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Measuring Financial Market Contagion Using Dually-Traded Stocks of Asian Firms*

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Abstract

This paper investigates stock market contagion between U.S. and Asian markets. To distinguish between contagion and fundamentals-based stock price comovement, we use NYSE-traded stocks issued by Asian firms. Among the results, first we find that the empirical results show significant bilateral contagion effects in returns and return volatility. Second, contagion effects from U.S. market to Asian markets are stronger than in the reverse direction, indicating that the U.S. market plays a major role in the transmission of information to foreign markets. Third, the intensity of contagion was significantly greater during the Asian financial crisis than after the crisis.

JEL classification: F37, G15.
Keywords: Asian financial crisis; ADRs; EGARCH; Contagion

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1. Introduction

The globalization of financial systems and the acceleration of information transmission have increased the risk of financial crises, as a crisis in one country can spread to other countries and bring about worldwide crises. The Mexican, Asian and Russian crashes were followed by a sequence of stock market and exchange rate crises in other markets. These financial collapses have driven researchers to ask how such shocks are transmitted internationally and why they have such intensity.

The controversy starts with the seminal work by King and Wadhwani (1990), which finds that the correlation in returns between markets increases with the volatility in each market. They interpret this as evidence supporting the 'market contagion' hypothesis. On the other hand, the traditional view stresses the role of common fundamental factors. Ross (1989) argues that market volatility is related to underlying information flow, including public information. Public information flows may then be associated with higher volatility and more pronounced comovement, all in the context of a rational approach to asset pricing.

There is now a reasonably large body of empirical studies testing for the existence of financial contagion during financial crises. Although a range of different methodologies have been presented, there exists no theoretical or empirical procedure for identifying contagion on which researchers agree.[1] The main econometric difficulties in distinguishing between the two competing explanations arise because the data on world stock markets suffer from problems of simultaneous equations, omitted variables and heteroskedasticity (Rigobon, 2003). As a result, the conventional econometric techniques for testing for the structural changes do not provide appropriate empirical results.

Craig, Dravid and Richardson (1995) (CDR, hereafter) propose alternative measures for identifying financial contagion between non-synchronous trading markets. Specifically, they exploit Nikkei index futures traded on the Chicago Mercantile

[1] The proposed methodologies to identify the contagion effect include the latent factor model (e.g., Bekaert, Harvey and Ng, 2005), correlation analysis (e.g., Forbes and Rigobon, 2002), the vector autoregressive (VAR) approach (e.g., Fravero and Giavazzi, 2002), probability models (e.g., Eichengreen, Rose and Wyplosz, 1995) and the co-exceedance approach (Bae, Karolyi and Stulz, 2003).

Exchange (CME), which are not traded during Tokyo exchange hours but reflect investors' perceptions about the Japanese stock market during U.S. trading hours. In an informationally efficient market, daytime returns of the Nikkei index futures on the CME should move one-to-one with overnight returns of the Nikkei index in the Tokyo market. As a result, other information released during U.S. trading hours, such as the daytime returns of the S&P index, should have no marginal influence on the overnight returns of the Nikkei index. In contrast, the contagion models of King and Wadhwani (1990) and others suggest that investors valuing Japanese securities ignore fundamental overnight information about Japan and instead react to observed price movements in the U.S. market. In these models, therefore, daytime returns of the S&P index will still be an important determinant of overnight returns on the Nikkei index.

CDR find that the Nikkei index futures traded in the U.S. provide complete information about contemporaneous overnight Japanese returns and the S&P index provides no additional information affecting overnight Japanese returns. These findings contradict the predictions of contagion models which include irrational traders who either overreact or only partially adjust to movements in foreign stock markets.[2]

This paper follows the approach of CDR in investigating the bilateral contagion effects between U.S. and Asian stock markets. It also examines the impact of the Asian financial crises on the extent of contagion by comparing sub-sample periods during and after the crises. In doing so, we use the NYSE-traded American Depositary Receipts (ADRs) issued by Asian firms. ADRs were developed as a method of enabling U.S. investors to trade in international securities within the U.S.[3] Since 1990, the number of Asian stocks listed on NYSE has increased significantly. If relevant information regarding the stock prices of Asian firms revealed during U.S. trading hours is

[2] By incorporating threshold effect in reaction to price changes, Ohno (1997) shows evidence suggesting an overreaction of investors to information. Ohno (2004) provide further evidence on contagion using inter-listed equity prices of Japanese and U.S. firms.

[3] ADRs are normally created by having one bank buy and deposit the actual foreign securities with another bank (called the depositary), who then issues certificates in the U.S. that represent (and are backed by) the deposited securities. These certificates may be freely traded by any investor and are commonly called American Depositary Receipts (ADRs for short). ADRs were first introduced in 1927.

incorporated into their ADRs, there would be a one-to-one correlation between daytime returns of the ADRs and overnight returns of the underlying stocks. In this sense, the ADRs play the same role as the Nikkei index futures do in the model of CDR. The contagion effect from U.S. to Asian markets can be detected by examining whether any other information released during U.S. trading hours, such as the S&P index, has additional explanatory power for the overnight returns of the underlying stocks.

To examine the contagion effect of stock market movements in Asia, we investigate whether daytime Asian stock indices have marginal effects on overnight returns of the ADRs of Asian firms listed on NYSE, conditional on the influence of daytime underlying stock returns. The impact of the Asian financial crisis on the extent of contagion is also of interest. Hence, we compare which stock indices among the Asian countries have the strongest contagion effect on ADR returns of Asian firms during and after the crisis.

Researchers have explored information transmission across international markets by examining the first and second moments of stock returns. Early studies using ARCH-type models (e.g., Bae and Karolyi, 1994; Koutmos and Booth, 1995; Hamao et al., 1990), have argued that the phenomenon of volatility spillover results from integration of international markets. Market integration is interpreted as prices in different markets reflecting the same fundamental information. On the other hand, volatility spillover represents a failure of the market to fully process information and may signal a violation of market efficiency.[4] It is noted that, by 'volatility spillover', most previous studies imply 'lagged volatility spillover of daytime returns'. A lagged volatility spillover is induced when private information is gradually incorporated into prices until all private information is revealed. In this study, however, we do not resort to lead-lag relations to test for the information efficiency. Since our methodology enables us to identify price comovement through contagion that cannot be explained by fundamentals, we examine *contemporaneous* relations of return and volatility contagion.

Much of the work on international information transmission in financial markets focuses on two hypotheses: international-center and home-bias. The *international-center*

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[4] Volatility spillover only implies information *in*efficiency, but not an arbitrage mechanism.

hypothesis suggests that a financial center plays a key role in spreading information to other markets, while the *home-bias hypothesis* implies that information flows between markets primarily radiate out from the home market.

Some research in the equity market literature has shown that the U.S. equity market more often transmits information to other markets than in the reverse direction (Ghosh et al., 1999; Kwan et al., 1995). These studies indicate that information flows are transmitted from the global financial center to offshore markets, implying that the U.S. market plays a major role in the transmission of news that is believed to be macroeconomic and global in nature (Cheung and Mak, 1992; Eun and Shim, 1989). By contrast, Shyy and Lee (1995), using Bund (German government bond) futures contracts traded in both London and Frankfurt, found that key information tends to flow from the home (Frankfurt) market to the offshore market (London), supporting the home-bias hypothesis.

Our methodology using dually-traded stocks of Asian firms provides a better understanding of this controversy by testing these two competing hypotheses, since ADRs are listed on the NYSE which may be influenced by both U.S. and Asian market conditions. We examine which has a greater influence on these Asian firms' stock prices, the U.S. stock index or any of the Asian stock indices, conditional on individual firm's fundamentals.

In this study, we find the following empirical results. First, there exist significant bilateral contagion effects in returns and return volatility between U.S. and Asian markets. Second, contagion effects are greater from U.S. market to Asian markets than in the reverse direction, indicating that the U.S. market plays a major role in the transmission of information to foreign markets. Third, the intensity of contagion was significantly greater during the Asian financial crisis than after the crisis.

The remainder of the paper is organized as follows. Section 2 describes the data and Section 3 explains the empirical methodology for identifying contagion effects. Section 4 presents the estimation results and Section 5 contains our conclusions.

2. Data

Our sample includes 22 Asian firms whose ADRs have been actively traded on the NYSE since prior to the Asian financial crisis. They are three South Korean firms, two Taiwanese firms, one Philippine firm, four Chinese firms, two Hong Kong firms and 10 Japanese firms. These data are collected from Datastream. We also collect data on stock indices for each country including the Hong Kong Hang Seng index, Korea SE composite, Japanese Nikkei 225 index, Taiwan SE index, Philippine PSE composite index, Shanghai SE composite, and the U.S. S&P 500 index. We obtained the stock indices data from Datastream and Bloomberg.

The Asian financial crisis began to emerge on July 2, 1997 when Thailand abandoned its currency peg to the U.S. dollar. When the Thai Baht plunged 15% against the U.S. dollar, it caused a currency devaluation panic which spread over the rest of Southeast Asia, especially Malaysia, Indonesia and the Philippines. Southeast Asia's crisis gradually rolled north into other Asian financial markets. On October 23, 1997, Hong Kong's stock prices collapsed. The Hang Seng Index dropped 10.4% on the day and dropped a further 13.1% on the following day. Following the subsequent stock market collapses in NY and London, the Hang Seng Index again dropped 13.7% on October 28, 1997. In the wake of the Asian market downturn, Moody's lowered the credit rating of South Korea several times. The Seoul stock exchange fell by 7% on November 8, the biggest one-day drop recorded to date. On November 24, stocks fell another 7.2% on fears that the IMF would demand tough reforms.

