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Abstract

The extent of international financial integration among the developed economies has been well documented in the literature. This paper examines whether there are lagged spillovers in return and volatility between the U.S. and Korea, an emerging economy, for a sample period including the financial crisis of 1977. Using open-to-close KOSPI and S&P 500 returns, this paper finds statistically significant lagged volatility spillovers from Korea to the U.S. but not from the U.S. to Korea. This paper also finds that statistically significant lagged return spillovers do not exist in neither the Korean nor the U.S. stock markets. Thus, that domestic market efficiently adjusts to foreign information holds even for an emerging market. Finally, this paper finds that when KOSPI returns measured in U.S. dollars are used, statistically significant lagged return spillovers exist from the U.S. to Korea but not from Korea to the U.S. This paper concludes that the lagged return spillovers with returns measured in U.S. dollars may result from the way the Korean government has intervened in the KRW/USD foreign exchange market.

JEL classification: G15

Keywords: Spillover, Stock Returns, Volatility, GARCH.

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1. Introduction

With increased globalization of financial markets, investors in a given market incorporate into their financial decisions not just their own domestic information but the information of foreign financial markets. The extent of international financial integration has received much attention in recent years. For example, dividing daily close-to-close returns into daytime and overnight returns, Hamao, Masulis, and Ng (1990) study the short run interdependence of returns and return volatilities across New York, London, and Tokyo stock markets. They find pre-crash evidence of lagged volatility spillovers from New York and London into Tokyo, but no spillover effect is found from Tokyo into London and New York. With the inclusion of the October 1987 crash period, these spillovers become significant in almost all directions and moreover, they find significant lagged return spillovers using open-to-close stock returns. Engle, Ito, and Lin (1990) find that news which is revealed when one foreign exchange market is open contributes to the return volatility of the next market to open trading. They do not find any evidence that news in one market could predict the mean return in subsequent markets. Lin, Engle and Ito (1994) find that except for lagged spillovers from New York to Tokyo for the period after the 1987 crash, there are no significant lagged spillovers in return or volatility. These studies examine interdependancies in daily stock returns focusing on the financial markets in developed counties such as the U.S., the U.K., and Japan.

Recently, a number of studies examine the stock market behavior of some emerging economies. For example, Harvey (1995) finds that emerging market returns are more likely to be influenced by local information than those in developed countries. Wang, Rui, and Firth (2002) study the return and volatility behavior of stocks of 15 Hong Kong companies listed both on the Hong Kong and London stock markets and find that the satellite market (London) reacts to information from the dominant market (Hong Kong) with a delay. Lee, Rui, and Wang (2002) find strong spillovers from the lagged NASDAQ returns and volatilities to Asian second board market returns and volatilities for a period that includes the Asian financial crisis of 1997.

This paper studies the extent of financial market integration between the U.S. and Korea using daily and intraday stock returns over the 50-month period, starting November 1, 1997 through December 31, 2001. The sample period includes the financial crisis in late 1997. During the crisis period, the Korean securities market underwent an overhaul. The Korean financial reform was focused on strengthening market infrastructure, accelerating deregulation and enhancing investor protection. For our purpose, the most relevant changes were the deregulation of the Korean government's restrictions on foreign portfolio investment. In November 1997, the aggregate foreign portfolio investment ceiling was raised from 23 percent to 26 percent of the outstanding shares of a company. In December 1997, it was raised to 50 percent on the 12th and raised again to 55 percent on the 30th. Finally in May 1998, the Korean government completely eliminated the aggregate foreign portfolio investment ceiling. With the elimination of the restriction on aggregate foreign portfolio investment, foreign investors now have much less difficulty in adjusting their emerging market portfolios. To separate the effects of deregulation and/or the financial crisis, this paper estimates the models over a full sample period, a period starting from November 1, 1997 to December 31, 2001 and a period starting from May 1, 1998 to December 31, 2001 (the post crisis period).[1]

Following Hamao et al. (1990), Engle et al. (1990), and Lin et al. (1994), this paper uses daily open and close price data to study whether there are lagged spillovers in return and volatility across countries using lagged returns and estimated squared residuals from the previously open foreign stock market. Some previous studies suggest that changes in exchange rates may affect the behavior of stock index returns. See, e.g., Roll (1992). Returns in terms of U.S. dollars may be relevant to international investors. Korean investors may also want to have information on the U.S. stock market net of any movements in the foreign exchange market. This consideration might be particularly relevant for Korea during the financial crisis. During November and December of 1997, Korean won depreciated dramatically from 961 won per U.S. dollar to 1962 won per U.S. dollar (USD). Such a change in the value of dollar with respect to Korean won (KRW) might have quite an impact on the behavior of Korean

[1] The Korean government requested to IMF a bailout package on Nov 21, 1997. Standard & Poors changed its sovereign credit rating on the Government of Korea from AA- to A+ on Oct 24, 1997, A- on Nov 25, BBB- on Dec 11, B+ on Dec 23, 1997; BB+ on Feb 17, 1998; BBB- on Jan 25, BBB on Nov 11, 1999; BBB+ on Nov 13, 2001; and A- on Jul 24, 2002. Note that BBB- or better is considered investment grade rating.

stock market participants. In order to study the impacts of changes in foreign exchange rates on cross market information transmission, this paper also examines open-to-close KOSPI returns measured in U.S. dollars.

In each market, this paper uses the most comprehensive and diversified stock index. For the Korea Stock Exchange, the Korea Composite Stock Price Index (KOSPI) is used. It is a market value weighted index and it accounts for 100 percent of the equity capitalization of the Korea Stock Exchange (KSE). There were 689 firms listed on the Korea Stock Exchange at the end of 2001. Until December 6, 1998, KSE opened its trading at 9:30 A.M. and at 9:00 A.M. thereafter,[2] and closes at 3:00 P.M., Korean Standard Time.[3] For the New York stock market, the Standard & Poor's 500 Composite Index (S&P 500) is used. It is also a market value weighted index. As of 2001, S&P 500 accounts for 85 percent of the equity capitalization of the New York Stock Exchange (NYSE) and some NASDAQ and AMEX stocks are also represented. NYSE opens at 9:30 A.M. and closes at 4:00 P.M. EST. Note that Korea is ahead of New York by either 13 hours (in the summer) or 14 hours (in the winter). Thus, the trading activity on the KSE and the NYSE are not concurrent.

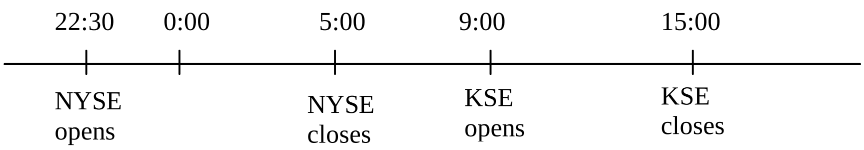

Figure 1. Exchange Trading Hours (Korean Standard Time, Summer)

Holidays across the U.S. and Korean stock markets are not synchronous and Saturday trading was allowed on the KSE until December 6, 1998. For such cases, the model is estimated without domestic returns for any days where the foreign market is closed. As is well known, the use of index prices near the open of trading may cause some difficulties. When individual stocks of the index have not yet opened trading, the previous day's closing price quotes are substituted into the index. This substitution procedure may artificially induce serial correlation in return data (see, e.g., Scholes and Williams (1977), Cohen et al. (1980), and Lo and MacKinley (1988)). To avoid such nonsynchronous trading problem or stale quote problem, the opening quote is chosen as a price index quoted 30 minutes after NYSE or KSE officially opens (see Lin et al. (1994)).[4]

The KRW/U.S. dollar exchange rates used in this paper are the ones determined in the interbank market of the Korean foreign exchange market. The Korean foreign exchange market is an over-the-counter (OTC) market, which opens at 9:30 A.M. and closes at 4:30 P.M. Although these open and close foreign exchange data are not perfectly synchronized with the corresponding open and close KOSPI data, this paper uses them due to data availability to convert KOSPI intraday returns in Korean won into those in U.S. dollars.[5]

This paper is organized as follows. Section 2 discusses the statistical characteristics of KOSPI and S&P 500 returns and their implications on empirical methodologies. Section 3 discusses preliminary OLS estimation of the co-movements between the U.S. and Korean stock returns. Section 4 reports the

[2] Note that investors can place orders one hour before KSE officially opens. Orders placed from 8:00 A.M. through 9:00 A.M. and 10 minutes before the market closing (2:50 P.M. – 3:00 P.M.) are aggregated and matched at a single price that minimizes the imbalance between buy and sell. From 9:00 A.M. through 2:50 P.M., orders are matched by continuous auctions.

