The Effect of the 1987 Stock Crash on International Financial Integration

Yasushi Hamao
Ronald W. Masulis
Victor Ng

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Professor Yasushi Hamao
Graduate School of Business, Columbia University

Professor Ronald W. Masulis
Owen Graduate School of Management, Vanderbilt University

Professor Victor Ng
School of Business Administration, University of Michigan

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Yasushi Hamao, Columbia University
Ronald W. Masulis, Vanderbilt University
Victor Ng, University of Michigan[1]

ABSTRACT

This paper examines daily open-to-close returns from three major stock markets over the past five years including the October 1987 Stock Market Crash. We find some evidence that volatility spillover effects emanating from Japan have been gathering strength over time, especially after the 1987 Crash. This may be attributed to a growing awareness of domestic investors about the economic interdependence of international financial markets.

1. Introduction

The October 19, 1987 stock market Crash is noteworthy not only for the severity of its impact on the U.S. market, but also for the pervasiveness of its impact throughout the world's stock markets. Prior to the Crash, the correlation in returns across international stock markets in high-frequency data was found to be weak and difficult to detect above the normal noise associated with domestic trading. However, around the time of the Crash a strong correlation was exhibited across markets. This strong interdependence among financial markets could have fundamentally altered investor perceptions concerning the importance of foreign financial news, thereby permanently increasing the correlation in stock returns and volatility across markets.

Numerous studies have examined various aspects of the 1987 Crash.[2] Roll (1988) offers a comprehensive analysis of the international transmission of the 1987 Crash across all major world stock markets. King-Wadhwani (1990) examine an eight month period surrounding the 1987 Crash and document a "contagion" effect where a "mistake" in one market such as the Crash is transmitted to other markets. They also show increased correlation between markets just after the Crash. Neumark-Tinsley-Tosini (1988) study U.S. stocks that are dually listed in Tokyo or London. Previous overnight price change in Tokyo or London is used to predict New York price movements. They find significantly increased predictability after the Crash for a one month period. Both von Furstenberg-Jeon (1989) and Rogers (1990) hypothesize that a structural shift in relations among

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[1] We thank participants of the conference "Statistical Models for Financial Volatility" at the University of California, San Diego for their useful comments.

[2] See Roll (1989) for an extensive review of this literature.

international stock returns occurs following the Crash.

Several recent papers have explored possible spillover effects across international financial markets. Ito-Roley (1987) investigate the effect of actual news announcements on the volatility of yen/dollar exchange rate in various geographic segments of the market around the clock. They find that the U.S. money supply announcement surprises have the most consistent effects on exchange rate volatility. Bailey (1990) examines the effect of U.S. money supply announcements on Pacific Rim stock indexes and reports that a number of these stock markets exhibit price reactions similar to reactions observed in New York. He finds that the differential sensitivity of this news across these markets can be partially explained by the degree of international capital flow restrictions that exist in these capital markets.

Engle-Ito-Lin (1990) examine intra-day foreign exchange rates in New York and Tokyo and find volatility spillover effects using a GARCH model. Ng-Chang-Chou (1991) present evidence on the extent of transmission of price volatility from the U.S. stock market to various Pacific Rim stock markets and the importance of government regulation of capital flows. Hamao-Masulis-Ng (1990) explore price change and volatility spillovers across Tokyo, London, and New York stock markets using a GARCH-M model. They report that over the pre-Crash period the transmission process of volatility across these markets differs in its impacts on domestic stock exchanges; while the Japanese market appears most sensitive to foreign volatility shocks, other markets, particularly the U.S. market is relatively insensitive to foreign (especially Japanese) volatility surprises.