Since there are no ADRs of Thai firms, we define the crisis period as stretching from October 17, 1997 to December 22, 1997, which covers the turmoil period of Hong Kong and Korea according to Forbes and Rigobon (2002, p.2244). In order to be able to compare the differences during and after the Asian crises, our sample period starts from October 17, 1997 and ends December 2005.

Daily opening and closing prices for the underlying stocks and their ADRs are used in this paper. Let $O_{i,t}$ and $C_{i,t}$ be the i th stock's opening and closing price on day t, respectively. We divide daily (close-to-close) returns of each underlying stock, $R_{i,t}$, into overnight (close-to-open) returns, $R_{N,it}$, and daytime (open-to-close) returns, $R_{D,it}$. These are all continuously compounded returns and are defined as follows:

$$R_{i,t} = R_{N,it} + R_{D,it}, \quad i = 1,....,n,$$

where

$$R_{N,it} = \ln(O_{i,t} / C_{i,t-1})$$
$$R_{D,it} = \ln(C_{i,t} / O_{i,t}).$$

The overnight and daytime returns on the ADRs are defined in the similar way. Let $O_{i,t}^{ADR}$ and $C_{i,t}^{ADR}$ be the i th stock's opening and closing price on the NYSE on day t, respectively. We divide daily returns of each ADR, $R_{i,t}^{ADR}$, into overnight returns, $R_{N,it}^{ADR}$, and daytime returns, $R_{D,it}^{ADR}$.

$$R_{i,t}^{ADR} = R_{N,it}^{ADR} + R_{D,it}^{ADR}, \quad n = 1,.....,n,$$

where

$$R_{N,it}^{ADR} = \ln(O_{i,t}^{ADR} / C_{i,t-1}^{ADR})$$
$$R_{D,it}^{ADR} = \ln(C_{i,t}^{ADR} / O_{i,t}^{ADR}).$$

To illustrate the time difference in the daytime and overnight trading hours between Asian and US markets, Figure 1 provides an example illustration for Japan/Korea and the U.S. Note that the Japan/Korea daytime on day t and the U.S. overnight on day t overlap, and the Japan/Korea overnight on day t and the U.S. daytime on day $t-1$ overlap. However, the Japanese/Korean daytime and the U.S. overnight on day t do not overlap. The daytime segment in one market is a subset of the overnight segment in other market and, as a result, information regarding stock price movements in one market is available when the other market opens.

Table 1 reports basic statistics for daytime and overnight return series for 22 dually-traded stocks. It is noted that daytime returns are more volatile (as measured by standard deviation) than overnight returns for most of the underlying stocks traded within their local markets. On the other hand, for most of the corresponding ADRs, the overnight volatilities are higher than the daytime volatilities. These results are consistent with the findings of previous studies (Wang, et al., 2002; Kim and Kim, 2004). Most corporate information is released and most trading takes place during the daytime in local markets. This may explain why we observe higher daytime volatility in the local markets and higher overnight volatility in the U.S.

Table 1 also reports the cross-correlation coefficients between overnight returns and daytime returns on underlying stocks and their ADRs. In most cases, the cross-correlation coefficient between the underlying daytime returns ($R_{D,t}$) and the ADR overnight returns ($R_{N,t}^{ADR}$) is greater than the cross-correlation between the underlying overnight returns ($R_{N,t}$) and the one-period lagged ADR daytime returns ($R_{D,t-1}^{ADR}$). This suggests that information transmission from daytime local markets to the overnight U.S. market is stronger than that from the daytime U.S. market to overnight local markets.

Next, we divide the whole sample into two sub-periods: during the crisis and after the crisis. Contrary to our expectations, the cross-correlation coefficients between the underlying stocks' daytime returns and the ADRs' overnight returns and those between the underlying overnight returns and the one-period lagged ADR daytime returns are not necessarily higher during the crisis than after the crisis. Indeed the volatilities of returns are higher during the crisis, but this does not lead to higher correlation during this period.

3. Models

We use a two-stage procedure to investigate the contagion effect in returns and return volatilities of the dually-traded stocks of Asian firms. In the first stage, we estimate the unexpected returns for each individual stock and for each stock index that cannot be predicted based on public information available when the market opens. In the second stage, we use the estimated unexpected returns and standardized volatilities to explore whether the stock prices of Asian firms respond to information other than their implied stock price movements.

Although several GARCH model specifications have been proposed in attempts to describe volatility clustering and the asymmetric nature of processes leading to volatility, we employ the exponential GARCH (EGARCH) model developed by Nelson (1991). Unlike ordinary GARCH and GJR-GARCH models, the EGARCH model has the advantage that we do not need to impose non-negativity constraints on parameters. The volatility equation of the EGARCH model is expressed with the following form:

$$\ln(\sigma_t^2) = \omega + \gamma(|z_{t-1}| - E|z_{t-1}| + \theta z_{t-1}) + \beta \ln(\sigma_{t-1}^2), \quad z_{t-1} = \varepsilon_{t-1} / \sigma_{t-1}, \tag{1}$$

where σ_t^2 is the conditional volatility, z_t the standardized residual and E an expectation operator. In this model, $|z_{t-1}| - E|z_{t-1}|$ determines the 'size effect' and θz_{t-1} captures the 'sign effect' of volatility shocks. If the asymmetric volatility parameter θ is significantly negative, then negative returns and bad news have a larger impact on volatility than positive returns and good news.

In the first stage, we extract the unexpected returns component from each stock's returns data using the following EGARCH(1,1)-*t* model. That is, for the daytime returns of the underlying stock,

$$\begin{aligned} &R_{D,t} = \alpha_0 + \alpha_1 R_{N,t} + e_{D,t}, \quad e_{D,t} \sim Student-t(0, h_{D,t}, v), \\ &\ln(h_{D,t}) = \beta_0 + \beta_1 |z_{D,t-1}| + \beta_2 z_{D,t-1} + \beta_3 \ln(h_{D,t-1}), \\ &where \ z_{D,t-1} = \frac{e_{D,t-1}}{\sqrt{h_{D,t-1}}}. \end{aligned} \tag{2}$$

The model for the corresponding ADR returns is similarly constructed as follows:

$$\begin{aligned} &R_{D,t}^{ADR} = \gamma_0 + \gamma_1 R_{N,t}^{ADR} + e_{D,t}^{ADR}, \quad e_{D,t}^{ADR} \sim Student-t(0, h_{D,t}^{ADR}, v), \\ &\ln(h_{D,t}^{ADR}) = \mu_0 + \mu_1 |z_{D,t-1}^{ADR}| + \mu_2 z_{D,t-1}^{ADR} + \mu_3 \ln(h_{D,t-1}^{ADR}), \\ &where \ z_{D,t-1}^{A} = \frac{\varepsilon_{D,t-1}^{A}}{\sqrt{h_{D,t}^{ADR}}}. \end{aligned} \tag{3}$$

Running the estimates for equations (2) and (3), we obtain the unexpected returns $\hat{e}_{D,t}$ and $\hat{e}_{D,t}^{ADR}$, and the standardized volatility components $\hat{G}_{D,t-1}(= \beta_1 |z_{D,t-1}| + \beta_2 z_{D,t-1})$ and $\hat{G}_{D,t-1}^{ADR}(= \mu_1 |z_{D,t-1}^{ADR}| + \mu_2 z_{D,t-1}^{ADR})$. The conditional errors are assumed to follow Student's t-distribution. The degree of freedom v is estimated simultaneously. The use of Student's t-distribution rather than the normal distribution and the generalized error distribution (GED) allows for more efficient estimation of the conditional errors (Susmel and Engle, 1994; Bollerslev, Engle and Nelson, 1994). If the standardized error (z_{t-1}) follows Student's t-distribution, then $E(|z_{t-1}|)$ equals

$\sqrt{(v-2)/\pi}\ \Gamma((v-1)/2)/\Gamma(v/2)$, which is a constant. The original EGARCH specification of equation (1) can be therefore represented by equations (2) and (3).

We also apply the same estimation method to stock indices for Hong Kong, Korea, Japan, Taiwan, the Philippines, China and the U.S. For example, with the Hong Kong Hang Seng index, we extract the unexpected return $\hat{e}_{HK,t}$ and the standardized volatility component $\hat{G}_{HK,t-1}(=\varphi_1|z_{HK,t-1}|+\varphi_2 z_{HK,t-1})$ from the following estimation equations:

$$\begin{aligned} &R_{HK,D,t} = \phi_0 + \phi_1 R_{HK,N,t} + e_{HK,t}, \quad e_{HK,t} \sim Student\ -t(0, h_{HK,t}, v), \\ &\ln(h_{HK,t}) = \varphi_0 + \varphi_1 |z_{HK,t-1}| + \varphi_2 z_{HK,t-1} + \varphi_3 \ln(h_{HK,t-1}), \\ &where\ z_{HK,t-1} = \frac{e_{HK,t-1}}{\sqrt{h_{HK,t-1}}}. \end{aligned} \tag{4}$$

