAN}	39.0459	27.5398	18.8664	15.4136	13.7434
(p-values)		(0.0000)***	(0.0000)***	(0.0000)***	(0.0000)***	(0.0000)***
		AFTER CRISIS				
1% VaR	M	5	10	20	30	40
S&P⇒Hangseng	Q_{1DAN}	9.0837	7.3783	4.9222	4.4398	4.3303
(p-values)		(0.0000)***	(0.0000)***	(0.0000)***	(0.0000)***	(0.0000)***
5% VaR	M	5	10	20	30	40
S&P⇒Hangseng	Q_{1DAN}	24.1012	18.1972	13.5550	11.7867	10.7975
(p-values)		(0.0000)***	(0.0000)***	(0.0000)***	(0.0000)***	(0.0000)***
10% VaR	M	5	10	20	30	40
S&P⇒Hangseng	Q_{1DAN}	41.9372	29.9960	21.9174	18.4081	16.2256
(p-values)		(0.0000)***	(0.0000)***	(0.0000)***	(0.0000)***	(0.0000)***

Notes: ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively.

5. S&P 500 and Japanese Nikkei Indices

Table 12 and 13 show the results between S&P 500 and Japanese Nikkei indices. The former significantly Granger-caused the latter at all VaR levels, in both periods. Results in the other direction of causation are not evident.

Risks from the U.S. stock market spilled over to Asian stock markets, and the effects became more significant during the global financial crisis, especially in the Taiwanese, Korean, and Chinese stock markets. Furthermore, the indices of some Asian stock markets such as the Shanghai, Hang Seng, and Taiwan SE indices had spillover effects in S&P 500.

TABLE 11
TESTING FOR RISK SPILLOVER FROM THE HONG KONG TO THE U.S. STOCK MARKET

		BEFORE CRISIS				
1% VaR	M	5	10	20	30	40
Hangseng⇒S&P	Q_{1DAN}	-1.0904	-1.3553	-1.8398	-1.9826	-2.1730
(p-values)		(0.8622)	(0.9123)	(0.9671)	(0.9763)	(0.9851)
5% VaR	M	5	10	20	30	40
Hangseng⇒S&P	Q_{1DAN}	0.0991	-0.0331	0.3666	0.6834	0.6639
(p-values)		(0.4605)	(0.5132)	(0.3570)	(0.2472)	(0.2534)
10% VaR	M	5	10	20	30	40
Hangseng⇒S&P	Q_{1DAN}	1.838	2.669	2.249	2.363	2.239
(p-values)		(0.0330)**	(0.0038)***	(0.0123)**	(0.0090)***	(0.0126)**
		AFTER CRISIS				
1% VaR	M	5	10	20	30	40
Hangseng⇒S&P	Q_{1DAN}	-0.5489	-0.8055	-0.8205	-0.8117	-1.006
(p-values)		(0.7085)	(0.7897)	(0.794)	(0.7915)	(0.8427)
5% VaR	M	5	10	20	30	40
Hangseng⇒S&P	Q_{1DAN}	0.6671	0.7682	0.2351	-0.2066	-0.5006
(p-values)		(0.2523)	(0.2212)	(0.4071)	(0.5818)	(0.6917)
10% VaR	M	5	10	20	30	40
Hangseng⇒S&P	Q_{1DAN}	2.2324	1.7970	1.5032	1.628	1.6574
(p-values)		(0.0128)**	(0.0361)**	(0.0664)*	(0.0518)*	(0.0487)**

Notes: ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively.

D. Extreme Risk Spillover: From Stock Markets to Currency Markets

Lee (2003) argues that stock and currency markets in most Asian countries have developed increasingly close relationships after the financial crisis in 1997. Lee (2003) reports that in most Asian countries, Granger causality from the stock market to the currency market is stronger than in the opposite direction. Lee's (2003) analysis is based on Granger causality in the mean returns for stock and exchange markets. In addition, Lee and Lee (2009) investigated the way in which risk spills over between the Korean stock market and foreign exchange market, employing the method developed by Hong *et al.* (2009). Lee and Lee (2009), however, did not include extreme events such as the recent global financial crisis originating from the U.S. market.