Over the last two years, the international stock markets have exhibited several interesting phenomena, including the "mini-crash of October 1989, the sustained period of stock price rises in Japan followed by the recent severe price drops and high volatility observed in the Tokyo Stock Exchange. These events have further increased interest in comovements of prices across international stock markets, as is illustrated by the following quotes in the business press:

> "On January 12, a 666-point plunge in Tokyo's key Nikkei average kicked off a 71-point sell-off in the Dow-Jones industrials. A few weeks later, a 600-point plunge in Japan sent the Dow tumbling 60 points in the first half-hour of trading. They used to say that when the U.S. sneezes, the rest of the world catches pneumonia. No more. Japan's awesome financial and economic muscle has reached the point where its *kushami*, or "sneezes," can make Wall Street sick." ("When Japan Gets the Jitters, the Rest of the World Trembles," *Business Week*, February 12, 1990).

> "Many of the people who thought Japan's stock market was stupendously overpriced worried that the bubble's inevitable burst would set of a chain reaction of stock market plunges around the globe. So far, there is no sign of that doomsday link. While the Tokyo stock market is down 14.37% this year, stock market elsewhere in the world haven't fallen as steeply and don't seem to be following the Nippon lead." ("So Far, Tokyo Isn't Dragging Rest of World Markets Down," *Wall Street Journal*, February 27, 1990).

These two contradictory perspectives highlight the current controversy concerning the strength of international financial integration and its impacts on the relations among major stock markets.

This paper studies the price processes and the relations of the world's largest stock exchanges over the last five years. The purpose of this study is to explore whether there are significant shifts in the stock return generating processes and the importance of volatility spillovers from foreign markets preceding and following the October 1987 Stock Market Crash. We use a modification of the GARCH return generating process for measuring structural shifts in this process at and around the 1987 Crash. The normalized residuals from some of our models exhibit high kurtosis compared to a normal distribution. Leptokurtosis generally causes the estimated standard errors to be unreliable which invalidates conventional statistical inference using t-tests. Therefore, we also use robust standard error based on the quasi maximum likelihood approach developed by Wooldridge (1988, 1990) and Bollerslev-Wooldridge (1990) to compute t-values.

The paper is organized as follows. Section 2 describes the stock price data and is followed by Section 3 which reviews the basic ARCH framework and the particular modifications that we employ. Section 4 presents initial estimates of the GARCH model and then presents estimates of volatility spillover effects in intraday returns among the three international stock markets using a GARCH-M framework. Section 5 presents estimates of the structural changes in spillover effects at and around the 1987 Crash. Evidence of non-Crash related time trends in these spillover effects is presented in Section 6. Section 7 concludes the paper.

2. Data

Our database covers the five year period, April 1, 1985 to February 28, 1990 and encompasses daily open and closing prices of major market indices on the Tokyo, London and New York stock exchanges.[3] For the Tokyo Stock Exchange, we use the Nikkei 225 Stock Index, which is a price-weighted average stock price index. Opening price data were recorded at 9:15 am until December 18, 1987 and at 9:01 am thereafter, while closing prices are recorded at 3:00 pm Tokyo time. The price data were obtained from Nihon Keizai Shimbun Sha. There are several peculiarities about the Tokyo market. First, no trading takes place between 11:00 am and 1:00 pm local time. Second, there was Saturday morning trading three times (or later twice) a month through January 1989. Third, there are price limits on individual stocks though they only apply for extremely large price changes.

In the London stock market, we use the Financial Times-Stock Exchange 100 Share (FTSE) Index which is a value weighted index. The opening price data were recorded at 9:00 am, while the official closing price was at 3:30 pm London time. While the actual close of the London market is at 5:00 pm, to minimize the

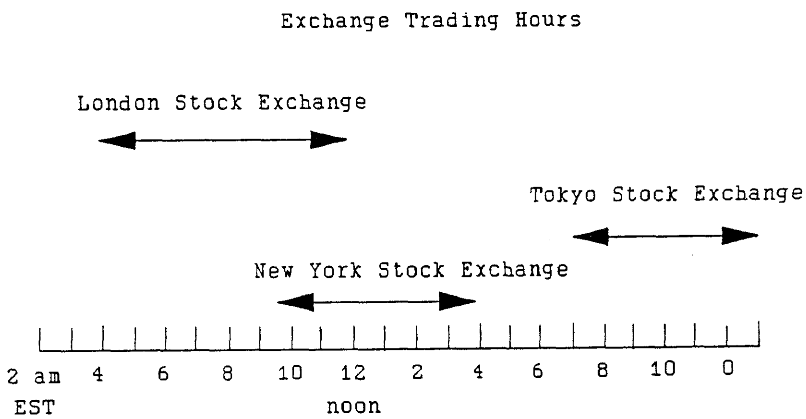
[3] These indices do not include dividend reinvestment which causes a small negative bias in the size of these recorded returns.