In the second stage of our test procedure, we estimate the EGARCH models which include several exogenous variables in the mean and variance equations. We first focus on the contagion effect from Asian markets to the U.S. The conditional mean and volatility of overnight returns of Asian ADRs are formulated as follows:

$$\begin{aligned} &R^{ADR}_{N,t} = a_0 + a_1 R^{ADR}_{D,t-1} + a_2\hat{e}_{D,t} + a_3\hat{e}_{HK,t} + a_4\hat{e}_{KR,t} + a_5\hat{e}_{JP,t} + a_6\hat{e}_{TW,t} + a_7\hat{e}_{PH,t} + a_8\hat{e}_{CH,t} + \varepsilon^{ADR}_{N,t}, \\ &\varepsilon^{ADR}_{N,t} \sim Student - t(0, h^{ADR}_{N,t}, v) \end{aligned} \tag{5}$$

$$\begin{aligned} &\ln(h^{ADR}_{N,t}) = b_0 + b_1|z^{ADR}_{N,t-1}| + b_2 z^{ADR}_{N,t-1} + b_3 \ln(h^{ADR}_{N,t-1}) + b_4\hat{G}_{D,t} + b_5\hat{G}_{HK,t} + b_6\hat{G}_{KR,t} + b_7\hat{G}_{JP,t} \\ &+ b_8\hat{G}_{TW,t} + b_9\hat{G}_{PH,t} + b_{10}\hat{G}_{CH,t}, \quad where\ z^{ADR}_{N,t-1} = \frac{\varepsilon^{ADR}_{N,t-1}}{\sqrt{h^{ADR}_{N,t-1}}}. \end{aligned}$$

The independent variables in the mean and volatility equations include not only the estimated unexpected return and volatility of the underlying stock *per se* ($\hat{e}_{D,t}$ and $\hat{G}_{D,t}$), but also other contagion factor candidates, such as the stock index returns and volatilities of Hong Kong, Korea and Japan ($\hat{e}_{HK,t}$, $\hat{e}_{KR,t}$, $\hat{e}_{JP,t}$ and $\hat{G}_{HK,t}$, $\hat{G}_{KR,t}$, $\hat{G}_{JP,t}$). Unlike Hong Kong and Korea, Japan did not suffer from a crisis, though stock prices in Japan are likely to influence other Asian stock markets and hence are also considered. The stock index returns and volatilities of Taiwan, the Philippines and China ($\hat{e}_{TW,t}$, $\hat{e}_{PH,t}$, $\hat{e}_{CH,t}$ and $\hat{G}_{TW,t}$, $\hat{G}_{PH,t}$, $\hat{G}_{CH,t}$) are added, depending on the nationality of the firm considered.

It is noted that since the daytime trading hours on day t in Asian markets overlap with the overnight hours on day t in the U.S. market, the time script t in the daytime return of the underlying stock and country stock indices in Asian markets are contemporaneous with the time script t in the overnight return variable of the ADRs traded in the U.S. market. The estimated volatility components at time t can be exogenously included in the volatility equation of the EGARCH model, because Asian markets close before the U.S. market opens and the estimated volatility components at time t are therefore predetermined.

In the above model (5), the parameter a_2 (b_4) is the coefficient of the market-adjusted unexpected daytime returns (volatility) of the underlying stock on the overnight return (volatility) of its ADR. Hence, this coefficient measures a spillover effect in unexpected returns (volatility) from the underlying stock in the local market to its corresponding ADR in the U.S. market. The key parameters are $a_3 \sim a_8$ ($b_5 \sim b_{10}$) for the hypothesis that there is contemporaneous returns (volatility) contagion from Asian markets to the U.S. market. Information relevant to Asian firms during Asian trading hours will be reflected by the daytime returns (volatility) of the underlying stock. If the Asian stock indices have a significant influence on overnight ADR returns, the contagion effects would be detectable.

The contagion mechanism from U.S. to Asian markets is similarly constructed with the following specifications:

$$
\begin{aligned}
&R_{N,t} = c_0 + c_1 R_{D,t-1} + c_2 \hat{e}^{ADR}_{D,t-1} + c_3 \hat{e}_{US,t-1} + \varepsilon_{N,t}, \quad \varepsilon_{N,t} \sim Student - t(0, h_{N,t}, \nu), \\
&\ln(h_{N,t}) = d_0 + d_1 \left| z_{N,t-1} \right| + d_2 z_{N,t-1} + d_3 \ln(h_{N,t-1}) + d_4 \hat{G}^{ADR}_{D,t-1} + d_5 \hat{G}_{US,t-1}, \\
&where\ z_{N,t-1} = \frac{\varepsilon_{N,t-1}}{\sqrt{h_{N,t-1}}}.
\end{aligned}
\tag{6}
$$

The overnight trading hours on day t in Asian markets overlap with the daytime hours on day $t-1$ in the U.S. market, so the time script $t-1$ in the daytime return variables of the ADR and U.S. stock index is contemporaneous with the time script t in the overnight return of the underlying stock in a local market. If information on Asian stock prices revealed during U.S. trading hours is perfectly incorporated into their ADR prices, then the estimated unexpected return and volatility ($\hat{e}_{US,t}$ and $\hat{G}_{US,t}$) have no additional explanatory power for returns on the underlying stocks. The significance of c_3 and d_5 indicates contagion from the U.S. to Asian markets.

Next, we examine whether the contagion effect is greater during the Asian financial crisis than the subsequent tranquil period. To address this issue, the previous models of equation (5) and (6) are employed with some modifications as follows.

For the ADRs,

$$\begin{aligned}
R_{N,t}^{ADR} &= f_0 + f_1 R_{D,t-1}^{ADR} + (f_2 + f_2^d CD_t)\hat{e}_{D,t} + (f_3 + f_3^d CD_t)\hat{e}_{HK,D,t} + (f_4 + f_4^d CD_t)\hat{e}_{KR,D,t} \\
&+ (f_5 + f_5^d CD_t)\hat{e}_{JP,D,t} + (f_6 + f_5^d CD_t)\hat{e}_{TW,D,t} + (f_7 + f_7^d CD_t)\hat{e}_{PH,D,t} + (f_8 + f_8^d CD_t)\hat{e}_{CH,D,t} + \varepsilon_{D,t}^{ADR}, \\
\varepsilon_{N,t}^{ADR} &\sim Student-t(0, h_{N,t}^{ADR}, \nu), \\
\ln(h_{N,t}^{ADR}) &= g_0 + g_1 \left| z_{N,t-1}^{ADR} \right| + g_2 z_{N,t-1}^{ADR} + g_3 \ln(h_{D,t-1}^{ADR}) + (g_4 + g_4^d CD_t)\hat{G}_{D,t} + (g_5 + g_5^d CD_t)\hat{G}_{HK,D,t} \\
&+ (g_6 + g_6^d CD_t)\hat{G}_{KR,D,t} + (g_7 + g_7^d CD_t)\hat{G}_{JP,D,t} + (g_8 + g_8^d CD_t)\hat{G}_{TW,D,t} + (g_9 + g_9^d CD_t)\hat{G}_{PH,D,t} \\
&+ (g_{10} + g_{10}^d CD_t)\hat{G}_{CH,D,t}, \\
where\ z_{N,t-1}^{ADR} &= \frac{\varepsilon_{N,t-1}^{ADR}}{\sqrt{h_{N,t-1}^{ADR}}}.
\end{aligned} \tag{7}$$

For the underlying stocks,

$$\begin{aligned}
R_{N,t} &= k_0 + k_1 R_{D,t-1} + (k_2 + k_2^d CD_t)\hat{e}_{D,t-1}^{ADR} + (k_3 + k_3^d CD_t)\hat{e}_{US,D,t-1} + \varepsilon_{N,t}, \\
\varepsilon_{N,t} &\sim Student-t(0, h_{N,t}, \nu), \\
\ln(h_{N,t}) &= l_0 + l_1 \left| z_{N,t-1} \right| + l_2 z_{N,t-1} + l_3 \ln(h_{N,t-1}) + (l_4 + l_4^d CD_t)\hat{G}_{D,t-1}^{ADR} + (l_5 + l_5^d CD_t)\hat{G}_{US,D,t-1}, \\
where\ z_{N,t-1} &= \frac{\varepsilon_{N,t-1}}{\sqrt{h_{N,t-1}}}.
\end{aligned} \tag{8}$$

We use a dummy variable (CD_t) which takes the value 1 during the Asian financial crisis (Oct. 17, 1997 ~ Dec. 22, 1997) and 0 otherwise. If there is more contagion during the crisis period than the post-crisis period, then coefficients with superscripts of d are expected to be significantly positive.

4. Empirical Results

Table 2-1 reports the estimation results of model (5), the second-stage model for Asian ADRs on the NYSE. The parameter a_2 (b_4) is the coefficient of the market-adjusted unexpected daytime returns (volatility) of the underlying stock on the overnight returns (volatility) of its ADR. All coefficient estimates of a_2, except for that of Philippine Telecom, and all estimates of b_4 are significantly positive. This indicates a contemporaneous return (volatility) spillover effect from the local market to the U.S. market.

The more important result in Table 2-1 is the significance of contemporaneous contagion effects of Asian stock indices on ADR stock prices. The parameters $a_3 \sim a_8$ are the coefficients for the unexpected daytime returns of the Asian stock indices (Hong Kong, Korea, Japan, Taiwan, the Philippines and China, respectively) on the overnight returns of the ADR. Almost all estimates of the coefficients $a_3 \sim a_8$ are positive and statistically significant at the one or five percent level for each estimation equation. It should be noted that not only the stock index of the home country but also those of neighboring countries have a marginal influence on the overnight returns of ADRs. For example, in the case of POSCO, Korea's biggest steel manufacturer, an unexpected jump in the Korea SE composite index has been shown to cause an increase in POSCO's ADR returns, conditional on the influence of the daytime underlying stock returns. Furthermore, the Hong Kong Hang Seng index and Japanese Nikkei 225 index also have a marginal effect on the overnight returns of POSCO's ADR. Such results support the hypothesis of contemporaneous returns contagion from Asian markets to the U.S. market.