In this section, we hypothesize that the global stock and exchange

TABLE 12
TESTING FOR RISK SPILLOVER FROM THE U.S. TO THE JAPANESE STOCK MARKET

		BEFORE CRISIS				
1% VaR	M	5	10	20	30	40
S&P⇒Nikkei	Q_{1DAN}	17.3364	13.6647	9.8939	7.6465	6.1710
(p-values)		(0.0000)***	(0.0000)***	(0.0000)***	(0.0000)***	(0.0000)***
5% VaR	M	5	10	20	30	40
S&P⇒Nikkei	Q_{1DAN}	24.9090	19.8654	14.7697	12.0990	10.2912
(p-values)		(0.0000)***	(0.0000)***	(0.0000)***	(0.0000)***	(0.0000)***
10% VaR	M	5	10	20	30	40
S&P⇒Nikkei	Q_{1DAN}	19.7574	14.7123	10.2247	8.0929	6.9805
(p-values)		(0.0000)***	(0.0000)***	(0.0000)***	(0.0000)***	(0.0000)***
		AFTER CRISIS				
1% VaR	M	5	10	20	30	40
S&P⇒Nikkei	Q_{1DAN}	8.3587	5.4659	3.7248	3.0872	2.6817
(p-values)		(0.0000)***	(0.0000)***	(0.0000)***	(0.0000)***	(0.0037)***
5% VaR	M	5	10	20	30	40
S&P⇒Nikkei	Q_{1DAN}	69.0061	49.0651	34.1844	27.8778	24.1529
(p-values)		(0.0000)***	(0.0000)***	(0.0000)***	(0.0000)***	(0.0000)***
10% VaR	M	5	10	20	30	40
S&P⇒Nikkei	Q_{1DAN}	67.0185	47.8587	33.1434	26.6003	22.7547
(p-values)		(0.0000)***	(0.0000)***	(0.0000)***	(0.0000)***	(0.0000)***

Notes: ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively.

markets have become increasingly interdependent during the current financial crisis. Specifically, we test the hypothesis that extreme movements in the U.S. stock markets, as a benchmark case of risks, affect extreme movements in the currency markets of several countries.

1. Dollar/Euro rate
   According to Table 14, downside movements in the U.S. stock market Granger-caused a large depreciation of the Euro currency at the 5% VaR level before the crisis. However, during the crisis, S&P 500 significantly Granger-caused downside movement in the Dollar/Euro rate at both the 5% and 10% VaR levels.

2. Dollar/Won rate
   According to Table 15, downside movements in the U.S. stock market

TABLE 13
TESTING FOR RISK SPILLOVER FROM THE JAPANESE TO THE U.S. STOCK MARKET

				BEFORE CRISIS		
1% VaR	M	5	10	20	30	40
Nikkei⇒S&P	Q_{1DAN}	0.0790	1.7913	1.6972	1.2364	0.6682
(p-values)		(0.4685)	(0.0366)	(0.0448)	(0.1082)	(0.2520)
5% VaR	M	5	10	20	30	40
Nikkei⇒S&P	Q_{1DAN}	-0.8776	-0.8699	-0.8292	-0.6247	-0.4466
(p-values)		(0.8099)	(0.8078)	(0.7965)	(0.7339)	(0.6724)
10% VaR	M	5	10	20	30	40
Nikkei⇒S&P	Q_{1DAN}	-0.5292	-0.3806	-0.8755	-1.3934	-1.6768
(p-values)		(0.7017)	(0.6482)	(0.8093)	(0.9183)	(0.9532)
				AFTER CRISIS		
1% VaR	M	5	10	20	30	40
Nikkei⇒S&P	Q_{1DAN}	-0.4236	0.9244	1.1978	0.8514	0.5741
(p-values)		(0.6641)	(0.1776)	(0.1155)	(0.1973)	(0.2830)
5% VaR	M	5	10	20	30	40
Nikkei⇒S&P	Q_{1DAN}	-0.7361	-1.1320	-0.9146	-0.9975	-0.9997
(p-values)		(0.7692)	(0.8712)	(0.8198)	(0.8407)	(0.8413)
10% VaR	M	5	10	20	30	40
Nikkei⇒S&P	Q_{1DAN}	-0.2876	-0.4734	0.3161	1.0390	1.3780
(p-values)		(0.6132)	(0.6820)	(0.3759)	(0.1493)	(0.0841)*

Notes: ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively.