overlap in trading periods with New York to one hour, we use the earlier official close used for U.K. tax purposes. The data source was the London International Stock Exchange and the London *Financial Times*.[4]

In the New York stock market, we use the Standard & Poor's 500 Composite Index. The S&P 500 is an equity value weighted arithmetic index. The primary data source was S&P's monthly "500 Information Bulletin." The opening stock price was measured at 10:01 am until September 30, 1985 and at 9:31 am thereafter and the close is at 4:00 pm EST.

Figure 1 shows trading hours of the three exchanges in Eastern Standard Time.

Figure 1



From these daily opening and closing prices, we compute daily open-to-close returns for our three stock indices. By studying open-to-close returns, we can focus our analysis on periods when trading is actively taking place (which is when most information appears to be released to the market) and which has the advantage of representing periods of non-contemporaneous trading on our three stock exchanges.[5] While London stock market prices are based on the average of the bid and ask quotes which must be available from 9:00 am to 5:00 pm local time, in New York and Tokyo only transaction prices are used and markets can frequently experience delayed openings of individual stocks. When delays of the

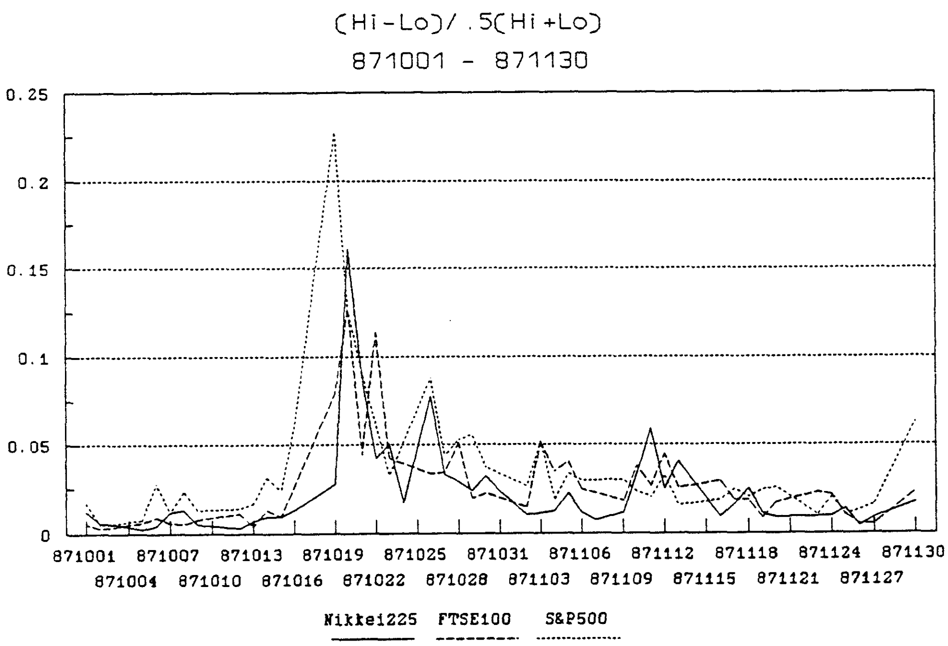
[4] Unfortunately, on October 16, 1987 the United Kingdom experienced a severe hurricane which caused the London market to remain closed for the day.

[5] The one exception to this statement is the last hour of trading on the London Stock Exchange represents the first hour of trading in New York.

open occur, the Nikkei 225 and the S&P 500 indices use the prior day's closing price as a substitute for the unavailable opening price. This procedure introduces some artificial effects (*e.g.*, serial correlation) in the open-to-close and close-to-open returns of the New York and Tokyo stock indices.[6]

Figure 2 depicts the difference between daily high and low prices divided by the average of high and low of the day for the period surrounding the 1987 Crash. It is clear from the figure that volatility rises at the time of the Crash and persists for a prolonged period thereafter for all of the three markets.