The estimation results of the variance equations also confirm the presence of contagion effects, though the volatility contagion is not as strong as the contagion in returns. The parameters $b_5 \sim b_{10}$ are the coefficients representing the effects of volatility contagion. The firms from Korea, Taiwan, the Philippines and Japan have significantly positive volatility coefficients for the stock indices of their home country as well as those of neighboring countries. Firms from Hong Kong do not demonstrate volatility contagion and Chinese stock returns are affected not by Chinese stock index but by Korean stock index.

The estimated coefficient b_3 shows little evidence of a volatility asymmetry between positive and negative news. Furthermore, although not reported, the estimated degree of freedom ν is around 3 ~ 5, which is much smaller than a normal distribution. This result supports the assumption of Student's t-distribution for conditional errors in the exponential GARCH (EGARCH) specification.

Table 2-2 presents the estimation results of model (6), the second-stage model in the opposite direction, i.e. contagion from the U.S. market to local markets. The coefficient estimates indicating return and volatility spillover effects (c_2 and d_4) are all positive and almost all statistically significant at the one percent level. Comparing the results presented in Tables 2-1 and 2-2, we find that the estimate of the return spillover coefficient from the Asian markets to the US market, a_2, is much greater in magnitude than the estimate of the return spillover coefficient in the opposite direction, c_2. Specifically, the return spillover from the underlying stock in the local market to its corresponding ADR in the U.S. market is much stronger than the return spillover effect in the reverse direction. These results are consistent with those in Table 1, showing that information transmission from daytime local market to the overnight U.S. market is stronger than that from the daytime U.S. market to overnight local market.

Table 2-2 also reports the results of return and volatility contagion effects from the U.S. market to Asian markets. All coefficient estimates of return contagion, c_3, and most estimates of volatility contagion, d_5, are statistically significant at the one or five percent levels. These results indicate a violation of information efficiency in that the U.S. stock index has a marginal explanatory power for both the overnight underlying stock returns and volatility of Asian firms.

Another noteworthy point is that the contagion effect of the U.S. stock index appears to be higher in magnitude than that of the Asian stock indices, as can been seen from the results presented in Tables 2-1 and 2-2. This indicates that, conditional on the influence of fundamentals, the information transmission about macroeconomic and global news from the U.S. market is stronger than from the home market. Therefore, it supports the international-center hypothesis emphasizing the key role of the U.S. market in the transmission of information to foreign markets.

Next, we examine the impact of the Asian financial crisis on contagion between U.S. and Asian markets. Table 3-1 displays the estimation results of the contagion model with an Asian financial crisis dummy variable (7). The coefficients $f_3^d \sim f_8^d$ ($g_5^d \sim g_{10}^d$) measure the difference in the returns (volatility) contagion effect from Asia to the U.S.

during and after the Asian financial crisis. Positive values are interpreted as indicating greater contagion in unexpected returns (volatility) from Asia to the U.S. during the crisis than in the post-crisis period.

As shown in the upper panel of Table 3-1, most firms from Korea and Hong Kong have significantly positive coefficient estimates for the stock indices of their home countries, while the coefficient estimates of stock indices of neighboring countries are insignificant. Firms from the other sample countries do not demonstrate contagion effects.

It seems puzzling that some estimated coefficients, f_2^d, measuring whether a spillover effect is stronger in the crisis period, are significantly negative. However, the firms with the negative coefficients are likely to have positive contagion effects. This may indicate that, during the Asian financial crisis, the correlation between ADRs and their underlying stocks declines because investors tend to ignore fundamental information and instead react to the movement of Asian stock indices. The volatility contagion effects, reported in the lower panel of Table 3-1, do not appear to be significant, unlike the return contagion effects described above.

Table 3-2 presents the estimation results of the models for testing contagion effects from the U.S. to Asia (8). The key parameters (k_3^d and l_5^d) are the coefficient representing the difference in the returns and volatility contagion during the Asian financial crisis. Surprisingly, the results shows that the return contagion from the U.S. market is significantly greater during the crisis period than in the post-crisis period, despite the crisis not originating in the U.S. but in Asian counties.

Taken together, the above results suggest that contagion effects during the Asian financial crisis come not only from the crisis countries (Hong Kong and Korea) but also from big country (U.S.). It should be noted, however, that the stock indices of Hong Kong and Korea affect the ADRs of their own countries, while the U.S. stock index affects Asian underlying stocks. The repercussion through the U.S. market has been overlooked by the existent literature on contagion, as it generally focuses on the direct contagion effects within Asian countries.

5. Conclusion

In this paper, we investigate stock market contagion between U.S. and Asian markets. To distinguish between contagion and fundamentals-based stock price comovement, we examine NYSE-traded stocks issued by Asian firms. Using these, we find the following empirical results. First, there exist significant bilateral contagion effects in returns and return volatility. Second, contagion effects from the U.S. market to Asian markets are stronger than in the reverse direction, indicating that U.S. market plays a major role in the transmission of information to foreign markets. Third, the intensity of contagion is significantly greater during the Asian financial crisis than after the crisis.

The methodology used in this paper has the advantage of distinguishing between contagion and fundamentals-based stock price comovement for non-synchronous trading markets in that it is possible to control for the fundamental factors embedded in the dually-traded stock prices and identify the impact of other factors such as country stock indices. On the other hand, the cost of this approach is that ADRs trade less on the NYSE than they do in their local markets. The main concern may be that close-to-open returns might be computed on only part of the trading day due to infrequent trading. However, we do not regard that this issue is important, as Chang et al. (1995) has shown that intraday returns of sample of Japanese ADRs can be reliably measured even for just the last five minutes of trading. Further investigation might be necessary to confirm whether this evidence is applicable to other Asian firms as well.

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Table 1: Basic statistics on the dually-traded stocks of Asian firms

		Underlying stock			A D R			Whole period		During the crisis		After the crisis	
		Mean (%)	Std. Dev (%)	ρ	Mean (%)	Std. Dev (%)	ρ	$\rho(R_{N,t}, R^{ADR}_{D,t-1})$	$\rho(R^{ADR}_{N,t}, R_{D,t})$	$\rho(R_{N,t}, R^{ADR}_{D,t-1})$	$\rho(R^{ADR}_{N,t}, R_{D,t})$	$\rho(R_{N,t}, R^{ADR}_{D,t-1})$	$\rho(R^{ADR}_{N,t}, R_{D,t})$
Korea:													
Korea Electric Power	D	0.082	1.751	-0.020	0.015	1.908	0.002	0.064	0.290	0.219	0.598	0.059	0.244
	N	-0.047	2.358	-0.038	0.014	2.126	0.076						
Posco	D	0.038	2.485	-0.054	-0.048	2.178	0.036	0.249	0.537	-0.019	0.540	0.270	0.545
	N	0.028	1.906	0.002	0.091	2.253	0.077						
SK Telecom	D	0.156	2.841	-0.025	0.027	2.397	-0.019	0.303	0.552	0.089	0.451	0.332	0.565
	N	-0.079	2.345	0.037	0.022	2.674	0.089						
Taiwan:													
Taiwan Semicon	D	0.010	1.953	-0.162	-0.025	2.804	0.048	0.492	0.446	0.388	0.584	0.503	0.435
	N	0.021	1.930	0.158	0.048	2.438	-0.020						
Macronix	D	-0.296	2.946	-0.125	-0.079	3.172	0.014	0.314	0.415	0.285	0.615	0.316	0.407
	N	0.215	2.231	0.193	-0.010	3.310	0.090						
The Philippines:													
Philippine Telecom	D	-0.147	3.937	-0.020	0.106	1.666	-0.035	0.188	0.162	0.305	0.006	0.187	0.169
	N	0.101	3.042	0.026	-0.097	1.684	0.153						
China:													
Guangshen Railway	D	-0.154	2.649	0.029	0.016	1.866	-0.074	0.232	0.632	0.337	0.736	0.222	0.622
	N	0.158	1.527	0.060	-0.011	2.230	0.079						
Sinopec Shanghai	D	-0.046	3.514	0.029	-0.041	1.858	0.034	0.331	0.723	0.762	0.659	0.278	0.725
	N	0.066	1.830	-0.006	0.060	2.851	0.091						
China Eastern Airlines	D	-0.224	3.293	-0.062	-0.104	1.908	-0.008	0.313	0.653	0.642	0.714	0.264	0.650
	N	0.206	1.886	-0.019	0.084	2.472	0.105						
China Southern Airlines	D	-0.168	3.495	0.053	-0.094	2.222	-0.023	0.317	0.710	0.762	0.730	0.276	0.709
	N	0.140	1.793	0.070	0.067	2.955	0.122						