Granger-caused a large depreciation of the Korean Won at the 5% VaR level before the crisis. However, during the crisis, the S&P 500 Granger-caused downside movement in the Dollar/Won rate at all VaR levels. By contrast, as Table 16 shows, downside movement in the Korean stock market did not Granger-cause a large depreciation of the Korean Won at most VaR levels before the crisis. However, during the crisis period, KOSPI 200 significantly Granger-caused downside movements in the Dollar/Won exchange rate at all VaR levels.

3. Dollar/Yen rate

Table 17 shows the results for the Granger causality from the S&P 500 index to the Dollar/Yen exchange rate. Before the crisis, downside movements in the S&P 500 index did not Granger-cause a large

TABLE 14
TESTING FOR RISK SPILLOVER FROM THE U.S. STOCK MARKET TO THE DOLLAR/EURO RATE

				BEFORE CRISIS		
1% VaR S&P⇒ Dollar/Euro (p-values)	M Q_{1DAN}	5 -1.1496 (0.8748)	10 -1.7008 (0.9555)	20 -2.4498 (0.9929)	30 -1.9653 (0.9753)	40 -0.7313 (0.7677)
5% VaR S&P⇒ Dollar/Euro (p-values)	M Q_{1DAN}	5 1.5682 (0.0584)**	10 2.7815 (0.0027)***	20 3.0819 (0.0010)***	30 2.8520 (0.0022)***	40 2.8570 (0.0021)***
10% VaR S&P⇒ Dollar/Euro (p-values)	M Q_{1DAN}	5 0.0209 (0.4917)	10 -0.1632 (0.5648)	20 -0.7573 (0.7756)	30 -1.0660 (0.8568)	40 -0.9012 (0.8162)
				AFTER CRISIS		
1% VaR S&P⇒ Dollar/Euro (p-values)	M Q_{1DAN}	5 0.9370 (0.1744)	10 0.2782 (0.3904)	20 -0.2801 (0.6103)	30 -0.764 (0.7776)	40 -0.6591 (0.7451)
5% VaR S&P⇒ Dollar/Euro (p-values)	M Q_{1DAN}	5 1.2423 (0.1071)	10 1.9840 (0.0236)**	20 1.8322 (0.0335)**	30 2.7098 (0.0034)**	40 2.8637 (0.0021)***
10% VaR S&P⇒ Dollar/Euro (p-values)	M Q_{1DAN}	5 3.2022 (0.0007)***	10 2.5370 (0.0056)***	20 2.1791 (0.0147)**	30 2.7905 (0.0026)***	40 2.7381 (0.0031)***

Notes: ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively.

depreciation of the Yen at all levels of VaR. However, during the crisis, S&P 500 significantly Granger-caused downside movements in the Dollar/Yen rate at the 1% VaR level. Table 18 shows the results between the Nikkei index and the Dollar/Yen exchange rate. Before the crisis, downside movements in the Nikkei index did not Granger-cause a large depreciation of the Yen at all levels of VaR. However, during the crisis, the former significantly Granger-caused a large depreciation of the latter at the 1% and 5% VaR level.

TABLE 15
TESTING FOR RISK SPILLOVER FROM THE U.S. STOCK MARKET TO THE DOLLAR/WON RATE

				BEFORE CRISIS		
1% VaR	M	5	10	20	30	40
S&P 500 ⇒	Q_{1DAN}	-0.9159	0.1206	1.8622	1.6007	0.9663
Dollar/Won (p-values)		(0.8201)	(0.4520)	(0.0313)	(0.0547)	(0.1669)
5% VaR	M	5	10	20	30	40
S&P 500 ⇒	Q_{1DAN}	0.3148	0.7245	0.5490	0.2626	0.6212
Dollar/Won (p-values)		(0.3765)	(0.2344)	(0.2915)	(0.3964)	(0.2672)
10% VaR	M	5	10	20	30	40
S&P 500 ⇒	Q_{1DAN}	1.2879	2.1110	2.1867	1.9202	1.6985
Dollar/Won (p-values)		(0.0989)*	(0.0174)***	(0.0144)***	(0.0274)**	(0.0447)**
				AFTER CRISIS		
1% VaR	M	5	10	20	30	40
S&P 500 ⇒	Q_{1DAN}	3.4835	3.6487	2.6437	3.2516	3.5216
Dollar/Won (p-values)		(0.0002)***	(0.0001)***	(0.0041)***	(0.0006)***	(0.0002)***
5% VaR	M	5	10	20	30	40
S&P 500 ⇒	Q_{1DAN}	18.4607	16.1328	13.2597	11.4304	10.4046
Dollar/Won (p-values)		(0.0000)***	(0.0000)***	(0.0000)***	(0.0000)***	(0.0000)***
10% VaR	M	5	10	20	30	40
S&P 500 ⇒	Q_{1DAN}	23.8655	22.6462	17.3648	14.3792	12.4650
Dollar/Won (p-values)		(0.0000)***	(0.0000)***	(0.0000)***	(0.0000)***	(0.0000)***