Figure 2



3. Application of the ARCH Framework to Intraday Stock Returns

To evaluate the interrelations of price movements among major international stock markets, we utilize variants of the autoregressive conditional heteroskedasticity (ARCH) model developed by Engle (1982) and extended by Bollerslev (1986, 1987), and Engle-Lilien-Robins (1987).[7] In this framework, the conditional variance,

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[6] This is not a serious problem for the Nikkei prior to December 18, 1987 since we are using prices fifteen minutes after the market opens.

[7] For a survey of the literature on applications of ARCH in finance, see Bollerslev-Chou-Kroner (1990).

h, is assumed to be a linear function of past squared errors as well as possible exogenous variables. This feature captures the observed serial correlation of second moments that stock returns typically manifest and is consistent with the leptokurtic frequency distributions that stock return time series exhibit.

We begin by specifying a GARCH-M model with weekend/holiday dummy variables in both the conditional mean and variance equations to capture not only the negative Monday effect in mean returns but also Monday's higher volatility as found in Gibbons-Hess (1981) and Keim-Stambaugh (1984). Following earlier studies that document serial correlations in daily returns, we adjust the conditional mean return for a first order moving average process in an effort to insure the serial independence of the conditional error.[8] The resulting GARCH(1,1)-M model is specified below:

$$(1)\qquad \begin{aligned} R_t &= \alpha + \beta h_t + \delta W_t + \gamma \epsilon_{t-1} + \epsilon_t \\ h_t &= a_t + b h_{t-1} + c \epsilon^2_{t-1} + d W_t \quad , \end{aligned}$$

where $a > 0$, $b, c \geq 0$, h_t is conditional variance of the error term ϵ_t, and W_t is a weekend/holiday dummy variable which equals one on a day following a weekend or holidays and zero otherwise.

4. Spillover Effects Under a GARCH Model

The results of estimating this GARCH model for our three stock exchanges using daily open-to-close returns for the full sample period are presented in Table 1. The formulation assumes that there are no structural shifts or nonstationarities across the estimation period and in particular that the return generating process is not altered around the October 1987 Crash. In all three markets, the GARCH parameters (b and c) are highly significant and these two parameter estimates sum to values between .9 and .92. On the other hand, the GARCH-M parameter estimate (β) is insignificant, or if marginally significant, it can take on either a positive or negative sign. The diagnostic statistics for skewness and serial correlations of residuals and residuals squared all appear to indicate that the model is successful in characterizing the returns data in these markets. On the other hand, the coefficients of kurtosis display somewhat high values relative to a normal distribution, indicating that conventional t-values used to evaluate parameter estimates may be misstated. In order to cope with this problem, we present robust t-statistics in the third column for each market.

The significance of the conditional variance parameter estimate in the mean equation is a controversial issue as the contradictory evidence and conclusions of Akgiray (1989) and French-Schwert-Stambaugh (1987) indicate. We present new evidence on this issue by estimating this parameter in our model and find that

[8] This specification is based on the earlier results of Hamao-Masulis-Ng (1990).

the GARCH model is a more persuasive characterization of our data than the GARCH-M model. We also find that the weekend/holiday dummy variable in the mean equation has a negative parameter value in all these markets, though it is not statistically significant for the U.S. market. On the other hand, the weekend/holiday variable in the conditional variance equation has a significant negative parameter value in the U.S., and an insignificant value in other two markets.