		Underlying stock			A D R			Whole period		During the crisis		After the crisis	
		Mean (%)	Std. Dev (%)	ρ	Mean (%)	Std. Dev (%)	ρ	$\rho(R_{N,t}, R^{ADR}_{D,t-1})$	$\rho(R^{ADR}_{N,t}, R_{D,t})$	$\rho(R_{N,t}, R^{ADR}_{D,t-1})$	$\rho(R^{ADR}_{N,t}, R_{D,t})$	$\rho(R_{N,t}, R^{ADR}_{D,t-1})$	$\rho(R^{ADR}_{N,t}, R_{D,t})$
Hong Kong:													
APT Satellite	D	0.150	2.930	0.012	-0.157	3.513	-0.007	0.269	0.298	0.130	0.335	0.270	0.299
	N	-0.256	2.645	0.057	0.046	2.468	0.083						
Asia Satellite Telecom	D	0.038	2.635	0.012	-0.070	1.515	0.043	0.196	0.701	0.313	0.473	0.193	0.704
	N	-0.055	1.478	0.027	0.049	2.268	0.073						
Japan:													
Hitachi	D	-0.042	1.623	0.026	0.125	1.243	-0.008	0.442	0.695	0.558	0.488	0.440	0.702
	N	0.027	1.634	0.073	-0.139	1.832	0.100						
Honda Motor	D	-0.059	1.564	-0.017	0.023	1.025	-0.045	0.348	0.655	0.589	0.610	0.344	0.656
	N	0.078	1.554	0.072	-0.001	1.694	0.036						
Kubota	D	-0.087	2.140	-0.017	0.085	0.873	0.018	0.093	0.590	0.132	0.656	0.092	0.585
	N	0.127	1.673	0.000	-0.044	1.982	0.079						
Kyocera	D	-0.015	1.903	-0.012	0.092	1.454	-0.017	0.452	0.691	0.415	0.543	0.454	0.694
	N	0.022	1.868	0.066	-0.084	2.191	0.094						
Matsushita Elec.	D	-0.100	1.472	-0.013	0.215	1.154	0.036	0.309	0.652	0.262	0.479	0.311	0.658
	N	0.100	1.242	0.064	-0.214	1.703	0.090						
NTT	D	-0.055	1.640	0.005	0.105	1.377	-0.016	0.359	0.665	0.431	0.411	0.355	0.673
	N	0.021	1.511	0.050	-0.137	1.875	0.089						
Sony	D	-0.054	1.471	-0.005	0.121	1.351	-0.026	0.555	0.673	0.250	0.697	0.571	0.673
	N	0.045	1.713	0.125	-0.129	1.785	0.053						
TDK	D	-0.019	2.069	-0.087	0.063	1.135	0.040	0.272	0.658	0.513	0.670	0.266	0.659
	N	0.003	1.951	0.040	-0.078	2.182	0.029						
Nissan Motor	D	-0.096	1.849	-0.008	-0.054	1.576	0.018	0.292	0.574	0.562	0.647	0.281	0.570
	N	0.123	1.756	0.095	0.082	1.971	0.124						
Sanyo	D	-0.122	1.966	-0.029	-0.037	1.826	0.026	0.103	0.474	0.386	0.704	0.098	0.463
	N	0.107	1.645	0.099	0.026	2.645	0.030						

Note:

D indicates daytime returns and N overnight returns. ρ is the first order auto-correlation coefficient.

Whole period: Oct. 17, 1997 ~ Dec. 2005; During the crisis: Oct. 17, 1997 ~ Dec. 22, 1997; Post-crisis period: Dec. 23, 1997 ~ Dec. 2005.

Table 2-1: Analysis of contemporaneous contagion effects from Asia to the U.S.

Mean equation	a_0	a_1	a_2	a_3	a_4	a_5	a_6	a_7	a_8
Korea:									
Korea Electric Power	0.0003	-0.0976 [a]	0.2979 [a]	0.1011 [a]	0.3412 [a]	-0.0146			
POSCO	0.0011 [a]	-0.0678 [a]	0.4509 [a]	0.1277 [a]	0.0918 [a]	0.0924 [a]			
SK Telecom	0.0000	-0.0452 [a]	0.4386 [a]	0.1741 [a]	0.1380 [a]	0.0296			
Taiwan:									
Taiwan Semicon	0.0010 [a]	0.0149	0.3252 [a]	0.1419 [a]	0.0684 [a]	0.1309 [a]	0.2061 [a]		
Macronix	0.0000	-0.1166 [a]	0.3873 [a]	0.0804 [b]	0.0400	0.0723 [c]	0.1053 [b]		
The Philippines:									
Philippine Telecom	-0.0006 [a]	0.0088	0.0063	0.0876 [a]	0.0201	0.0499 [b]		0.3359 [a]	
China:									
Guangshen Railway	-0.0004 [b]	-0.0836 [a]	0.4553 [a]	0.0442 [c]	-0.0054	0.0998 [a]			0.0096
Sinopec Shanghai	0.0002	-0.0969 [a]	0.5136 [a]	0.0467 [b]	0.0222	0.0627 [a]			0.0096
China Eastern Airlines	-0.0003	-0.0123	0.3051 [a]	0.0505 [b]	0.0209	0.0441 [b]			0.0077
China Southern Airlines	-0.0005	-0.1238 [a]	0.5492 [a]	0.1989 [a]	0.0147	0.0313			0.0385
Hong Kong:									
APT Satellite	-0.0012 [a]	-0.0530 [a]	0.1772 [a]	0.0827 [a]	0.0452 [b]	0.0798 [b]			
Asia Satellite Telecom	0.0001	-0.1369 [a]	0.4583 [a]	0.0159	0.0317 [b]	0.0532 [a]			
Japan:									
Hitachi	-0.0016 [a]	-0.0428 [b]	0.6657 [a]	0.0710 [a]	0.0297 [b]	0.1449 [a]			
Honda Motor	0.0000	-0.0471 [b]	0.6038 [a]	0.0720 [a]	0.0259 [b]	0.1007 [a]			
Kubota	-0.0001	-0.0797 [a]	0.4898 [a]	0.0203	0.0021	0.0635 [b]			
Kyocera	-0.0013 [a]	-0.0837 [a]	0.7037 [a]	0.0680 [a]	0.0517 [a]	0.1212 [a]			
Matsushita Elec.	-0.0016 [a]	-0.1731 [a]	0.6584 [a]	0.0860 [a]	0.0383 [a]	0.1031 [a]			
NTT	-0.0012 [a]	-0.0863 [a]	0.6389 [a]	0.0310	0.0177	0.1184 [a]			
Sony	-0.0012 [a]	-0.0223	0.6196 [a]	0.0857 [a]	0.0396 [a]	0.1554 [a]			
TDK	-0.0012 [a]	0.0107	0.6018 [a]	0.0397	0.0406 [b]	0.1776 [a]			
Nissan Motor	-0.0001	-0.1142 [a]	0.5404 [a]	0.0003	0.0176	0.0833 [a]			
Sanyo	-0.0003	-0.1729 [a]	0.5038 [a]	0.1067 [a]	-0.0165	0.1757 [a]			

Variance equation	b_0	b_1	b_2	b_3	b_4	b_5	b_6	b_7	b_8	b_9	b_{10}
Korea:											
Korea Electric Power	-0.3157 [a]	0.0892 [a]	0.0237 [b]	0.9814 [a]	0.4803 [a]	0.3412	0.1196 [b]	0.2755 [b]			
POSCO	-0.1280 [a]	-0.0229 [a]	-0.0025	0.9926 [a]	0.4991 [a]	0.3916 [a]	0.0386 [a]	0.2038 [a]			
SK Telecom	-0.1923 [a]	0.0352 [a]	0.0104	0.9928 [a]	0.8001 [a]	-0.3341	0.0034	0.2213 [b]			
Taiwan:											
Taiwan Semicon	-0.3733 [a]	0.0935 [a]	-0.0061	0.9767 [a]	0.5857 [b]	0.6162 [c]	0.0226	0.1621	0.4032 [b]		
Macronix	-0.2406 [a]	0.1110 [a]	-0.0454 [a]	0.9795 [a]	0.2278 [b]	0.0479	-0.1407	-0.1309	0.1318		
The Philippines:											
Philippine Telecom	-1.3550 [a]	0.2004 [a]	-0.0423 [c]	0.8924 [a]	0.1335 [c]	1.4230 [b]	0.0663	0.4879 [c]		1.0457 [a]	
China:											
Guangshen Railway	-0.5086 [a]	0.0696 [a]	-0.0153	0.9675 [a]	1.2688 [a]	0.0934	0.1407 [a]	0.0979			-0.0159
Sinopec Shanghai	-4.2042 [a]	0.3994 [a]	-0.0532	0.6236 [a]	6.7172 [a]	-0.5190	1.0142 [a]	0.3899			-0.0941
China Eastern Airlines	-4.3490 [a]	0.5170 [a]	-0.0226	0.6105 [a]	6.8532 [a]	1.1124	1.1661 [a]	-0.5189			-0.1952
China Southern Airlines	-1.8343 [a]	0.2187 [a]	-0.0393 [c]	0.8482 [a]	2.5711 [a]	-0.0698	0.3768 [a]	0.2596			-0.0338
Hong Kong:											
APT Satellite	-0.9796 [a]	0.1694 [a]	0.0085	0.9044 [a]	0.3890 [a]	-0.2458	-0.0739	0.2820			
Asia Satellite Telecom	-3.8413 [a]	0.0372	0.0429	0.6272 [a]	1.1133 [a]	0.4220	0.2755	0.4015			
Japan:											
Hitachi	-3.6479 [a]	0.2613 [a]	-0.0003	0.6689 [a]	7.3306 [a]	0.9226	0.6962 [a]	0.6530 [c]			
Honda Motor	-0.6379 [a]	0.0942 [a]	-0.0054	0.9571 [a]	0.8767 [a]	0.4975	0.0190	0.7683 [a]			
Kubota	-4.8117 [a]	0.1633 [a]	0.0078	0.5150 [a]	4.3538 [a]	-0.0565	0.3473 [c]	1.2844 [a]			
Kyocera	-0.3480 [a]	0.0716 [a]	0.0053	0.9823 [a]	1.0294 [a]	0.5389 [c]	0.0776 [b]	0.2927 [c]			
Matsushita Elec.	-2.9299 [a]	0.1288 [a]	-0.0528 [c]	0.7217 [a]	2.2472 [a]	1.2121 [c]	0.3020 [c]	0.5915 [c]			
NTT	-2.6297 [a]	0.2317 [a]	-0.0002	0.7647 [a]	2.5691 [a]	-0.1178	0.3069 [b]	0.7631 [b]			
Sony	-1.4001 [a]	0.1763 [a]	0.0141	0.8939 [a]	1.9559 [a]	0.7322	0.1514	0.8739 [a]			
TDK	-0.3149 [a]	0.0571 [a]	-0.0153 [c]	0.9835 [a]	0.9497 [a]	0.4870 [c]	0.0492	0.0951			
Nissan Motor	-0.2435 [a]	0.0449 [a]	-0.0094	0.9879 [a]	0.5343 [a]	0.5673 [b]	0.0555	0.1836			
Sanyo	-0.4134 [a]	0.0585 [a]	-0.0091	0.9684 [a]	0.5538 [a]	0.0611	0.0264	0.2791 [c]			