[3] Until Dec 6, 1998, KSE closed for lunch breaks between 11:30 A.M. and 1:00 P.M., and until May 21, 2000, between noon and 1:00 P.M. Lunch breaks were abolished on May 22, 2000.

[4] For open prices, 10:00 A.M. quote is used for NYSE. For KSE, 10:00 A.M. quote is used through December 6, 1998 and 9:30 A.M. quote is used thereafter.

[5] Prior to Dec 16, 1997, the Korean foreign exchange rate system was called the Market Average Rate System, which consisted of the previously determined KRW/USD base rate and the daily foreign exchange fluctuation band. Between Dec 1, 1995 and Nov 19, 1997, the daily allowable foreign exchange band width was 2.25% (up or down from the base rate); and between Nov 20 and Dec 15, 1997, the band width became 10%. Since Dec 16, 1997, the foreign exchange fluctuation band was abolished and the exchange rate system became free floating.

GARCH estimation results for KOSPI and S&P 500 returns. Lagged volatility and return spillovers are examined in Section 5 and Section 6, respectively. Section 7 summarizes the main findings.

2. Statistical Characteristics of KOSPI and S&P 500 Returns and their Implications

This paper begins with an examination of the serial correlation of the close-to-close and open-to-close returns on the KSE and the NYSE for the full sample period and the post crisis subperiod.[6] See Table 1. For the full sample period starting November 1, 1977 through December 31, 2001, the close-to-close KOSPI returns exhibit statistically significant serial correlation at every lag, some positive and some negative. The open-to-close KOSPI returns also exhibit serial correlation at every lag, mostly negative. The close-to-close KOSPI returns measured in U.S. dollars again exhibit serial correlation at every lag.[7] The open-to-close returns exhibit serial correlation at every lag except lag 1. The close-to-close S&P 500 returns do not exhibit any significant serial correlation. The open-to-close S&P 500 returns do not exhibit serial correlation except at the lag 1. The close-to-close Korean won/U.S. dollar foreign exchange returns exhibit serial correlation at every lag. The open-to-close foreign exchange returns also exhibits serial correlation at every lag.

For the post crisis subperiod starting May 1, 1998 through December 31, 2001, the close-to-close KOSPI returns exhibit positive serial correlation at lag 1 and negative serial correlation at lags 2 and 5. The open-to-close KOSPI returns exhibit serial correlation at every lag, some positive and some negative. The returns exhibit large negative correlation at lag 1 and diminished serial correlation at lag 2 and higher. The close-to-close KOSPI returns measured in U.S. dollars exhibit serial correlation at lags 1 through 7, and the magnitude of the serial correlation at lag 1 is the largest. For the open-to-close KOSPI returns measured in U.S. dollars, the serial correlation at lag 1 is large and negative and higher order lagged autocorrelation are less important. The close-to-close S&P 500 returns do not exhibit any serial correlation. The open-to-close S&P 500 returns exhibit negative serial correlation at lag 1. The close-to-close Korean won/U.S. dollar foreign exchange returns exhibit serial correlation at every lag. The open-to-close foreign exchange returns also exhibit serial correlation at every lag.

For the open-to-close S&P 500 returns, estimating a GARCH(1,1)-M model with higher order MA processes specified produced no evidence supporting the significance of moving-average parameters of a higher order than an MA(1). It has been also considered whether to include a dummy variable for the trading day following a weekend or holiday to capture potential day of the week effects. Yet, inclusion of the Monday dummy does not significantly help the model in explaining the behavior of the open-to-close S&P 500 returns.

For the open-to-close KOSPI returns, a GARCH(1,1)-M model with ARMA(1,1) is posited to account for the significant serial correlation in the open-to-close KOSPI returns. Inclusion of the Monday dummy does not significantly help the model for the entire sample period or for the post crisis subperiod. For the open-to-close KOSPI returns measured in U.S. dollars, a GARCH-M model with ARMA(1,1) is also used to account for the significant serial correlation and autoregressive conditional heteroskedasticity in residuals. In this case, inclusion of the Monday dummy in the conditional variance equations helps the model in explaining the KOSPI returns for the full sample period but not for the post crisis subperiod.

The severe serial correlation in stock returns does not seem specific to the Korean case. Rather, it seems common for the emerging economies. See, e.g., Harvey (1995) and Lee et al. (2002). Some may consider it as evidence of market inefficiency regarding information transmission. Yet, it may also result from the liquidity constraints facing individual traders which seem much severe in the emerging economies, the government interventions in the stock markets, or the explicit or implicit government and/or the exchange imposed restrictions on trading activities.

[6] S&P 500 and KOSPI data were directly obtained from S&P and KSE, respectively.

[7] KRW/USD exchange rate data were obtained from the Bank of Korea.

Table 1. Data Summary

November 1, 1997 ~ December 31, 2001

	Number of obs	Mean	Standard Deviation	Autocorrelations									
				lag 1	2	3	4	5	6	7	8	9	10
KSE c-c	987	.00039	.02925	.074*	-.054*	-.039*	-.019*	-.056*	.009*	.080*	-.007*	.026*	.017*
KSE o-c	987	-.00052	.01932	-.132*	-.047*	-.044*	.004*	-.032*	-.035*	.041*	-.035*	.037*	-.020*
KSEA c-c	987	.00007	.03685	.107*	-.066*	-.066*	-.094*	-.057*	.077*	.151*	.028*	.058*	-.015*
KSEA o-c	987	-.00030	.02370	-.057	-.053*	-.074*	-.075*	-.063*	-.037*	.132*	-.018*	.022*	-.049*
S&P c-c	987	.00024	.01392	-.047	-.019	-.073	.028	-.040	-.031	.006	-.041	-.022	.056
S&P o-c	987	.00009	.01076	-.070*	.000	-.032	.048	.006	-.021	-.013	-.008	.003	.013
Forex c-c	987	.00032	.01597	.077*	-.142*	-.060*	-.175*	-.068*	.215*	.189*	.101*	.020*	.011*
Forex o-c	987	-.00022	.01111	.149*	-.081*	-.096*	-.213*	-.122*	.006*	.231*	-.014*	-.102*	-.011*

May 1, 1998 ~ December 31, 2001

	Number of obs	Mean	Standard Deviation	lag 1	2	3	4	5	6	7	8	9	10
KSE c-c	872	.00057	.02735	.068*	-.054*	-.035	.026	-.064*	-.008	.024	-.011	.021	.028
KSE o-c	872	-.00026	.01864	-.117*	-.069*	-.030*	.028*	-.050*	-.033*	.027*	-.037*	.032*	-.018*
KSEA c-c	872	.00058	.02955	.088*	-.050*	-.025*	.052*	-.048*	-.007*	.025*	-.001	.019	.023
KSEA o-c	872	.00006	.02022	-.101*	-.093*	-.013*	.057*	-.059*	-.035*	.035*	-.046*	.022*	-.025*
S&P c-c	872	.00005	.01431	-.054	-.014	-.065	.040	-.039	-.040	-.004	-.045	-.029	.047
S&P o-c	872	.00003	.01119	-.072*	-.002	-.026	.051	.010	-.024	-.018	-.005	.002	.005
Forex c-c	872	-.00001	.00599	.121*	-.019*	-.001*	.044*	-.001*	.024*	.118*	-.017*	-.042*	-.023*
Forex o-c	872	-.00031	.00559	.111*	-.037*	-.005*	.018*	-.013*	.093*	.165*	-.026	-.062*	-.016*

1) * refers to significance at the 5% level.
2) c-c and o-c refer to close-to-close and open-to close, respectively.
3) KSE, KSEA, S&P, and Forex refer to KOSPI returns, KOSPI returns in USD, S&P 500 returns, and KRW/USD returns, respectively.