We next modify model (1) to include a volatility spillover effect from both foreign markets trading while the domestic market was closed. The expanded model is specified below:

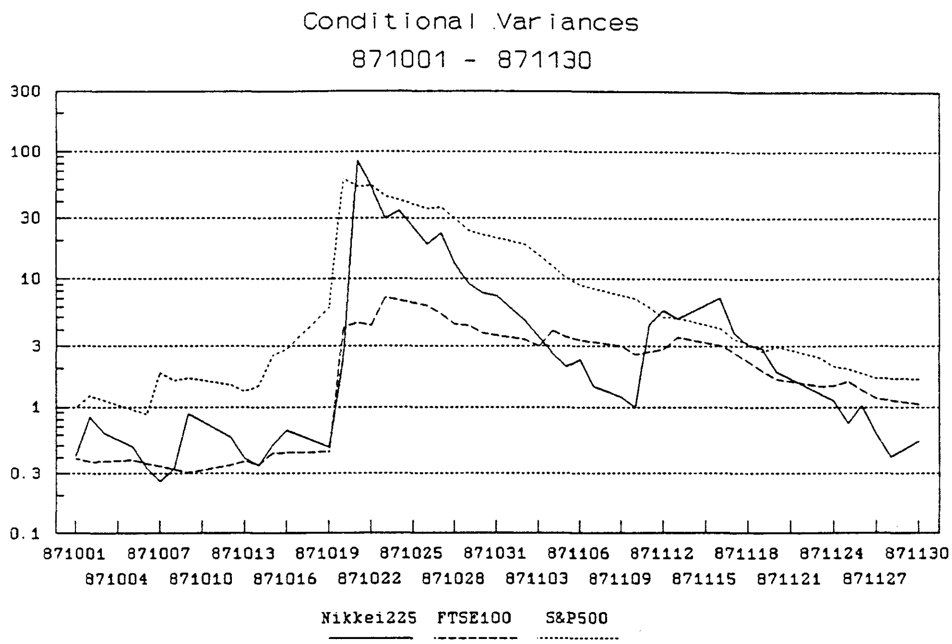
$$(2) \qquad \begin{aligned} R_t &= \alpha + \beta h_t + \delta W_t + \gamma \epsilon_{t-1} + \epsilon_t \\ h_t &= a_t + b h_{t-1} + c \epsilon^2_{t-1} + d W_t + f X_{1t} + p X_{2t} \quad , \end{aligned}$$

where X_{it} is the most recent residual squared estimated from model (1) in foreign market i. X_{it} can be interpreted as the most recent volatility "surprise" realized in the foreign market while the domestic market is closed. Throughout the analysis, whenever the foreign market is closed for a holiday while the domestic market is open, we use the prior day's squared residual in the foreign market to estimate the spillover effect.

Table 2 shows the results of applying model (2) to intraday returns on the three exchanges over the full sample period. This model implicitly assumes that there is no structural change over the sample period including the period subsequent to the October 1987 Crash. Consistent with the results of Hamao-Masulis-Ng (1990), significant spillover effects from both foreign markets onto each of the three domestic markets are observed. It is also interesting to observe the substantial drop in the persistence parameters in the conditional variance, especially for the U.S. market. Further, much of the leptokurtosis evident in Table 1 is eliminated by allowing cross market spillover effects. The Ljung-Box statistics also indicate no significant serial correlation in residuals or squared residuals of the model for any the three markets.

Figure 3 visualizes the extent of volatility spillover effects around the Crash. The figure presents the natural logs of the conditional variances (h_t) estimated from model (1). A jump in the U.S. conditional variance is followed by an even larger reaction in the Japanese market and an increase in the U.K. market as well. The persistence of the increased level of volatility in the three international markets after the Crash is also clearly depicted.

Figure 3



5. Estimates of Structural Changes in Spillover Effects

The model we use to estimate potential shifts in these spillover relations involves two step functions representing the Crash (the month of October 1987) and post Crash (from November 1987 to February 1990) subperiods, which allow for shifts in the impacts of the foreign volatility surprises. This expanded model is described below:

$$R_t = \alpha + \beta h_t + \delta W_t + \gamma \epsilon_{t-1} + \epsilon_t$$

(3)