Note:

$$R_{N,t}^{ADR} = a_0 + a_1 R_{D,t-1}^{ADR} + a_2 \hat{e}_{D,t} + a_3 \hat{e}_{HK,D,t} + a_4 \hat{e}_{KR,D,t} + a_5 \hat{e}_{JP,D,t} + a_6 \hat{e}_{TW,D,t} + a_7 \hat{e}_{PH,D,t} + a_8 \hat{e}_{CH,D,t} + \varepsilon_{D,t}^{ADR},$$

$$\varepsilon_{N,t}^{ADR} \sim Student-t(0, h_{N,t}^{ADR}, v),$$

$$\ln(h_{N,t}^{ADR}) = b_0 + b_1 \left| z_{N,t-1}^{ADR} \right| + b_2 z_{N,t-1}^{ADR} + b_3 \ln(h_{D,t-1}^{ADR}) + b_4 \hat{G}_{D,t} + b_5 \hat{G}_{HK,D,t} + b_6 \hat{G}_{KR,D,t} + b_7 \hat{G}_{JP,D,t} + b_8 \hat{G}_{TW,D,t} + b_9 \hat{G}_{PH,D,t} + b_{10} \hat{G}_{CH,D,t},$$

$$where\ z_{N,t-1}^{ADR} = \frac{\varepsilon_{N,t-1}^{ADR}}{\sqrt{h_{N,t-1}^{ADR}}}$$

$\hat{e}_{D,t}$, $\hat{e}_{HK,D,t}$, $\hat{e}_{KR,D,t}$, $\hat{e}_{JP,D,t}$, $\hat{e}_{TW,D,t}$ $\hat{e}_{PH,D,t}$, and $\hat{e}_{CH,D,t}$ are estimated unexpected returns and $\hat{G}_{D,t}$, $\hat{G}_{HK,D,t}$, $\hat{G}_{KR,D,t}$, $\hat{G}_{JP,D,t}$, $\hat{G}_{TW,D,t}$ $\hat{G}_{PH,D,t}$, and $\hat{G}_{CH,D,t}$ are estimated standardized volatility components for the underlying stock, Hong Kong Hang Seng index, Korea SE composite, Japanese Nikkei 225 stock average, Taiwan SE index, Philippine PSE composite index, and Shanghai SE composite. v is the degree of freedom of the t distribution. Boxed values are used to signify coefficients for the stock's home market index. The superscripts *a*, *b* and *c* indicate significance at the 1, 5 and 10 percent levels, respectively.

Table 2-2: Analysis of contemporaneous contagion effects from the U.S. to Asia

	Mean equation				Variance equation					
	c_0	c_1	c_2	c_3	d_0	d_1	d_2	d_3	d_4	d_5
Korea:										
Korea Electric Power	-0.0003	0.0120	0.0833 [a]	-0.1131 [a]	-0.0553 [b]	0.0536 [a]	-0.0003	0.9986 [a]	0.0859	-0.0386
POSCO	-0.0004 [c]	0.0025	0.1564 [a]	0.4548 [a]	-0.7210 [a]	0.1781 [a]	0.0384 [b]	0.9392 [a]	1.0055 [a]	0.4713 [a]
SK Telecom	-0.0009 [a]	-0.0279 [a]	0.1532 [a]	0.5100 [a]	-0.1989 [a]	0.1005 [a]	-0.0181	0.9913 [a]	0.6232 [a]	0.1775
Taiwan:										
Taiwan Semicon	0.0001	0.0431 [a]	0.1937 [a]	0.5620 [a]	-0.6043 [a]	0.2209 [a]	0.0166	0.9591 [a]	0.8103 [a]	0.3395 [c]
Macronix	0.0030 [a]	0.0690 [a]	0.0860 [a]	0.6738 [a]	-1.8520 [a]	0.4815 [a]	-0.0661 [c]	0.8104 [a]	0.5466 [a]	0.6840 [b]
The Philippines:										
Philippine Telecom	0.0006 [c]	0.0212 [b]	0.1334 [a]	0.1141 [a]	-0.8444 [a]	0.5356 [c]	0.2020	0.8790 [a]	1.6762 [a]	0.1838
China:										
Guangshen Railway	0.0020 [a]	-0.0339 [a]	0.1020 [a]	0.2734 [a]	-0.2017 [a]	0.0820 [a]	-0.0034	0.9900 [a]	0.3294 [b]	0.3461 [a]
Sinopec Shanghai	0.0010 [a]	-0.0111	0.1484 [a]	0.4834 [a]	-0.2262 [a]	0.0565 [a]	-0.0147 [c]	0.9883 [a]	0.5155 [a]	0.2600 [b]
China Eastern Airlines	0.0021 [a]	0.0011	0.1047 [a]	0.4862 [a]	-0.0859 [a]	-0.0115	0.0046	0.9971 [a]	0.6189 [a]	0.1260 [a]
China Southern Airlines	0.0016 [a]	-0.0062	0.1032 [a]	0.5048 [a]	-0.7131 [a]	0.1361 [a]	0.0002	0.9404 [a]	1.0700 [a]	0.5112 [a]
Hong Kong:										
APT Satellite	-0.0007 [a]	-0.0255 [b]	0.0370 [a]	0.1260 [a]	-0.3762 [a]	0.5711 [b]	0.1083	0.9741 [a]	0.9109 [a]	0.5608 [a]
Asia Satellite Telecom	-0.0002	-0.0127 [b]	0.0655 [a]	0.1066 [a]	-0.1038 [a]	0.0403 [a]	-0.0010	0.9977 [a]	0.5209 [a]	0.4987 [a]
Japan:										
Hitachi	0.0005 [c]	-0.0414 [b]	0.2809 [a]	0.4650 [a]	-0.2712 [a]	0.0710 [a]	0.0026	0.9838 [a]	0.6554 [a]	0.2998 [a]
Honda Motor	0.0012 [a]	-0.0905 [a]	0.2512 [a]	0.3303 [a]	-0.3135 [a]	0.1062 [a]	0.0044	0.9809 [a]	0.4751 [a]	0.3264 [b]
Kubota	0.0008 [a]	-0.0619 [a]	0.1075 [a]	0.3655 [a]	-0.1706 [a]	0.0634 [a]	0.0263 [a]	0.9900 [a]	0.1857 [b]	0.3845 [a]
Kyocera	0.0001	-0.0654 [a]	0.3299 [a]	0.4761 [a]	-0.3033 [a]	0.1124 [a]	-0.0075	0.9832 [a]	0.7774 [a]	0.0945
Matsushita Elec.	0.0008 [a]	-0.0668 [a]	0.1596 [a]	0.3639 [a]	-0.2655 [a]	0.0666 [a]	0.0032	0.9836 [a]	0.7871 [b]	0.3974 [a]
NTT	0.0003	-0.0651 [a]	0.1948 [a]	0.4063 [a]	-0.3216 [a]	0.0928 [a]	-0.0018	0.9807 [a]	1.0260 [a]	0.3249 [a]
Sony	0.0005 [b]	-0.0200	0.3795 [a]	0.4193 [a]	-0.5730 [a]	0.1062 [a]	-0.0040	0.9585 [a]	1.0316 [a]	0.0647
TDK	0.0002	-0.0312 [b]	0.2185 [a]	0.5716 [a]	-0.2614 [a]	0.1009 [a]	0.0014	0.9874 [a]	0.6637 [a]	0.4397 [a]
Nissan Motor	0.0009 [a]	-0.0380 [b]	0.1494 [a]	0.3492 [a]	-0.4097 [a]	0.1671 [a]	-0.0194	0.9704 [a]	0.6355	0.2347
Sanyo	0.0012 [a]	0.0001	0.0400 [a]	0.5676 [a]	-0.4657 [a]	0.2226 [a]	-0.0131	0.9694 [a]	0.0098	0.6783 [a]

Note:

$$R_{N,t} = c_0 + c_1 R_{D,t-1} + c_2 \hat{e}_{D,t-1}^{ADR} + c_3 \hat{e}_{US,D,t-1} + \varepsilon_{N,t}, \quad \varepsilon_{N,t} \sim Student - t(0, h_{N,t}, v), \ ,$$

$$\ln(h_{N,t}) = d_0 + d_1 \left| z_{N,t-1} \right| + d_2 z_{N,t-1} + d_3 \ln(h_{N,t-1}) + d_4 \hat{G}_{D,t-1}^{ADR} + d_5 \hat{G}_{US,D,t-1},$$

$$where\ z_{N,t-1} = \frac{\varepsilon_{N,t-1}}{\sqrt{h_{N,t-1}}}.$$

$\hat{e}_{D,t-1}^{ADR}$ and $\hat{e}_{US,D,t-1}$ are estimated unexpected returns and $\hat{G}_{D,t-1}^{ADR}$ and $\hat{G}_{US,D,t-1}$ are estimated standardized volatility components for the ADR and the U.S. S&P 500 index. v is the degree of freedom of the t distribution. The superscripts *a*, *b* and *c* indicate significance at the 1, 5, and 10 percent levels, respectively.