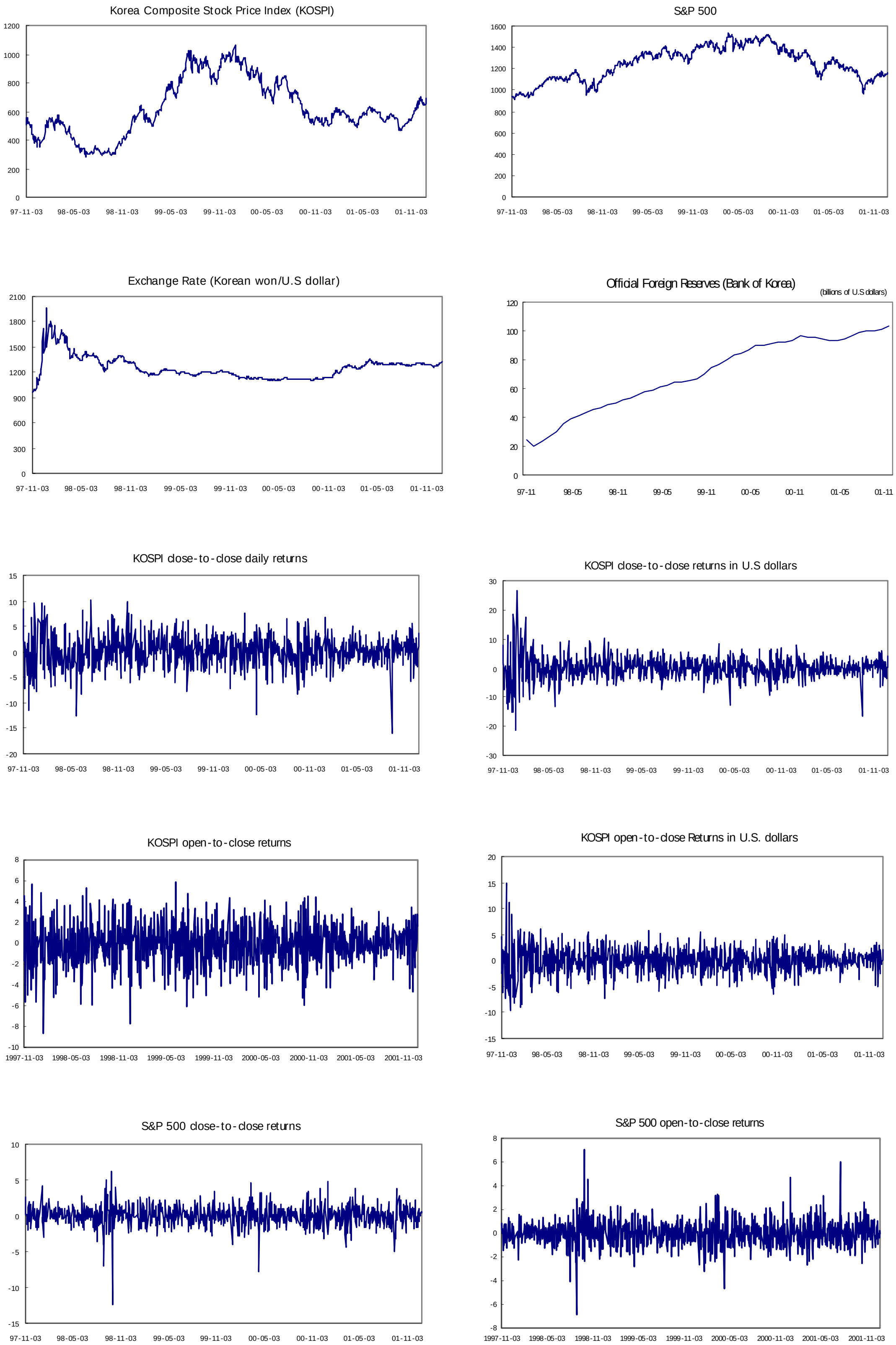

Figure 2. The Behavior of KOSPI, S&P 500, KRW/USD, and Foreign Reserves

3. OLS estimation: preliminary

To account for the co-movements between the U.S. and the Korean stock returns, the following OLS model is estimated using close-to-close domestic stock returns.

$$RKc_t = \alpha + \beta_1 RKc_{t-1} + \beta_2 RUSc_{t-1} + \varepsilon_t$$
$$RUSc_t = \alpha + \beta_1 RUSc_{t-1} + \beta_2 RKc_t + \eta_t, \qquad (1)$$

where RKc_t = close-to-close KOSPI daily return and $RUSc_t$ = close-to-close S&P 500 daily return. Table 2 presents the OLS estimation results of close-to-close stock returns in terms of own lagged returns and the most recent foreign close-to-close returns. According to table 2, the most recent close-to-close U.S. stock returns help predict the current Korean returns and the most recent close-to-close Korean stock returns help predict the current U.S. stock returns. These results hold for the full sample period and also for the post crisis period. They result from the fact that by using close-to-close returns, their trading periods overlap in time. These results are contrary to the popular belief that the U.S. stock returns influence Korea but not vice versa. Note that they seem consistent with the findings of Lin et al. (1994) that cross market interdependence in returns is bi-directional for the two developed markets, the U.S. and Japan.

Now, to examine whether news from a foreign market has lasting effects, the following OLS model is estimated using open-to-close returns.

$$RK_t = \alpha + \beta_1 RK_{t-1} + \beta_2 RUS_{t-1} + \varepsilon_t$$
$$RUS_t = \alpha + \beta_1 RUS_{t-1} + \beta_2 RK_t + \eta_t, \qquad (2)$$

where RK_t = open-to-close KOSPI return, and RUS_t = open-to-close S&P500 return. Table 3 presents the OLS estimation results using open-to-close stock returns. In this case, the most recent foreign stock returns do not significantly help predict the current domestic stock returns for neither the U.S. nor Korea. This is consistent with our previous discussion that with open-to-close stock returns, their trading periods do not overlap in time. Note that for the open-to-close KOSPI returns, the Ljung-Box statistic for first 12 normalized residuals indicate significant serial correlation and that for the residuals squared indicate significant autoregressive conditional heteroskedasticity (ARCH) at conventional levels for the full sample period. For the open-to-close S&P 500 returns, the Ljung-Box statistics for the residuals squared also indicate significant conditional heteroskedasticity in the residuals for the full sample period (see Panel A, Table 3). Such results tend to also hold for the post crisis period (see Panel B, Table 3). These results indicate that a GARCH model is an appropriate specification.