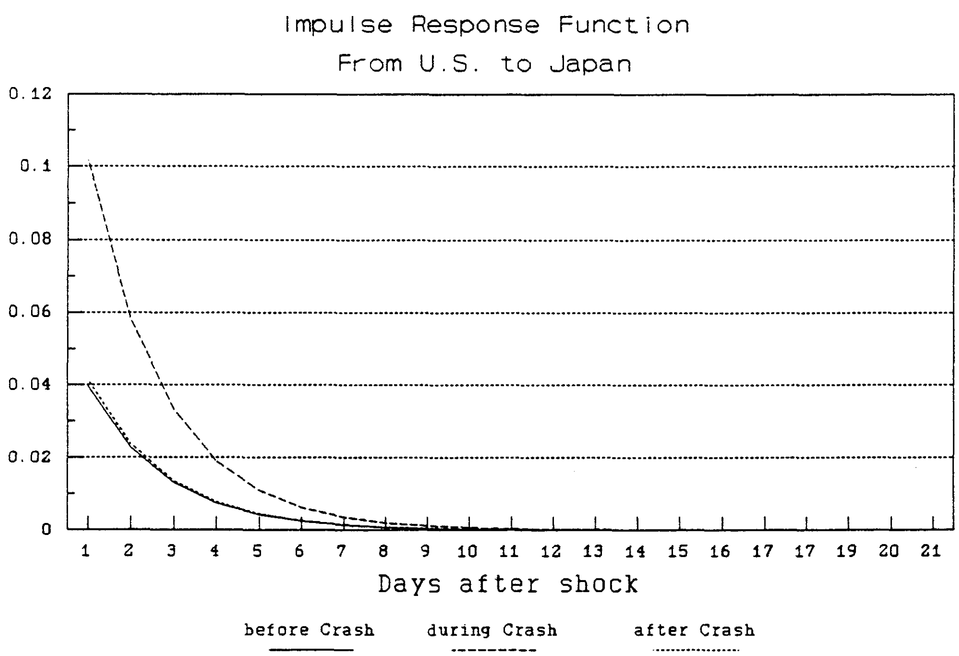
$$h_t = a_t + bh_{t-1} + c\epsilon^2_{t-1} + dW_t + (f + gD_t + kA_t)X_{1t} + (p + qD_t + rA_t)X_{2t} ,$$

where D_t equals one if t is in October 1987 (during the Crash month) and zero otherwise, and A_t equals one if t is in the post-Crash period (November 1987-February 1990) and zero otherwise. Modifying the model as described in (3) enables us to examine not only the significance of volatility spillover effects, but also the extent of discrete shifts in the levels of these effects across the three subperiods. As such, this evidence can be interpreted as a robustness test of the stationary model described by (2).

The results of estimating model (3) are presented in Table 3. Overall, the diagnostic statistics do not indicate model misspecification. The Ljung-Box statistics are not significant and importantly the measures of kurtosis do not appear to be particularly leptokurtic relative to a normal distribution. This suggests that the conventional t-statistics are likely to be valid, especially once it is recognized that the sample period was chosen precisely because a large set of abnormal price changes were known to occur.

The spillover effect from the U.S. market to Japan is significant before the Crash, but does not change significantly during the Crash month or thereafter. This pattern can also be discerned from Figure 4, which shows the response of the Japanese market to U.S. price volatility shocks. This figure is obtained by recursively solving the variance equation in model (3). The impulse response to foreign market i is given by coefficients on X_{it}, X_{it-1}, ..., holding the effect of the other foreign market ($X_{j\cdot}$ terms) constant.

Figure 4



The volatility spillover effect from the U.K. onto the Japanese market is significant before October 1987, exhibits no significant change in October 1987, and shows a decrease in spillover level after the Crash. The post-Crash level, defined by the sum of parameters f and k is 0.032. This is approximately one-third the pre-Crash level, 0.090.[9]

Looking at the volatility spillover experienced in the U.K. market, we find that the Japanese market's influence is significant before October 1987, but there is no evidence of a significant change during the Crash month or afterwards. On the other hand, we find that the U.S. market's influence on U.K. price volatility to be insignificant before, during, and after the Crash month. This may be due to the fact that U.S. market movements occur further back in time or that their influence is felt indirectly through its effect on the Japanese market which in turn spills over on the U.K. market.[10]

Turning to volatility spillovers experienced in the U.S. market, we find that the volatility spillover effect from the U.K. onto the U.S. market to be significant before October 1987, and increases during October 1987.[11] However, after the Crash, the spillover effect diminishes and falls below its pre-Crash level. In contrast, the Japanese market has an insignificant influence before and in the month of October 1987, but then acquires a significant positive effect thereafter. Figure 5 depicts the impulse response function of the U.S. market to Japanese price volatility surprises. The figure suggests an increase in the Japanese market's influence after the Crash.