Notes: ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively.

4. Other currency markets: Hong Kong and Taiwan

As with other currency markets, extreme risk spillover from the U.S. market to the Taiwan and Hong Kong currency markets intensified during the crisis (Tables 19 and 20). In particular, before the crisis, downside movements in S&P 500 did not Granger-cause a large depreciation of the Taiwanese currency at all VaR levels. However, during the crisis, S&P 500 significantly Granger-caused downside movements in the Dollar/Taiwan Dollar rate at both the 5% and 10% VaR levels.

TABLE 16
TESTING FOR RISK SPILLOVER FROM THE KOREAN STOCK MARKET TO THE DOLLAR/WON RATE

				BEFORE CRISIS		
1% VaR	M	5	10	20	30	40
KOSPI ⇒	Q_{1DAN}	2.0967	3.2149	1.9221	0.8790	0.7304
Dollar/Won		(0.0180)**	(0.0007)***	(0.0273)**	(0.1897)	(0.2326)
(p-values)						
5% VaR	M	5	10	20	30	40
KOSPI ⇒	Q_{1DAN}	1.7776	1.6073	1.2072	1.0330	0.8161
Dollar/Won		(0.0377)**	(0.0540)*	(0.1137)	(0.1508)	(0.2072)
(p-values)						
10% VaR	M	5	10	20	30	40
KOSPI ⇒	Q_{1DAN}	3.6030	2.7564	1.8064	1.3884	1.0043
Dollar/Won		(0.0002)***	(0.0030)***	(0.0354)**	(0.0825)*	(0.1576)
(p-values)						
				AFTER CRISIS		
1% VaR	M	5	10	20	30	40
KOSPI ⇒	Q_{1DAN}	59.3142	41.7110	28.5067	22.8489	19.5395
Dollar/Won		(0.0000)***	(0.0000)***	(0.0000)***	(0.0000)***	(0.0000)***
(p-values)						
5% VaR	M	5	10	20	30	40
KOSPI ⇒	Q_{1DAN}	57.4811	40.7559	27.8763	22.3557	19.3255
Dollar/Won		(0.0000)***	(0.0000)***	(0.0000)***	(0.0000)***	(0.0000)***
(p-values)						
10% VaR	M	5	10	20	30	40
KOSPI ⇒	Q_{1DAN}	60.7290	42.6147	29.1967	23.5188	20.0992
Dollar/Won		(0.0000)***	(0.0000)***	(0.0000)***	(0.0000)***	(0.0000)***
(p-values)						

Notes: ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively.

Overall, downside risks in the US stock market had little influence on the depreciation risk in currencies of Asian economies before the crisis. However, downside risks in the US stock market significantly Granger-caused the depreciation risk in Asian currency markets during the crisis. Furthermore, for both Japan and Korea, downside risks in domestic stock markets significantly Granger-caused the depreciation risk of the respective currencies during the crisis. During the period of financial crisis, large downside movements in values of riskier assets (stocks) can affect the demand for safer assets, such as the U.S. dollar