Table 2. OLS estimation using close-to-close domestic stock returns

$$RKc_t = \alpha + \beta_1 RKc_{t-1} + \beta_2 RUSc_{t-1} + \varepsilon_t$$

$$RUSc_t = \alpha + \beta_1 RUSc_{t-1} + \beta_2 RKc_t + \eta_t ,$$

where $RKc_t =$ close-to-close KOSPI daily return and $RUSc_t =$ close-to-close S&P 500 daily return.

Panel A: Sample period: Nov 1, 1997 - Dec 31, 2001

	KOSPI		**S&P 500**	
Number of obs	987		987	
Log-likelihood	-2426.47		-1713.64	
	Coeff.	t-stat	Coeff.	t-stat
α	0.0251	0.2785	0.0233	0.5328
β_1	0.0376	1.2070	-0.0846	-2.6020
β_2	0.5167	7.9031	0.0752	4.8612
F-stat	33.88 (Prob=0.00)		12.83 (Prob=0.00)	
R-squared	0.0644		0.0254	
Ljung-Box (12) for residuals	29.27 (Prob=0.00)		15.64 (Prob=0.21)	
Ljung-Box (12) for residuals squared	76.38 (Prob=0.00)		52.41 (Prob=0.00)	

Panel B: Sample period: May 1, 1998 – Dec 31, 2001

	KOSPI		**S&P 500**	
Number of obs`	872		872	
Log-likelihood	-2075.56		-1540.11	
	Coeff.	t-stat	Coeff.	t-stat
α	0.0519	0.5846	0.0014	0.0284
β_1	0.0345	1.0564	-0.0935	-2.6691
β_2	0.5439	8.7180	0.0735	4.0081
F-stat	40.12 (Prob=0.00)		9.28 (Prob=0.00)	
R-squared	0.0845		0.0209	
Ljung-Box (12) for residuals	24.44 (Prob=0.02)		14.43 (Prob=0.27)	
Ljung-Box (12) for residuals squared	18.00 (Prob=0.12)		45.34 (Prob=0.00)	

Table 3. OLS Estimation using open-to-close stock returns

$$RK_t = \alpha + \beta_1 RK_{t-1} + \beta_2 RUS_{t-1} + \varepsilon_t$$

$$RUS_t = \alpha + \beta_1 RUS_{t-1} + \beta_2 RK_t + \eta_t ,$$

where $RK_t =$ open-to-close KOSPI return and $RUS_t =$ open-to-close S&P 500 return.

	KOSPI		S&P 500	
	Panel A: Sample period: Nov 1, 1997 - Dec 31, 2001			
Number of obs	987		987	
Log-likelihood	-2041.09		-1469.46	
	Coeff.	t-stat	Coeff.	t-stat
α	-0.0586	-0.9601	0.0102	0.3000
β_1	-0.1314	-4.1561	-0.0698	-2.1980
β_2	-0.0125	-0.2211	0.0136	0.7695
F-stat	8.69 (Prob=0.00)		2.72 (Prob=0.06)	
R-squared	0.0173		0.0055	
Ljung-Box (12) for residuals	21.44 (Prob=0.04)		7.54 (Prob=0.82)	
Ljung-Box (12) for residuals squared	37.99 (Prob=0.00)		29.63 (Prob=0.00)	

	KOSPI		S&P 500	
	Panel B: Sample period: May 1, 1998 - Dec 31, 2001			
Number of obs	872		872	
Log-likelihood	-1773.67		-1332.37	
	Coeff.	t-stat	Coeff.	t-stat
α	-0.0284	-0.4533	0.0041	0.1103
β_1	-0.1173	-3.4821	-0.0719	-2.1272
β_2	-0.0082	-0.1456	0.0205	1.0109
F-stat	6.10 (Prob=0.00)		2.79 (Prob=0.06)	
R-squared	0.0138		0.0064	
Ljung-Box (12) for residuals	19.77 (Prob=0.07)		7.03 (Prob=0.86)	
Ljung-Box (12) for residuals squared	53.65 (Prob=0.00)		21.91(Prob=0.04)	

4. GARCH models for open-to-close returns

To examine the behavior of stock returns further, the following ARMA(1,1)-GARCH(1,1)-M model is estimated for KOSPI open-to-close returns.

$$R_t = \alpha + \beta h_t + \rho R_{t-1} + \gamma\varepsilon_{t-1} + \varepsilon_t ,$$
$$h_t = a + bh_{t-1} + c\varepsilon_{t-1}^2 \ , \qquad (3)$$

where $R_t =$ open-to-close stock index return measured in domestic currency x 100, and $h_t =$ the conditional variance of the open-to-close stock index return. An ARMA(1,1) structure is posited to account for severe serial correlation in the Korean open-to-close stock returns. For the open-to-close U.S. stock returns, the above GARCH model with $\rho = 0$ is estimated as the past stock returns do not help the model in describing the current open-to-close U.S. stock return behavior. The results of this estimation for the full sample period are shown in Table 4-a, Panel A. In order for a GARCH model to be stable, the sum of b and c must be less than one. For a model describing the Korean stock returns, the sum is 0.9888 and for S&P 500 returns, 0.9746, and they are both significantly different from zero and less than one.[8] For KOSPI returns, an increase in volatility tends to lower open-to-close returns, while for S&P 500 returns, an increase in volatility tends to raise its intraday returns. The likelihood ratio statistics, LR(4) for U.S. and LR(5) for Korea, are both significant at the one percent level. None of the Ljung-Box statistics for the first 12 residuals or residuals squared are significant at conventional levels. The coefficient of kurtosis is 3.61 for the KOSPI returns, but it is 6.82 for the S&P 500 returns, much greater than the predicted value of 3.00 for normality.

For the open-to-close KOSPI returns measured in USD, the following model is estimated

$$Ra_t = \alpha + \beta h_t + \rho Ra_{t-1} + \gamma\varepsilon_{t-1} + \varepsilon_t$$
$$h_t = a + bh_{t-1} + c\varepsilon_{t-1}^2 + dD_t \ , \qquad (3')$$

where $Ra_t =$ open-to-close KOSPI return measured in USD x 100, $h_t =$ conditional variance of Ra_t, and $D_t =$ a dummy variable that takes a value of one on days following weekends and holidays and is zero otherwise. The GARCH model (3') is estimated for the full sample period, a period starting November 1, 1997 through December 31, 2001. The results of the estimation are shown in table 4-b. The likelihood ratio statistic LR(6) is significant at the one percent level, indicating that the GARCH model is well specified. The sum of b and c is 0.9497, significantly different from zero and less than one. As before, the coefficient of the conditional variance in the mean equation is negative and significantly different from zero. Thus, a rise in volatility tends to reduce intraday KOSPI returns in U.S. dollars. The coefficient for the Monday dummy is significantly different from zero and is negative. So unlike Fama (1965) for the U.S. case, open-to-close KOSPI return variances in U.S. dollars tend to be lower on Mondays. A decrease in volatility tends to raise the open-to-close returns on average, which implies positive mean returns for Korean stocks measured in U.S. dollars on Mondays, which is contrary to French (1980) and Gibbons and Hess (1981) for the U.S. case. Ljung-Box statistics for the first 12 normalized residuals or residuals squared are not significant at the conventional level. The skewness for the normalized residuals is –0.0872 and the Kurtosis is 3.6637. Thus, there is no indication for serious model misspecification.

For the post crisis subperiod starting May 1, 1998, through December 31, 2001, the Monday dummy does not help the GARCH-M model in explaining the behavior of the open-to-close KOSPI stock returns measured in U.S. dollars. Thus, for this subperiod the model (3') is estimated with d = 0. The result of the estimation is reported in Table 4-b, panel B. The likelihood ratio statistic LR(5) is significant at the one percent level, indicating that the GARCH-M model is well specified. Unlike the full sample case, the conditional variance does not have a significant effect on the conditional mean in the post crisis period. Again, the sum of b and c is 0.9653, significantly different from zero and less than one. Ljung-Box statistics for the normalized residuals or residuals squared are not significant at the conventional level. The skewness for the residuals is -0.2279 and the Kurtosis is 3.3006. There is not much indication of serious model misspecification.