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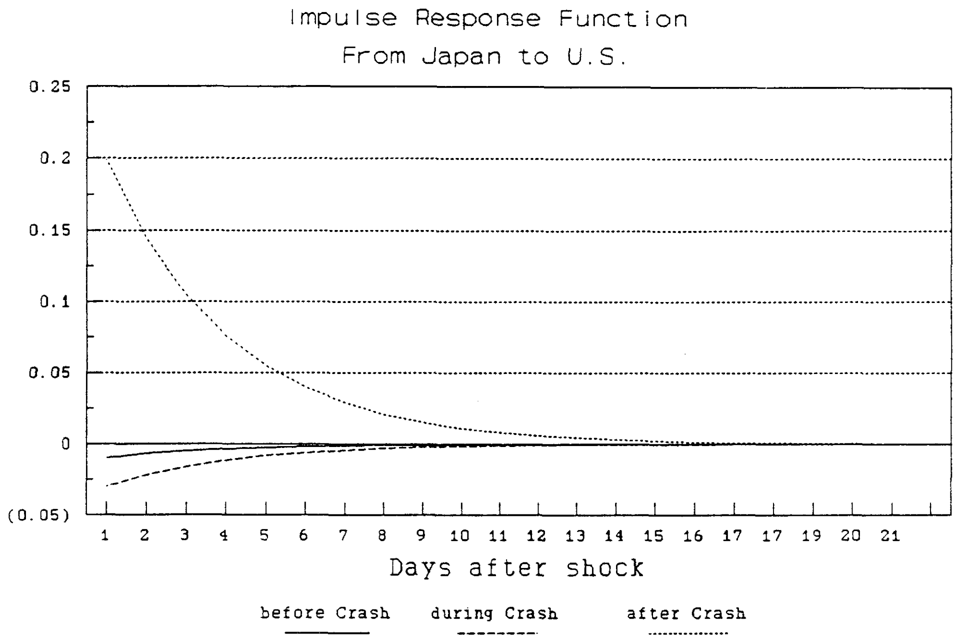
[9] It is noteworthy that the b and c parameter estimates in the conditional variance equation shown in Table 3 which allow for structural shift in the Crash month and beyond, are very similar in magnitude to the corresponding parameter estimates in Table 4 of Hamao-Masulis-Ng (1990) which specifies a stationary GARCH model using only pre-Crash data. This similarity and the insignificance of nearly all the parameters associated with the step functions indicate that the GARCH model does not appear to experience significant structural shifts after the Crash with the possible exception of the U.S. market.

[10] This may be further caused by the overlap in London and New York trading periods.

[11] The strength of this spillover effect may be exaggerated by the partially overlapping trading period in London and New York. It is also noteworthy that the volatility persistence in the U.S. market strengthens noticeably once we allow a shift in the GARCH process after the Crash.

Figure 5



The above results are consistent with our earlier study which document a pronounced asymmetry in the transmission of volatility between Japan and the U.S. However, the current analysis which utilizes more recent data suggest a potentially important shift in these relationships subsequent to the 1987 Crash. We find that while the volatility spillover effect from the U.S. to Japan is consistently significant before, during and after the Crash, the volatility spillover effect from Japan to the U.S., though insignificant before and during the Crash period, increases to a possibly significant positive level in the post-Crash period.[12]