TABLE 17
TESTING FOR RISK SPILLOVER FROM THE U.S. STOCK MARKET TO THE DOLLAR/YEN RATE

		BEFORE CRISIS				
1% VaR	M	5	10	20	30	40
S&P 500 ⇒	Q_{1DAN}	-1.0323	-1.5997	-0.1770	0.6175	0.8379
Dollar/Yen		(0.8490)	(0.9452)	(0.5703)	(0.2685)	(0.2010)
(p-values)						
5% VaR	M	5	10	20	30	40
S&P 500 ⇒	Q_{1DAN}	-0.3327	-0.1056	0.2014	0.5972	0.6261
Dollar/Yen		(0.6303)	(0.5421)	(0.4202)	(0.2752)	(0.2656)
(p-values)						
10% VaR	M	5	10	20	30	40
S&P 500 ⇒	Q_{1DAN}	-0.8055	-1.0946	-0.6332	-0.3790	-0.3662
Dollar/Yen		(0.7897)	(0.8632)	(0.7367)	(0.6477)	(0.6429)
(p-values)						
		AFTER CRISIS				
1% VaR	M	5	10	20	30	40
S&P ⇒	Q_{1DAN}	2.464	3.722	3.84	3.607	4.134
Dollar/Yen		(0.0069)***	(0.0000)***	(0.0000)***	(0.0000)***	(0.0000)***
(p-values)						
5% VaR	M	5	10	20	30	40
S&P ⇒	Q_{1DAN}	-1.045	-0.6445	-0.4573	-0.3491	-0.1691
Dollar/Yen		(0.8520)	(0.7404)	(0.6763)	(0.6365)	(0.5671)
(p-values)						
10% VaR	M	5	10	20	30	40
S&P ⇒	Q_{1DAN}	-0.8155	-0.9917	-1.212	-1.015	-0.9919
Dollar/Yen		(0.7926)	(0.8393)	(0.8872)	(0.8449)	(0.8394)
(p-values)						

Notes: ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively.

and the U.S. T-bill.

E. Extreme Risk Spillover: From Stock Market to Commodity Market

During financial crises, investors prefer safer assets, as results from the previous subsection imply. We also examined the effects of extreme movements in the US stock market on the future of international gold prices. We consider both the “downside” and “upside” extreme movements of daily gold futures prices.[2]

TABLE 18
TESTING FOR RISK SPILLOVER FROM THE JAPANESE STOCK MARKET TO THE DOLLAR/YEN RATE

		BEFORE CRISIS				
1% VaR	M	5	10	20	30	40
Nikkei ⇒	Q_{1DAN}	-1.1533	-1.6832	-2.2450	-2.6340	-2.1820
Dollar/Yen		(0.8756)	(0.9538)	(0.9876)	(0.9958)	(0.9854)
(p-values)						
5% VaR	M	5	10	20	30	40
Nikkei ⇒	Q_{1DAN}	-0.8051	0.6317	0.9136	0.8029	0.8447
Dollar/Yen		(0.7896)	(0.2638)	(0.1805)	(0.211)	(0.1991)
(p-values)						
10% VaR	M	5	10	20	30	40
Nikkei ⇒	Q_{1DAN}	-0.6059	-0.8999	-0.7354	-0.2026	-0.0097
Dollar/Yen		(0.7277)	(0.8159)	(0.769)	(0.5803)	(0.5039)
(p-values)						
		AFTER CRISIS				
1% VaR	M	5	10	20	30	40
Nikkei ⇒	Q_{1DAN}	3.9042	4.4170	3.1210	2.250	1.5622
Dollar/Yen		(0.0000)***	(0.0000)***	(0.0000)***	(0.0122)**	(0.0591)*
(p-values)						
5% VaR	M	5	10	20	30	40
Nikkei ⇒	Q_{1DAN}	1.7460	1.6880	1.8324	2.2420	2.3270
Dollar/Yen		(0.0404)**	(0.0457)**	(0.0336)**	(0.0125)**	(0.0100)***
(p-values)						
10% VaR	M	5	10	20	30	40
Nikkei ⇒	Q_{1DAN}	0.7494	0.6988	0.7446	0.9680	1.1014
Dollar/Yen		(0.2268)	(0.2423)	(0.2282)	(0.1665)	(0.1355)
(p-values)						

Notes: ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively.

1. S&P 500 and gold futures prices (Downside)
   A downside movement in the stock market may cause downside movement in gold price through the wealth effect. The wealth effect seems to exist before the crisis. However, the result is different after

[2] The extreme downside risk of gold future price is defined as extreme negative values below the α% negative quantile value, as defined in Equations (2) and (3). The upside risk is defined by extreme positive values above the α% positive quantile value.