[8] Unlike Hamao et al. (1990), none of the coefficients in the conditional variance equations in this paper violate the nonnegativity assumption.

Table 4-a. GARCH estimation using open-to-close returns

$$R_t = \alpha + \beta h_t + \rho R_{t-1} + \gamma \varepsilon_{t-1} + \varepsilon_t$$

$$h_t = \alpha + b h_{t-1} + c \varepsilon_{t-1}^2 ,$$

where $R_t =$ open-to-close domestic return x100 and $h_t =$ conditional variance of R_t.

	KOSPI		S&P 500	
	Panel A: Sample period: Nov 1, 1997 - Dec 31, 2001			
Number of obs	987		987	
Log-likelihood	-2009.93		-1429.72	
	Coeff.	t-stat	Coeff.	t-stat
α	0.2741	2.2865	-0.1688	-1.9306
β	-0.0818	-2.3748	0.1860	2.1820
γ	-0.7382	-9.8285	-0.0429	-1.1778
ρ	0.5976	6.5010		
a	0.0396	1.8644	0.0311	3.3774
b	0.9496	70.8349	0.9131	56.5305
c	0.0392	3.8690	0.0615	5.7199
LR (4) for H_0: $\beta = \gamma = b = c = 0$			84.94	
LR (5) for H_0: $\beta = \gamma = \rho = b = c = 0$	79.60			
Ljung-Box (12) for residuals	11.68 (Prob=0.39)		5.91 (Prob=0.88)	
Ljung-Box (12) for residuals squared	5.87 (Prob=0.88)		5.60 (Prob=0.90)	
Skewness	0.2904		0.1201	
Kurtosis	3.6116		6.8217	
	Panel B: Sample period: May 1, 1998 - Dec 31, 2001			
Number of obs	872		872	
Log-likelihood	-1750.02		-1307.46	
	Coeff.	t-stat	Coeff.	t-stat
α	0.1992	1.7976	-0.3024	-2.3279
β	-0.0604	-1.7937	0.2722	2.4309
γ	-0.7803	-9.2977	-0.0513	-1.3274
ρ	0.6585	6.2737		
a	0.0620	1.9388	0.0578	3.8262
b	0.9339	51.2448	0.8966	41.9740
c	0.0482	3.8051	0.0581	4.6920
LR (4) for H_0: $\beta = \gamma = b = c = 0$			55.40	
LR (5) for H_0: $\beta = \gamma = \rho = b = c = 0$	59.44			
Ljung-Box (12) for residuals	9.45 (Prob=0.58)		5.01 (Prob=0.93)	
Ljung-Box (12) for residuals squared	7.79 (Prob=0.73)		4.61 (Prob=0.95)	
Skewness	-0.2783		0.1691	
Kurtosis	3.5615		6.9807	

χ^2(4) critical values: 7.78 (10%), 9.49 (5%), 13.27 (1%)

χ^2(5) critical values: 9.24 (10%), 11.07 (5%), 15.08 (1%)

Table 4-b. GARCH estimation using open-to-close KOSPI returns in U.S. dollars

$$Ra_t = \alpha + \beta h_t + \rho Ra_{t-1} + \gamma\varepsilon_{t-1} + \varepsilon_t$$

$$h_t = a + bh_{t-1} + c\varepsilon_{t-1}^2 + dD_t\,,$$

where $Ra_t =$ open-to-close KOSPI return in U.S. dollars x100 and $h_t =$ conditional variance of Ra_t.

KOSPI in U.S. dollars

Panel A: Sample period: Nov 1, 1997 - Dec 31, 2001

Number of obs	987	
Log-likelihood	-2139.95	
	Coeff.	t-stat
α	0.1091	2.2629
β	-0.0210	-2.2120
γ	-0.8286	-12.0817
ρ	0.7281	8.6015
a	0.4365	2.5267
b	0.8644	24.5282
c	0.0853	4.1437
d	-0.0664	-2.1845
LR (1) for $H_0: d = 0$	7.92	
LR (6) for H_0: $\beta = \gamma = \rho = b = c = d = 0$	223.58	
Ljung-Box (12) for residuals	13.51 (Prob=0.26)	
Ljung-Box (12) for residuals squared	16.08 (Prob=0.14)	
Skewness	-0.0872	
Kurtosis	3.6637	

Panel B: Sample period: May 1, 1998 - Dec 31, 2001

Number of obs	872	
Log-likelihood	-1823.29	
	Coeff.	t-stat
α	0.1196	1.1381
β	-0.0285	-1.0644
γ	-0.8070	-9.4364
ρ	0.7098	6.7125
a	0.1415	2.2113
b	0.8970	31.5549
c	0.0683	3.8668
LR (5) for H_0: $\beta = \gamma = \rho = b = c = 0$	54.84	
Ljung-Box (12) for residuals	12.96 (Prob=0.30)	
Ljung-Box (12) for residuals squared	10.09 (Prob=0.52)	
Skewness	-0.2279	
Kurtosis	3.3006	

χ^2 (1) critical values: 2.71 (10%), 3.84 (5%), 6.64 (1%)

χ^2 (5) critical values: 9.24 (10%), 11.07 (5%), 15.08 (1%)

χ^2 (6) critical values: 10.64 (10%), 12.59 (5%), 16.81 (1%)

5. Lagged Volatility Spillovers

This section examines whether there are lagged volatility spillovers from the previously open foreign stock market into the domestic stock market. Following Engle et al. (1990), Hamao et al. (1990), and Lin et al. (1994), let us define x_t as the most recent squared residual from model (3), using open-to-close returns of the previously open foreign market. With the inclusion of x_t in the conditional variance equation, it becomes:

$$R_t = \alpha + \beta h_t + \rho R_{t-1} + \gamma \varepsilon_{t-1} + \varepsilon_t$$
$$h_t = a + bh_{t-1} + c\varepsilon_{t-1}^2 + fx_t, \qquad (4)$$

where x_t is the most recent volatility surprise observed in the foreign market. Note that for the U.S. stock returns, the above GARCH model with $\rho = 0$ is estimated. The results of estimation using open-to-close returns measured in domestic monetary units are shown in Table 5-a. The parameter estimates reported in Table 5-a are not significantly different from those of the model (3) reported in Table 4-a. For the full sample period, a lagged volatility surprise from the U.S. stock market to the Korean stock market is not statistically significant. However, a lagged volatility surprise from the Korean stock market to the U.S. stock market is statistically significant. More specifically, the parameter estimate of the Korean volatility surprise is negative and significant at the one percent level. Note that the t-statistics and likelihood ratio statistics can be regarded as a causality test. The statistical significance implies that the Korean open-to-close returns provide additional information in predicting the U.S. open-to-close returns. The coefficient of the conditional variance in the mean equation for the U.S. stock returns is positive though it is significant only at the ten percent level – its p-value is 0.0601. A volatility surprise from the Korean stock market tends to lower the U.S. open-to-close stock returns for the full sample period.[9] For the post crisis subperiod, the effect of a foreign volatility surprise is not statistically significant for both stock exchanges.