Table 3-1: Analysis of contemporaneous contagion effects from Asia to the U.S. using dummy variables for the Asian financial crisis

Mean equation	f_2	f_3	f_4	f_5	f_6	f_7	f_8	f_2^d	f_3^d	f_4^d	f_5^d	f_6^d	f_7^d	f_8^d
Korea:														
Korea Electric Power	0.280 [a]	0.097 [a]	0.335 [a]	-0.016				0.663 [a]	0.511 [b]	0.567 [a]	-0.075			
POSCO	0.450 [a]	0.127 [a]	0.093 [a]	0.089 [a]				-0.224 [c]	0.113	0.766 [a]	-0.075			
SK Telecom	0.432 [a]	0.167 [a]	0.152 [a]	0.023				-0.167	0.056	0.370 [b]	-0.092			
Taiwan:														
Taiwan Semicon	0.318 [a]	0.136 [a]	0.072 [a]	0.141 [a]	0.202 [a]			0.144	0.038	-0.038	-0.313	0.007		
Macronix	0.380 [a]	0.073 [c]	0.047 [c]	0.076 [c]	0.102 [b]			0.716 [a]	0.277 [c]	-0.155	-0.305	-0.378		
The Philippines:														
Philippine Telecom	0.008	0.089 [a]	0.022 [c]	0.056 [a]		0.316 [a]		-0.032	-0.019	0.082	-0.096		-0.121	
China:														
Guangshen Railway	0.456 [a]	0.039 [c]	-0.004	0.093 [a]			0.010	-0.168 [c]	0.219	-0.025	0.315 [c]			0.016
Sinopec Shanghai	0.551 [a]	0.036	0.019	0.055 [b]			0.003	-0.287 [a]	0.356 [b]	-0.001	0.389 [a]			0.230
China Eastern Airlines	0.277 [a]	0.057 [b]	0.024 [c]	0.036 [c]			0.001	0.227 [a]	0.156	0.016	0.247			-0.247
China Southern Airlines	0.572 [a]	0.198 [a]	0.009	0.027			0.029	-0.045	0.147	-0.110	0.307 [b]			0.125
Hong Kong:														
APT Satellite	0.183 [a]	0.069 [b]	0.059 [b]	0.079 [b]				-0.096	0.002	-0.062	0.046			
Asia Satellite Telecom	0.494 [a]	0.015	0.028 [b]	0.055 [b]				-0.380 [a]	0.117 [b]	-0.046	-0.035			
Japan:														
Hitachi	0.680 [a]	0.064 [a]	0.026 [c]	0.128				-0.140	0.036	0.001	-0.210			
Honda Motor	0.606 [a]	0.084 [a]	0.027 [b]	0.089 [a]				-0.014	-0.076	-0.014	-0.045			
Kubota	0.516 [a]	0.001	0.015	0.039				-0.070	-0.085	-0.170 [c]	0.158			
Kyocera	0.703 [a]	0.076 [a]	0.050 [a]	0.119 [a]				-0.101	-0.224 [a]	-0.013	-0.083			
Matsushita Elec.	0.655 [a]	0.082 [a]	0.042 [a]	0.106 [a]				0.302 [c]	0.043	-0.026	-0.278 [b]			
NTT	0.667 [a]	0.038	0.023	0.127 [a]				-0.392 [b]	0.015	-0.020	-0.035			
Sony	0.630 [a]	0.076 [a]	0.042 [a]	0.156 [a]				-0.080	0.074	-0.062	-0.179 [c]			
TDK	0.606 [a]	0.026	0.051 [a]	0.172 [a]				-0.044	0.109	-0.136	0.089			
Nissan Motor	0.537 [a]	-0.006	0.020	0.080 [a]				0.132	0.071	0.096	-0.070			
Sanyo	0.502 [a]	0.107 [a]	-0.020	0.169 [a]				0.240 [c]	-0.055	0.339 [a]	0.121			

Variance equation	g_4	g_5	g_6	g_7	g_8	g_9	g_{10}	g_4^d	g_5^d	g_6^d	g_7^d	g_8^d	g_9^d	g_{10}^d
Korea:														
Korea Electric Power	-0.005	0.067	-0.002	0.013 [a]				0.194	0.216	-0.020	-0.016			
POSCO	0.183 [a]	0.027	-0.001	0.006				-1.894 [b]	1.124 [a]	0.023	0.016			
SK Telecom	-0.091	-0.033	0.002	0.013 [b]				2.575 [a]	-0.186	-0.031	0.017			
Taiwan:														
Taiwan Semicon	-0.079	0.114 [a]	0.003 [b]	0.007	0.021			-0.097	0.223	0.054 [b]	-0.025	1.662		
Macronix	0.000	0.026	0.000	-0.007	0.047			-0.306	-0.192	0.030	-0.001	1.695		
The Philippines:														
Philippine Telecom	-0.165	0.265 [a]	0.002	0.019 [b]		-0.050 [b]		-1.725	-0.605	0.046 [b]	0.016		-0.072	
China:														
Guangshen Railway	-0.324 [a]	0.166 [b]	0.000	0.010			0.008	-0.290	-1.709 [a]	-0.070 [b]	0.166 [a]			-0.083
Sinopec Shanghai	-0.002	0.140 [a]	0.000	0.005			-0.004	0.984	-1.460 [b]	-0.040	0.116 [b]			-0.248
China Eastern Airlines	-2.016 [a]	0.775 [a]	0.006	0.012			0.002	1.881 [c]	0.855	-0.005	0.113			0.008
China Southern Airlines	0.054	0.111 [c]	0.001	0.015 [b]			0.002	0.206	1.417 [b]	0.008	-0.037			0.452 [a]
Hong Kong:														
APT Satellite	0.009	0.040	-0.001	0.013 [b]				0.248	-0.396	0.017	-0.005			
Asia Satellite Telecom	0.141 [a]	0.043	0.000	0.008				0.687	-0.009	0.008	-0.043			
Japan:														
Hitachi	0.481 [a]	0.057	0.002	0.020 [a]				0.122	1.019 [b]	0.012	-0.099			
Honda Motor	0.060	0.120 [b]	-0.002	0.043 [a]				-0.959	0.487	0.020	-0.046			
Kubota	-0.055	0.148 [a]	-0.002	0.035 [a]				2.122 [b]	0.492	0.023	0.069			
Kyocera	-0.349 [a]	0.085 [b]	0.001	0.015 [a]				1.327	0.614	-0.023	0.005			
Matsushita Elec.	-0.010	0.048	0.001	0.019 [a]				0.048	0.382	-0.008	-0.024			
NTT	0.001	0.016	-0.001	0.039 [a]				-0.018	0.229	0.031 [c]	-0.027			
Sony	0.266 [a]	0.082	0.000	0.043 [a]				1.847 [b]	0.280	0.009	-0.112 [b]			
TDK	0.120	0.089 [b]	0.003	0.019 [a]				-1.763 [b]	0.929 [b]	0.017	-0.087 [b]			
Nissan Motor	0.146 [a]	0.106 [a]	0.000	0.016 [a]				2.244	0.377	0.031	-0.086			
Sanyo	0.050 [b]	0.041	-0.001	0.026 [a]				-0.348	-0.052	0.033	0.031			

Note:

$$R_{N,t}^{ADR} = (f_0 + f_0^d) + (f_1^d + f_1)R_{D,t-1}^{ADR} + (f_2 + f_2^d CD_t)\hat{e}_{D,t} + (f_3 + f_3^d CD_t)\hat{e}_{HK,D,t} + (f_4 + f_4^d CD_t)\hat{e}_{KR,D,t} + (f_5 + f_5^d CD_t)\hat{e}_{JP,D,t} + (f_6 + f_5^d CD_t)\hat{e}_{TW,D,t}$$

$$+ (f_7 + f_7^d CD_t)\hat{e}_{PH,D,t} + (f_8 + f_8^d CD_t)\hat{e}_{CH,D,t} + \varepsilon_{D,t}^{ADR},$$

$$\varepsilon_{N,t}^{ADR} \sim Student - t(0, h_{N,t}^{ADR}, v),$$

$$\ln(h_{N,t}^{ADR}) = g_0 + g_1\left|z_{N,t-1}^{ADR}\right| + g_2 z_{N,t-1}^{ADR} + g_3 \ln(h_{D,t-1}^{ADR}) + (g_4 + g_4^d CD_t)\hat{G}_{D,t} + (g_5 + g_5^d CD_t)\hat{G}_{HK,D,t} + (g_6 + g_6^d CD_t)\hat{G}_{KR,D,t} + (g_7 + g_7^d CD_t)\hat{G}_{JP,D,t} +$$

$$(g_8 + g_8^d CD_t)\hat{G}_{TW,D,t} + (g_9 + g_9^d CD_t)\hat{G}_{PH,D,t} + (g_{10} + g_{10}^d CD_t)\hat{G}_{CH,D,t},$$

$$where\ z_{N,t-1}^{ADR} = \frac{\varepsilon_{N,t-1}^{ADR}}{\sqrt{h_{N,t-1}^{ADR}}}$$

and CD is a dummy variable for the Asian financial crisis. $\hat{e}_{D,t}$, $\hat{e}_{HK,D,t}$, $\hat{e}_{KR,D,t}$, $\hat{e}_{JP,D,t}$, $\hat{e}_{TW,D,t}$ $\hat{e}_{PH,D,t}$, and $\hat{e}_{CH,D,t}$ are estimated unexpected returns and $\hat{G}_{D,t}$, $\hat{G}_{HK,D,t}$, $\hat{G}_{KR,D,t}$, $\hat{G}_{JP,D,t}$, $\hat{G}_{TW,D,t}$ $\hat{G}_{PH,D,t}$, and $\hat{G}_{CH,D,t}$ are estimated standardized volatility components for the underlying stock, Hong Kong Hang Seng index, Korea SE composite, Japanese Nikkei 225 stock average, Taiwan SE index, the Philippine PSE composite index, and Shanghai SE composite. ν is the degree of freedom of the t distribution. Boxed values are used to signify coefficients for the stock's home market index. The superscripts *a*, *b* and *c* indicate significance at the 1, 5, and 10 percent levels, respectively.