TABLE 19
TESTING FOR RISK SPILLOVER FROM THE U.S. STOCK MARKET TO THE DOLLAR/HONG KONG DOLLAR (HKD) RATE

				BEFORE CRISIS		
1% VaR	M	5	10	20	30	40
S&P ⇒	Q_{1DAN}	-1.0553	-1.4670	-1.5720	-0.4554	-0.1000
Dollar/HKD		(0.8542)	(0.9288)	(0.942)	(0.6756)	(0.5398)
(p-values)						
5 % VaR	M	5	10	20	30	40
S&P ⇒	Q_{1DAN}	1.2932	1.0418	1.2113	2.1612	2.7742
Dollar/HKD		(0.0980)*	(0.1488)	(0.1130)	(0.0154)**	(0.0028)***
(p-values)						
10% VaR	M	5	10	20	30	40
S&P ⇒	Q_{1DAN}	-0.3124	-0.3101	-0.1993	-0.3067	-0.3231
Dollar/HKD		(0.6226)	(0.6217)	(0.579)	(0.6205)	(0.6267)
(p-values)						
				AFTER CRISIS		
1% VaR	M	5	10	20	30	40
S&P ⇒	Q_{1DAN}	5.8110	6.4852	5.4569	4.9793	4.3530
Dollar/HKD		(0.0000)***	(0.0000)***	(0.0000)***	(0.0000)***	(0.0000)***
(p-values)						
5% VaR	M	5	10	20	30	40
S&P ⇒	Q_{1DAN}	-0.4646	-0.2954	-0.5120	-0.4000	-0.3490
Dollar/HKD		(0.6789)	(0.6162)	(0.6957)	(0.6554)	(0.6364)
(p-values)						
10% VaR	M	5	10	20	30	40
S&P ⇒	Q_{1DAN}	4.1357	3.1922	2.204	2.2811	2.2677
Dollar/HKD		(0.0000)***	(0.0007)***	(0.0138)**	(0.0113)**	(0.0117)**
(p-values)						

Notes: ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively.

crisis. Table 21 shows the results of testing for Granger causality in VaRs between the U.S. stock market and the gold futures market (downside movement). Before the crisis, downside movements in the U.S. stock market Granger-caused the downside movements of international gold futures prices, especially at 5% and 10% VaRs. By contrast, however, this evidence does not exist during the crisis at all VaR levels.

2. S&P 500 and gold futures prices (Upside)
   Table 22 shows the results for testing for the causality of a downside

TABLE 20
TESTING FOR RISK SPILLOVER FROM THE U.S. STOCK MARKET TO THE DOLLAR/TAIWAN DOLLAR (TWD) RATE

		BEFORE CRISIS				
1% VaR S&P⇒ Dollar/TWD (p-values)	M Q_{1DAN}	5 -1.1143 (0.8674)	10 -1.6054 (0.9458)	20 -2.1902 (0.9857)	30 -2.4750 (0.9933)	40 -2.4781 (0.9934)
5% VaR S&P ⇒ Dollar/TWD (p-values)	M Q_{1DAN}	5 1.3316 (0.0915)*	10 1.3963 (0.0813)	20 0.6168 (0.2687)	30 0.2045 (0.419)	40 0.0014 (0.4994)
10% VaR S&P⇒ Dollar/TWD (p-values)	M Q_{1DAN}	5 -0.4200 (0.6628)	10 -0.3450 (0.6349)	20 -0.5061 (0.6936)	30 -0.4355 (0.6684)	40 -0.5419 (0.7061)
		AFTER CRISIS				
1% VaR S&P ⇒ Dollar/TWD (p-values)	M Q_{1DAN}	5 -0.5708 (0.7159)	10 -0.8002 (0.7882)	20 -0.9507 (0.8291)	30 -0.9489 (0.8287)	40 -0.4441 (0.6715)
5% VaR S&P ⇒ Dollar/TWD (p-values)	M Q_{1DAN}	5 2.1057 (0.0176)**	10 2.3804 (0.0086)***	20 2.5378 (0.0056)***	30 2.5471 (0.0054)***	40 2.5439 (0.0055)***
10% VaR S&P ⇒ Dollar/TWD (p-values)	M Q_{1DAN}	5 2.6072 (0.0046)***	10 3.5057 (0.0002)***	20 3.1310 (0.0008)***	30 2.5538 (0.0053)***	40 2.1597 (0.0154)**

Notes: ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively

movement in the U.S. stock market to extreme upside movements in gold futures prices. It does not show any clear evidence that an extreme downside movement in the S&P 500 Granger-caused extreme upside movements of gold futures prices before the crisis period on all VaR levels. During the crisis, however, strong evidence of Granger causality in VaRs from the U.S. stock market to the gold futures market exists. This result implies that extreme movements in the value of riskier assets (stocks) during the current crisis caused a significantly higher demand for safer assets such as gold.