The remainder of this section examines whether significant volatility spillovers still exist in the case where all the open-to-close returns are measured in U.S. dollars. Let xa_t be the most recent squared residual from the model (3'), using open-to-close returns measures in U.S. dollars of the previously open foreign market. With the inclusion of xa_t in the variance equation, it becomes:

$$Ra_t = \alpha + \beta h_t + \rho Ra_{t-1} + \gamma \varepsilon_{t-1} + \varepsilon_t$$
$$h_t = a + bh_{t-1} + c\varepsilon_{t-1}^2 + dD_t + fxa_t, \qquad (4')$$

where xa_t = the most recent foreign volatility surprise derived from a model using open-to-close return in U.S. dollars. The above model is used to estimate the effect of a volatility spillover from U.S. to Korea for the full sample period. For the post crisis subperiod, the above model with $d = 0$ is estimated. For the U.S. stock returns, the above GARCH model with $\rho = d = 0$ is estimated. The results of estimation using returns measured in U.S. dollars are shown in Table 5-b. The same qualitative results are found. For the full sample period, statistically significant volatility spillovers are observed from Korea to the U.S., but not from the U.S. to Korea. For the post crisis subperiod, statistically significant volatility spillovers are not observed.

This section has found that whether returns are measured in domestic currency units or in U.S. dollars, for the full sample period statistically significant lagged volatility spillovers are observed from Korea to the U.S., but not from the U.S. to Korea.[10] Such volatility spillovers from an emerging economy to the United States is surprising given the relative size of the KSE: the market value of NYSE is sixty times greater than that of the KSE.[11] However, since no such volatility spillovers are observed for the post crisis subperiod, the findings in this section imply that the lagged volatility spillovers from Korea to the

[9] Since the kurtosis of the normalized returns is large particularly for the S&P 500 returns, this paper has re-estimated t-values for the U.S. case using the Bollerslev and Wooldrige (1992) robust standard errors and covariance procedure, and got the same qualitative results. Note that this procedure does not change the parameter estimates. For the full sample period, the t-statistic of the coefficient f is –2.0551 and its p-value is 0.039; the t-statistic of the coefficient β is 2.1545 and its p-value is 0.031.

[10] Wang et al. (2002) have indicated lagged volatility spillovers from Hong Kong to London from inspecting stock returns of 15 Hong Kong firms listed both on the Hong Kong and London stock exchanges. Their results are not derived from examining the returns of major market indices such as FTSE 100 and Hang Seng Index. Thus, it is not clear whether their results are specific to the fact that their sample firms are all headquartered in Hong Kong.

[11] The market value of KSE listed securities amounted to 195 billion USD and that of NYSE listed securities amounted to 11,714 billion USD at the end of 2001.

U.S. are concentrated during the financial crisis period. Furthermore, it may be the result of the financial integration across the stock markets in East Asia. The trading activities of the Tokyo Stock Exchange (TSE), the Hong Kong Exchange (HKEx), the Singapore Exchange (SGX), and the Korea Stock Exchange are mostly concurrent. Thus, any information that may cause the volatility spillovers from any of the East Asian stock market may be reflected in the Korean stock returns. That is, the volatility spillovers from Korea to the U.S. might be regarded as the volatility spillovers from East Asia to the U.S.

Table 5-a. GARCH estimation of lagged volatility spillovers using open-to-close returns

$$R_t = \alpha + \beta h_t + \rho R_{t-1} + \gamma \varepsilon_{t-1} + \varepsilon_t$$

$$h_t = \alpha + b h_{t-1} + c\varepsilon_{t-1}^2 + f x_t ,$$

where R_t = open-to-close return x 100 and x_t = most recent squared residual derived from a GARCH model applied to the open-to-close return of the previously open foreign market.

Panel A: Sample period: Nov 1, 1997 – Dec 31, 2001

	From U.S. to Korea		**From Korea to U.S.**	
Number of obs	987		987	
Log-likelihood	-2009.92		-1427.12	
	Coeff.	t-stat	Coeff.	t-stat
α	0.2721	2.2710	-0.1347	-1.6020
β	-0.0813	-2.3601	0.1547	1.8802
γ	-0.7382	-9.8094	-0.0411	-1.1494
ρ	0.5979	6.4915		
a	0.0384	1.7232	0.0483	3.3319
b	0.9492	69.8097	0.9248	70.3100
c	0.0395	3.8363	0.0498	6.4749
f	0.0011	0.1711	-0.0041	-2.6105
LR (1) for $H_0: f = 0$	0.02		5.20	
LR (5) for $H_0: \beta = \gamma = b = c = f = 0$	90.14			
LR (6) for H_0: $\beta = \gamma = \rho = b = c = f = 0$	79.60			
Ljung-Box (12) for residuals	11.59 (Prob=0.40)		6.26 (Prob=0.86)	
Ljung-Box (12) for residuals squared	5.80 (Prob=0.89)		6.10 (Prob=0.87)	
Skewness	-0.2906		0.0977	
Kurtosis	3.6112		6.4840	

Panel B: Sample period: May 1, 1998 – Dec 31, 2001

	From U.S. to Korea		**From Korea to U.S.**	
Number of obs	872		872	
Log-likelihood	-1749.91		-1306.49	
	Coeff.	t-stat	Coeff.	t-stat
α	0.1954	1.7685	-0.2783	-2.1904
β	-0.0593	-1.7659	0.2527	2.2890
γ	-0.7810	-9.2747	-0.0493	-1.2867
ρ	0.6600	6.2646		
a	0.0577	1.7825	0.0690	3.2118
b	0.9324	50.3779	0.9037	46.0344
c	0.0492	3.8020	0.0532	4.9976
f	0.0046	0.5443	-0.0037	-1.3406
LR (1) for $H_0: f = 0$	0.22		1.94	
LR (5) for $H_0: \beta = \gamma = b = c = f = 0$	57.34			
LR (6) for H_0: $\beta = \gamma = \rho = b = c = f = 0$	59.68			
Ljung-Box (12) for residuals	9.11 (Prob=0.61)		5.25 (Prob=0.92)	
Ljung-Box (12) for residuals squared	7.69 (Prob=0.74)		5.01 (Prob=0.93)	
Skewness	-0.2779		0.1689	
Kurtosis	3.5613		6.8035	

χ^2 (1) critical values: 2.71 (10%), 3.84 (5%), 6.64 (1%)

χ^2 (5) critical values: 9.24 (10%), 11.07 (5%), 15.08 (1%)

χ^2 (6) critical values: 10.64 (10%), 12.59 (5%), 16.81 (1%)

Table 5-b. GARCH estimation of volatility spillovers using open-to-close returns measured in U.S. dollars

$$Ra_t = \alpha + \beta h_t + \rho Ra_{t-1} + \gamma\varepsilon_{t-1} + \varepsilon_t$$

$$h_t = a + bh_{t-1} + c\varepsilon_{t-1}^2 + dD_t + fxa_t\,,$$

where $Ra_t =$ open-to-close return in U.S. dollars x 100 and $xa_t =$ most recent squared residual derived from a GARCH model applied to the open-to-close return of the previously open foreign market, measured in U.S. dollars.