Table 3-2:
Analysis of contemporaneous contagion effects from the U.S. to Asia using dummy variables for the Asian financial crisis

	Mean equation				Variance equation			
Korea:	k_2	k_3	k_2^d	k_3^d	l_4	l_5	l_4^d	l_5^d
Korea Electric Power	0.0816 [a]	-0.1171 [a]	-0.0179	0.6692 [c]	0.0390	0.0055	0.6633	0.0555
POSCO	0.1532 [a]	0.4596 [a]	0.0366	-0.0300	-0.3448 [a]	0.0443 [a]	-2.5418 [b]	-0.0149
SK Telecom	0.1470 [a]	0.5073 [a]	-0.2614 [b]	0.8717 [c]	-0.0802	0.0183 [b]	1.7869	-0.0031
Taiwan:								
Taiwan Semicon	0.1913 [a]	0.5674 [a]	0.0127	0.2211	-0.2182 [b]	0.0451 [a]	-2.0204 [b]	-0.1001
Macronix	0.0800 [a]	0.6787 [a]	-0.1945 [b]	0.1467	1.4842 [b]	0.0492 [a]	10.5804 [b]	0.0219
The Philippines:								
Philippine Telecom	0.1401 [a]	0.1136 [a]	-0.1270	0.2480	-0.2365 [a]	0.0436 [a]	0.7146	0.1201
China:								
Guangshen Railway	0.1034 [a]	0.2690 [a]	-0.1461 [c]	0.3372 [b]	0.0059	0.0186 [a]	-1.5237 [a]	-0.0623 [b]
Sinopec Shanghai	0.1386 [a]	0.4837 [a]	0.2681 [a]	0.7531 [a]	-0.0512 [c]	0.0231 [a]	0.6986	0.0618 [c]
China Eastern Airlines	0.0923 [a]	0.4839 [a]	0.2091 [c]	1.1473 [a]	-0.0738	0.0350 [a]	-0.2543	-0.0076
China Southern Airlines	0.0944 [a]	0.4998 [a]	0.2282 [a]	0.6464 [a]	0.1712	0.0461 [a]	-0.5476	0.0110
Hong Kong:								
APT Satellite	0.0528 [a]	0.1668 [a]	-0.0194	-0.0929	0.6944 [a]	0.1341 [a]	-0.0632	-0.3168 [a]
Asia Satellite Telecom	0.0711 [a]	0.1059 [a]	0.0094	0.1155 [c]	0.3800 [a]	0.0321 [a]	1.0450	-0.0253
Japan:								
Hitachi	0.2769 [a]	0.4693 [a]	-0.0217	-0.0204	-0.1038 [c]	0.0251 [a]	-0.1514	-0.0064
Honda Motor	0.2674 [a]	0.3281 [a]	-0.1081	0.0065	0.0873 [a]	0.0176 [b]	-0.5269	0.0329
Kubota	0.1101 [a]	0.3722 [a]	-0.1535	-0.0480	-1.0928 [b]	0.0213 [a]	1.1070	0.0521
Kyocera	0.3371 [a]	0.4645 [a]	-0.2754 [b]	0.2804 [a]	0.0241	0.0127	-0.3075	-0.0013
Matsushita Elec.	0.1647 [a]	0.3586 [a]	-0.1704	0.1949 [c]	-0.0480	0.0168 [b]	-1.3047	-0.0221
NTT	0.2032 [a]	0.3906 [a]	-0.1847 [b]	0.3885 [b]	0.3691 [a]	0.0055	0.6295	-0.0550
Sony	0.3623 [a]	0.4248 [a]	0.0351	0.3685	0.0435	0.0231 [b]	0.9209	0.0176
TDK	0.2100 [a]	0.5549 [a]	0.6491 [c]	0.7046 [a]	0.1139	0.0176 [b]	0.7371	0.0110
Nissan Motor	0.1462 [a]	0.3407 [a]	-0.0154	0.2070	-0.0114	0.0232 [b]	-1.8806 [c]	-0.1182
Sanyo	0.0369 [a]	0.5763 [a]	0.2357	-0.0329	0.0048	0.0612 [a]	0.1245	0.0469 [b]

Note:

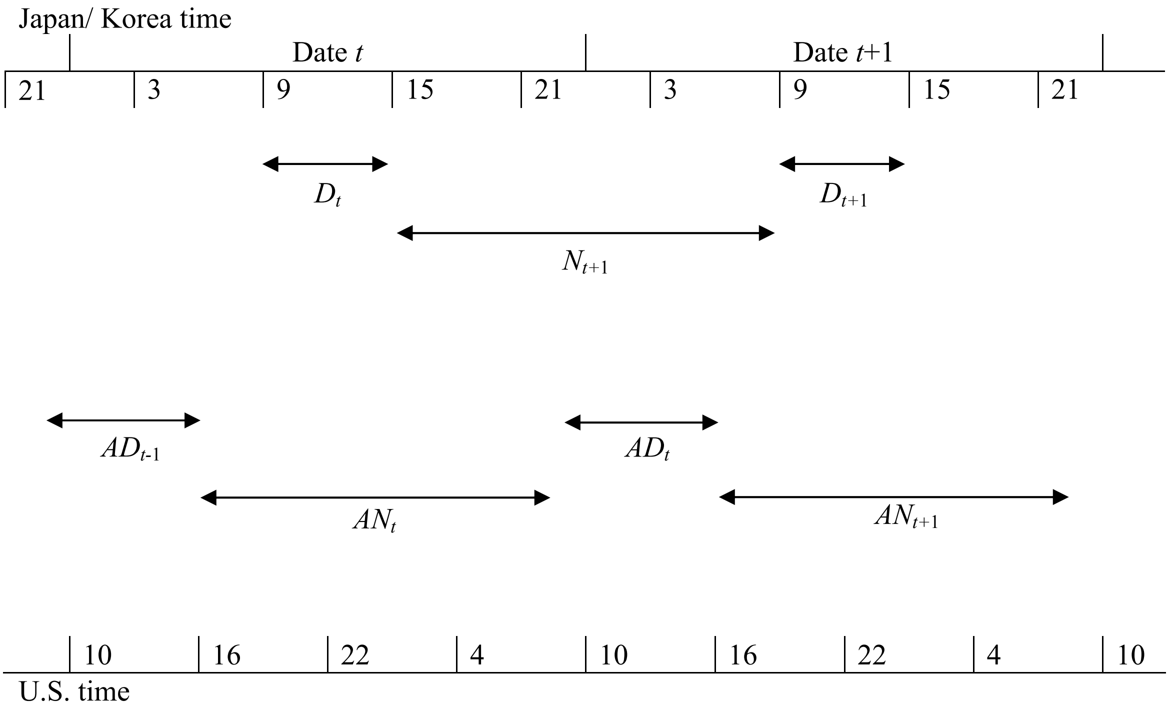
$$R_{N,t} = (k_0 + k_0^d) + (k_1 + k_1^d)R_{D,t-1} + (k_2 + k_2^d CD_t)\hat{e}_{D,t-1}^{ADR} + (k_3 + k_3^d CD_t)\hat{e}_{US,D,t-1} + \varepsilon_{N,t}, \quad \varepsilon_{N,t} \sim Student-t(0, h_{N,t}, \nu),,$$

$$\ln(h_{N,t}) = l_0 + l_1|z_{N,t-1}| + l_2 z_{N,t-1} + l_3 \ln(h_{N,t-1}) + (l_4 + l_4^d CD_t)\hat{G}_{D,t-1}^{ADR} + (l_5 + l_5^d CD_t)\hat{G}_{US,D,t-1},$$

$$where\ z_{N,t-1} = \frac{\varepsilon_{N,t-1}}{\sqrt{h_{N,t-1}}}$$

and CD is a dummy variable for the Asian financial crisis. $\hat{e}_{D,t-1}^{ADR}$ and $\hat{e}_{US,D,t-1}$ are estimated unexpected returns and $\hat{G}_{D,t-1}^{ADR}$ and $\hat{G}_{US,D,t-1}$ are estimated standardized volatility components for the ADR and the U.S. S&P 500 index. ν is the degree of freedom of the t distribution. The superscripts *a*, *b* and *c* indicate significance at the 1, 5, and 10 percent levels, respectively.

Figure 1: Daytime and overnight timing between Asia and the U.S.



NOTE 1. D and N indicate daytime and overnight in Japan/Korea, respectively. AD and AN indicate daytime and overnight in the U.S., respectively.

NOTE 2. Trading hours

China: 9:30 – 11:30, 13:00 – 15:00 (10:30 – 12:30, 14:00 – 16:00)
Hong Kong: 10:00 – 12:30, 14:30 – 15:55 (11:00 – 13:30, 15:30 – 16:55)
Japan: 9:00 – 11:00, 12:30 – 15:00
Korea: 9:00 – 15:00
The Philippines: 9:30 – 12:10 (10:30 – 13:10)
Taiwan: 9:00 – 13:30 (10:00 – 14:30)
Thailand: 10:00 – 12:30, 14:30 – 16:30 (12:00 – 14:30, 16:30 – 18:30)
United States: 9:30 – 16:00 (23:30 – 6:00)

* The parentheses indicate the time in Japan during the listed trading hours.