TABLE 21
TESTING FOR RISK SPILLOVER FROM THE U.S. STOCK MARKET TO GOLD PRICE (DOWNSIDE RISK)

				BEFORE CRISIS		
1% VaR	M	5	10	20	30	40
S&P ⇒ Gold	Q_{1DAN}	3.5046	2.4303	1.7408	1.0235	1.0593
(down)		(0.0000)***	(0.0075)***	(0.0409)*	(0.1530)	(0.1447)
(p-values)						
5% VaR	M	5	10	20	30	40
S&P ⇒ Gold	Q_{1DAN}	4.5595	3.7247	2.7555	1.9104	1.4046
(down)		(0.0000)***	(0.0000)***	(0.0029)***	(0.0280)**	(0.0800)*
(p-values)						
10% VaR	M	5	10	20	30	40
S&P ⇒ Gold	Q_{1DAN}	1.9982	1.9383	2.0875	1.6805	1.4588
(down)		(0.0229)**	(0.0263)**	(0.0184)**	(0.0464)**	(0.07231)*
(p-values)						
				AFTER CRISIS		
1% VaR	M	5	10	20	30	40
S&P ⇒ Gold	Q_{1DAN}	-0.8676	-1.2228	0.2756	0.7704	1.3870
(down)		(0.8072)	(0.8893)	(0.3914)	(0.2205)	(0.08272)*
(p-values)						
5% VaR	M	5	10	20	30	40
S&P ⇒ Gold	Q_{1DAN}	-0.2456	-0.6376	-1.0726	-1.5426	-1.6868
(down)		(0.5970)	(0.7381)	(0.8583)	(0.9385)	(0.9542)
(p-values)						
10% VaR	M	5	10	20	30	40
S&P ⇒ Gold	Q_{1DAN}	3.1569	1.8756	1.4005	1.0970	0.8739
(down)		(0.0008)***	(0.0304)**	(0.0807)*	(0.1363)	(0.1911)
(p-values)						

Notes: ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively.

IV. Concluding Remarks

We examined the extreme risk spillover effect in international financial markets during the recent global financial crisis. We have, in various cases, obtained statistically significant results that an extreme downside movement in a market causes extreme movements in other markets during the crisis period, which is not evident before the crisis. Such spillover effects are found in various links: from the U.S. stock market

TABLE 22
TESTING FOR RISK SPILLOVER FROM THE U.S. STOCK MARKET TO GOLD PRICE (UPSIDE)

				BEFORE CRISIS		
1% VaR	M	5	10	20	30	40
S&P ⇒ Gold	Q_{1DAN}	0.3558	-0.0313	-0.3541	-0.3467	-0.4996
(Up)		(0.3610)	(0.5125)	(0.6384)	(0.6356)	(0.6913)
(p-values)						
5% VaR	M	5	10	20	30	40
S&P ⇒ Gold	Q_{1DAN}	1.4452	0.5373	0.0477	-0.0151	0.1803
(Up)		(0.0742)*	(0.2955)	(0.4810)	(0.5060)	(0.4285)
(p-values)						
10% VaR	M	5	10	20	30	40
S&P ⇒ Gold	Q_{1DAN}	0.0270	0.2212	-0.0068	0.1484	0.6500
(Up)		(0.4892)	(0.4125)	(0.5027)	(0.4410)	(0.2579)
(p-values)						
				AFTER CRISIS		
1% VaR	M	5	10	20	30	40
S&P ⇒ Gold	Q_{1DAN}	2.7115	4.8541	3.6605	2.7005	2.1406
(Up)		(0.0033)***	(0.0000)***	(0.0000)***	(0.0035)***	(0.0162)**
(p-values)						
5% VaR	M	5	10	20	30	40
S&P ⇒ Gold	Q_{1DAN}	0.0123	0.5116	0.2659	0.6698	0.6075
(Up)		(0.4951)	(0.3045)	(0.3952)	(0.2515)	(0.2718)
(p-values)						
10% VaR	M	5	10	20	30	40
S&P ⇒ Gold	Q_{1DAN}	-0.1636	0.1945	-0.0174	0.2322	0.0734
(Up)		(0.5650)	(0.4229)	(0.5069)	(0.4082)	(0.4707)
(p-values)						

Notes: ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively.

to Asian stock markets, from the stock market to the currency market of each economy under study, and from the stock market to the gold futures market.