Panel A: Sample period: Nov 1, 1997 - Dec 31, 2001

	From U.S. to Korea		**From Korea to U.S.**	
Number of obs	987		987	
Log-likelihood	-2139.40		-1427.80	
	Coeff.	t-stat	Coeff.	t-stat
α	0.1099	2.2785	-0.1794	-2.0287
β	-0.0211	-2.2225	0.1952	2.2809
γ	-0.8307	-12.2904	-0.0445	-1.2356
ρ	0.7298	8.7258		
a	0.5191	2.6422	0.0417	3.6201
b	0.8609	23.6035	0.9120	54.9729
c	0.0860	4.0916	0.0569	5.6036
d	-0.0775	-2.3561		
f	-0.0303	-1.2861	-0.0008	-2.7601
LR (1) for $H_0: f = 0$	1.10		3.84	
LR (5) for $H_0: \beta = \gamma = b = c = f = 0$			88.78	
LR (7) for $H_0: \beta = \gamma = \rho = b = c = d = f = 0$	224.68			
Ljung-Box (12) for residuals	13.81 (Prob=0.24)		5.76 (Prob=0.89)	
Ljung-Box (12) for residuals squared	15.14 (Prob=0.18)		5.31 (Prob=0.92)	
Skewness	-0.0934		0.0945	
Kurtosis	3.6189		6.7003	

Panel B: Sample period: May 1, 1998 - Dec 31, 2001

	From U.S. to Korea		**From Korea to U.S.**	
Number of obs	872		872	
Log-likelihood	-1823.19		-1307.45	
	Coeff.	t-stat	Coeff.	t-stat
α	0.1189	1.1313	-0.3020	-2.3121
β	-0.0284	-1.0585	0.2719	2.4061
γ	-0.8088	-9.4713	-0.0513	-1.3289
ρ	-0.7122	6.7337		
a	0.1403	2.1059	0.0586	2.6124
b	0.8939	30.5123	0.8972	41.2091
c	0.0692	3.8119	0.0578	4.6966
f	0.0079	0.4599	-0.0003	-0.0893
LR(1) for $H_0: f = 0$	0.20		0.02	
LR (5) for $H_0: \beta = \gamma = b = c = f = 0$			55.42	
LR (6) for $H_0: \beta = \gamma = \rho = b = c = f = 0$	55.04			
Ljung-Box (12) for residuals	12.57 (Prob=0.32)		5.04 (Prob=0.93)	
Ljung-Box (12) for residuals squared	10.00 (Prob=0.53)		4.62 (Prob=0.95)	
Skewness	-0.2280		0.1693	
Kurtosis	3.3047		6.9780	

χ^2 (1) critical values: 2.71 (10%), 3.84 (5%), 6.63 (1%)

χ^2 (5) critical values: 9.24 (10%), 11.07 (5%), 15.08 (1%)

χ^2 (6) critical values: 10.64 (10%), 12.59 (5%), 16.81 (1%)

6. Lagged Return Spillovers

This section examines whether there are lagged spillovers on the conditional mean return, using open-to-close returns. Following Hamao et al. (1990) and Lin et al. (1994), the GARCH model (4) is modified to include the open-to-close return of the most recent foreign market, y_t in the conditional mean equation. For the open-to-close returns measured in domestic currency units, it becomes

$$R_t = \alpha + \beta h_t + \rho R_{t-1} + \phi y_t + \gamma \varepsilon_{t-1} + \varepsilon_t$$
$$h_t = a + b h_{t-1} + c\varepsilon_{t-1}^2 + f x_t, \qquad (5)$$

where y_t = open-to-close return of the previously open foreign market. In actual estimation, several variations of the model described above are used. To check whether there are return spillovers from the U.S. in the Korean open-to-close data, the above model with $f = 0$ is estimated since the volatility surprise from the U.S. is not statistically significant regardless of the sample period, according to Table 5-a. For the U.S. open-to-close returns, $\rho = 0$ is posited since the own past returns do not help explain the current returns, as indicated before. For the full sample period the model (5) is estimated with the Korean volatility surprise x_t, and for the post crisis subperiod the model without x_t is examined since the Korean volatility surprise is not statistically significant, according to Table 5-a.

The results of the estimation are shown in Table 6-a. In comparison with the estimates reported in Table 5-a, the corresponding parameter estimates do not differ significantly. According to the results in Table 6-a, statistically significant lagged return spillovers do not exist in neither the Korean stock market nor the U.S. stock market regardless of the sample period, using open-to-close returns measured in domestic currency.[12] Note that Hamao et al.(1990) find significant return spillovers from the U.S. to Japan. In contrast to their findings, after adjusting for nonsynchronous trading at open, Lin et al. (1994) find little evidence against hypothesis that domestic market efficiently adjust to foreign information for developed markets, such as the U.S. and Japan. This paper indicates that their results also hold for an emerging market.

Finally, this paper examines whether statistically significant return spillovers exist when all the open-to-close returns are measured in U.S. dollars. Let ya_t be the open-to-close return of the most recent foreign market, measured in U.S. dollars. For the open-to-close returns measured in U.S. dollars, it becomes

$$Ra_t = \alpha + \beta h_t + \rho Ra_{t-1} + \phi ya_t + \gamma \varepsilon_{t-1} + \varepsilon_t$$
$$h_t = a + b h_t + c\varepsilon_{t-1}^2 + dD_t + f xa_t \qquad (5')$$

To examine the return spillovers from the U.S. into Korea, the model (5') with $f = 0$ is estimated since the volatility surprise from the U.S., when KOSPI returns are measured in USD, is not statistically significant according to Table 5-b. To examine such effects from Korea into the U.S., this paper estimates model (5') with $\rho = d = 0$ for the full sample period and with $\rho = d = f = 0$ for the post crisis subperiod, incorporating the results in Table 5-b.

The results of the estimation for full sample are reported in Table 6-b. In both of the markets, the parameter estimates do not change significantly from those obtained in Table 5-b. Unlike the previous case where returns are measured in domestic currency units, statistically significant return spillovers are observed in the Korean stock market. More specifically, return spillovers from the U.S. into Korea are significant at the 5 percent level. Yet, those from Korea into the U.S. are not.

The existence of return spillovers from the U.S. to Korea, when open-to-close KOSPI returns are measured in USD, does not seem consistent with the predictions of international asset pricing model. One might consider it as evidence of inefficient use of information by the investors participating in the Korean stock market. However, the existence of return spillovers with stock returns measured in USD must be explained in terms of the behavior of the KRW/USD exchange rate since statistically significant return spillovers do not exist with returns measured in domestic currency. One of the major participant in the KRW/USD exchange market is the Korean government. The official foreign reserve holdings of the Korean government (or the Bank of Korea) amounted to \$24.4 billion in November 1997, and \$20.4 billion in December 1997. Ever since the government's official foreign reserve holdings have increased steadily -- \$31.6 billion in 1998, \$22.0 billion in 1999, \$22.2 billion in 2000, and \$6.6 billion in 2001, so that its

[12] For the reasons indicated in footnote 9, this paper has re-estimated t-values for the U.S. case using the Bollerslev - Wooldrige procedure, and got the same qualitative results. For the full sample period, the t-statistic of the coefficient ϕ is 1.090 and its p-value is 0.276; the t-statistic of the coefficient f is –2.0354 and its p-value is 0.042.

foreign reserve holdings amounted to $102.8 billion at the end of 2001 (see figure 2). The Korean government raised its official foreign reserve holdings mostly to lower the country default risk in the first two or three years after the financial crisis and then to relieve the appreciation pressure on the Korean won. The government's action must have tremendous impacts on the KRW/USD foreign exchange rate since the major portion of the Korean government's foreign reserve holdings is in USD. Thus, the existence of lagged return spillovers with returns measured in U.S. dollars may reflect the way the Korean government has accumulated its U.S. dollar based assets.