Markets become more closely related for transmitting risks during some abnormal situations. Investors try to avoid or reduce risks in their investment decisions by reducing the amount of risky assets or by replacing risky assets with safer assets in their portfolios.

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References

Chakrabarti R., and Roll R. "East Asia and Europe during the 1997 Asian collapse: A clinical study of a financial crisis." *Journal of Financial Markets*, 5 (No. 1 2002): 1-30.

Cheung, W., Scott Fung, and Shih-Chuan Tsai. "Global Capital Market Interdependence and Spillover Effect of Credit Risk: Evidence from the 2007-2009 Global Financial Crisis." *Applied Financial Economics, Taylor and Francis Journals* 20(No.s 1-2 2010): 85-103.

Engle, R. F., and T. Bollerslev "Modelling the Persistence of Conditional Variances." *Econometric Reviews* 5 (1986): 1-50.

______, Ito T., and Lin W. "Meteor Shower or Heat Wave? Heteroskedastic Intra-Daily Volatility in the Foreign Exchange Market." *Econometrica* 59 (1990): 524-542.

______, and Magnanelli, S. "CAViaR Conditional Autoregressive Value at Risk by Regression Quantiles." *Journal of Business and Economic Statistics* 22 (2004): 524-542.

______, and Victor K. Ng. "Measuring and Testing the Impact of News on Volatility." *The Journal of Finance* 48 (No. 5 1993): 1749-1778.

Granger, C. W. J. "Testing for Causality a Personal View." *Journal of Economic Dynamics and Control* 2 (1980): 329-352.

Glosten, Lawrence R., Ravi Jagannathan, and David E. Runkle. "On the Relation between the Expected Value and the Volatility of the Nominal Excess Return on Stocks." *The Journal of Finance* 48 (No. 5 1993): 1779-1801.

Hong, Y. "A Test for Volatility Spillover with Applications to Exchange Rates." *Journal of Econometrics* 103 (2001): 183-224.

______, Yanhui Liu, and Shouyang Wang, "Extreme Risk Spillover Between Chinese Stock Markets and International Stock Markets." *China Economic Quarterly Beijing* (No. 3 2004): 703-726

______, Yanhui Liu, and Shouyang Wang. "Granger Causality in Risk and Detection of Extreme Risk Spillover between Financial Markets." *Journal of Econometrics* 150 (2009): 271-287.

J. P. Morgan. *Risk Metrics Technical Document*, 2^{nd} Edition. New York: Morgan Guaranty Trust Company, 1994.

Kose, M., Ayhan, Otrok C., and Whiteman C. H. "Understanding the Evolution of World Business Cycles." *Journal of International Economics* 75 (No. 1 2008): 110-130.

Lee, K. Y. "The Analysis of Dynamic Relations between Stock Prices and

Exchange Rates in Asian Countries." *KUKJE KYUNGJE YONGU* 9 (No. 3 2003): 259-290.

Lee, J., and H. Y. Lee. "Testing for Risk Spillover between Stock Market and Foreign Exchange Market in Korea." *Journal of Economic Research* 14 (2009): 329-340.

Longstaff, F. A. "The Subprime Credit Crisis and Contagion in Financial Markets." *Journal of Financial Economics* 97 (No. 3 2010): 436-450.

Ng, Angela. "Volatility Spillover Effects from Japan and the US to the Pacific Basin." *Journal of International Money and Finance* 19 (2000): 207-233.

Yang, J., James Kolari, and Insik Min. "Stock Market Integration and Financial Crises: the Case of Asia." *Applied Financial Economics* 13 (No. 7 2002): 477-486.

______, Cheng Hsiao, Qi Li, and Zijun Wang. "The Emerging Market Crisis and Stock Market Linkages: Further Evidence." *Journal of Applied Econometrics* 21 (No. 6 2006): 727-744.