7. Conclusion

The extent of international financial integration among the developed economies has been well documented in the literature. This paper has examined whether there are lagged spillovers in return and volatility between the U.S. and Korea, an emerging economy, for a sample period including the financial crisis of 1977. Using open-to-close KOSPI and S&P 500 returns, this paper has found statistically significant lagged volatility spillovers from Korea to the U.S., but not from the U.S. to Korea. Such spillovers are not observed for the post crisis subperiod. These findings imply that volatility spillovers are concentrated during the crisis period. Furthermore, since trading activities in the East Asian stock markets are mostly concurrent, any information that may cause the spillover from any of the Asian stock markets may be reflected in the Korean stock returns. This paper has also found that statistically significant lagged return spillovers do not exist in neither the Korean stock market nor the U.S. stock markets. This is consistent to the finding of Lin et al. (1994) that domestic market efficiently adjust to foreign information for the U.S. and Japan. This paper indicates that their results also hold for an emerging economy. Finally, this paper has found that statistically significant lagged return spillovers exist from the U.S. to Korea when returns measured in USD are used. Given that the amount of the Korean government's official foreign reserve holdings increased by 400 percent between December 1997 and December 2001, the lagged return spillovers with returns measured in U.S. dollars may result from the way the Korean government has intervened in the KRW/USD foreign exchange market.

Table 6-a. GARCH estimation of return spillovers using open-to-close returns measured in domestic currency

$$R_t = \alpha + \beta h_t + \rho R_{t-1} + \phi y_t + \gamma \varepsilon_{t-1} + \varepsilon_t$$

$$h_t = a + b h_{t-1} + c\varepsilon_{t-1}^2 + f x_t ,$$

where $R_t =$ open-to-close return x 100 and $y_t =$ open-to-close return of the previously open foreign stock market x 100.

Panel A: Sample period: Nov 1, 1997 - Dec 31, 2001

	From U.S. to Korea		**From Korea to U.S.**	
Number of obs	987		987	
Log-likelihood	-2009.52		-1426.53	
	Coeff.	t-stat	Coeff.	t-stat
α	0.2728	2.3409	-0.1257	-1.4974
β	-0.0812	-2.4256	0.1476	1.8001
γ	-0.7603	-10.6645	-0.0393	-1.1010
ρ	0.6222	7.0206		
ϕ	0.0333	0.9169	0.0167	1.0714
a	0.0380	1.8311	0.0483	3.3091
b	0.9515	72.4227	0.9236	69.7839
c	0.0377	3.8118	0.0509	6.4281
f			-0.0041	-2.5212
LR (1) for $H_0 : \phi = 0$	0.82		1.18	
LR (6) for $H_0 :\ \beta = \gamma = \rho = \phi = b = c = 0$	80.42			
LR (6) for $H_0 :\ \beta = \gamma = \phi = b = c = f = 0$			91.32	
Ljung-Box (12) for residuals	11.94 (Prob=0.37)		6.42 (Prob=0.84)	
Ljung-Box (12) for residuals squared	6.15 (Prob=0.86)		5.82 (Prob=0.89)	
Skewness	-0.2930		0.1040	
Kurtosis	3.6341		6.4956	

Panel B: Sample period: May 1, 1998 - Dec 31, 2001

	From U.S. to Korea		**From Korea to U.S.**	
Number of obs	872		872	
Log-likelihood	-1749.42		-1306.17	
	Coeff.	t-stat	Coeff.	t-stat
α	0.1939	1.8289	-0.2872	-2.2940
β	-0.0589	-1.8287	0.2608	2.4021
γ	-0.8045	-10.3787	-0.0506	-1.3061
ρ	0.6860	6.9580		
ϕ	0.0368	1.0804	0.0303	1.5400
a	0.0597	1.9128	0.0588	3.8949
b	0.9363	52.3681	0.8929	41.5004
c	0.0464	3.7352	0.0613	4.7683
LR (1) for $H_0 : \phi = 0$	1.20		2.58	
LR (5) for $H_0 :\ \beta = \gamma = \phi = b = c = 0$			57.98	
LR (6) for $H_0 :\ \beta = \gamma = \rho = \phi = b = c = 0$	60.64			
Ljung-Box (12) for residuals	9.92 (Prob=0.54)		5.21 (Prob=0.92)	
Ljung-Box (12) for residuals squared	7.53 (Prob=0.76)		4.40 (Prob=0.96)	
Skewness	-0.2841		0.1758	
Kurtosis	3.5860		6.9858	

χ^2 (1) critical values: 2.71 (10%), 3.84 (5%), 6.63 (1%)

χ^2 (5) critical values: 9.24 (10%), 11.07 (5%), 15.08 (1%)

χ^2 (6) critical values: 10.64 (10%), 12.59 (5%), 16.81 (1%)

Table 6-b. GARCH estimation of return spillovers using open-to-close returns measured in USD

$$Ra_t = \alpha + \beta h_t + \rho Ra_{-1} + \phi ya_t + \gamma \varepsilon_{t-1} + \varepsilon_t$$

$$h_t = a + bh_{t-1} + c\varepsilon_{t-1}^2 + dD_t + fxa_t ,$$

where Ra_t = open-to-close return in USD x100 and ya_t = open-to-close return of the previously open foreign market in USD x100.

Panel A: Sample period : Nov 1, 1997 - Dec 31, 2001

	From U.S. to Korea		**From Korea to U.S.**	
Number of obs	987		987	
Log-likelihood	-2136.69		-1426.95	
	Coeff.	t-stat	Coeff.	t-stat
α	0.0834	2.4677	-0.1754	-2.0011
β	-0.0162	-2.4395	0.1922	2.2607
γ	-0.9036	-22.0399	-0.0433	-1.2022
ρ	0.8147	14.6153		
ϕ	0.0723	2.2743	0.0154	1.2181
a	0.4132	2.4401	0.0432	3.6711
b	0.8667	24.9115	0.9092	53.5113
c	0.0840	4.1877	0.0587	5.5401
d	-0.0612	-2.0757		
f			-0.0009	-2.6764
LR (1) for $H_0: \phi = 0$	6.52		1.70	
LR (5) for $H_0: \beta = \gamma = \phi = b = c = 0$			90.48	
LR (7) for $H_0: \beta = \gamma = \rho = \phi = b = c = d = 0$	30.10			
Ljung-Box (12) for residuals	15.49 (Prob=0.16)		5.99 (Prob=0.87)	
Ljung-Box (12) for residuals squared	13.86 (Prob=0.24)		5.05 (Prob=0.93)	
Skewness	-0.0406		0.1018	
Kurtosis	3.7644		6.7201	

Panel B: Sample period: May 1, 1998 - Dec 31, 2001

	From U.S. to Korea		**From Korea to U.S.**	
Number of obs	872		872	
Log-likelihood	-1820.18		-1305.78	
	Coeff.	t-stat	Coeff.	t-stat
α	0.0945	1.1837	-0.2958	-2.3543
β	-0.0229	-1.1291	0.2670	2.4513
γ	-0.8919	-17.7119	-0.0516	-1.3286
ρ	0.8062	11.9509		
ϕ	0.0729	2.1462	0.0323	1.8146
a	0.1564	2.2135	0.0589	3.8920
b	0.8912	29.2162	0.8931	40.6998
c	0.0699	3.8067	0.0610	4.6150
LR (1) for $H_0: \phi = 0$	6.22		3.36	
LR (5) for $H_0: \beta = \gamma = \phi = b = c = 0$			58.76	
LR (6) for $H_0: \beta = \gamma = \rho = \phi = b = c = 0$	31.06			
Ljung-Box (12) for residuals	14.73 (Prob=0.20)		5.23 (Prob=0.92)	
Ljung-Box (12) for residuals squared	9.03 (Prob=0.62)		4.27 (Prob=0.96)	
Skewness	-0.2075		0.1768	
Kurtosis	3.2689		7.0460	

χ^2 (1) critical values: 2.71 (10%), 3.84 (5%), 6.63 (1%), χ^2 (5) critical values: 9.24 (10%), 11.07 (5%), 15.08 (1%)

χ^2 (6) critical values: 10.64 (10%), 12.59 (5%), 16.81 (1%), χ^2 (7) critical values: 12.02 (10%), 14.07 (5%), 18.48 (1%)

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