6. Time-Varying Spillover Effects

The previous section documents that the volatility spillover effect exhibits significant shifts around the 1987 Crash. This leads us to question whether the volatility spillover effects actually exhibit a general time trend instead of a structural shift. In order to investigate this issue, we further modify our basic GARCH model to allow for a non-stochastic time trend in the volatility spillover variable which may be linear or non-linear as well as the step functions for the Crash and post-Crash periods as specified below:

[12] This conclusion depends on whether or not one judges that the model residuals are significantly leptokurtic which would necessitate the use of robust standard errors.

$$R_t = \alpha + \beta h_t + \delta W_t + \gamma \epsilon_{t-1} + \epsilon_t$$

(4)

$$h_t = a_t + bh_{t-1} + c\epsilon_{t-1}^2 + dW_t + [f(t^m) + gD_t + kA_t]X_{1t} + [p(t^s) + qD_t + rA_t]X_{2t} ,$$

where parameters m and s signify trends in spillover effects and

m, s = 0	stationary spillover effect;
m, s < −1	spillover effect decreasing at an increasing rate;
−1 < m, s < 0	spillover effect decreasing at a decreasing rate;
0 < m, s < 1	spillover effect increasing at a decreasing rate; and
1 < m, s	spillover effect increasing at an increasing rate.

This formulation also allows us to examine whether the spillover effect exhibits a discrete jump after the Crash. The results of estimating the GARCH model as specified above are presented in Table 4. As in Table 3, the coefficients of kurtosis for the model residuals are not particularly high, indicating that the use of conventional t-statistics may be justified.[13] The spillover effect from the U.S. market to Japan exhibits some upward trend which drops after the Crash. The spillover effect from the U.K. market to Japan exhibits a relatively large positive effect with an insignificant trend, but after October 1987 this effect declines. When we examine the U.K. market, we find no significant spillover effects from either the Japanese or U.S. markets. Turning to the U.S. market, we find no evidence of any trend in the spillover effect from the Japanese market, although there is evidence of a jump up in its level after the 1987 Crash. In looking at volatility spillovers from the U.K. market, we find a positive effect on the U.S. market during the Crash month, but not before or after. The coefficients for dummy variables for during and after the Crash (g, k, q, and r) show qualitatively similar patterns as Table 3.

While in most cases volatility spillover effects increase during the Crash period and then decline afterwards, the spillover effects from the Japanese market appear to be an exception. The spillover effects from the Japanese market to the U.S. market steadily increase over time, and experience a further jump in magnitude after the Crash period. One might attribute this change following the Crash to the increased awareness by U.S. investors of the importance of the Japanese economy to global economic conditions.

7. Conclusions

This study analyzes daily open-to-close returns from three major stock markets over the past five years, a period that includes the celebrated October 1987 Stock Market Crash. We find that the international transmission of volatility

[13] This is especially true when we take into account the fact that the sample period was explicitly chosen to include a period of abnormally large price changes.

does not occur evenly around the world; instead, there are spillover effects of disproportionate size from one market to the next. We also find that the volatility spillover effects have been relatively stable over our five year period even when we separate the Crash and post-Crash periods. The one major exception to this statement is that there is some weak evidence that volatility spillover effects emanating from Japan have been gathering strength over time, and these changes appear to be more pronounced following the 1987 Crash. This latter evidence is weakly supportive of the proposition that domestic investors have become more aware of the growing economic interdependence of international financial markets and the importance of Japanese financial developments for non-Japanese markets, since the 1987 Crash.

Table 1. GARCH Estimation of Open-Close Returns:
Sample period April 1, 1985 - February 28, 1990

$$R_t = \alpha + \beta h_t + \delta W_t + \gamma \epsilon_{t-1} + \epsilon_t$$

$$h_t = a_t + b h_{t-1} + c \epsilon_{t-1}^2 + d W_t ,$$

where h_t represents the conditional variance of R_t, the stock index return and W_t represents a dummy variable which takes a value of one on days following weekends and holidays and zero otherwise.

	Japan Nikkei 225:			U.K. FTSE 100:			U.S. S&P 500:		
Number of Obs.:	1330			1242			1243		
	coeff.	t-stat.	robust t-stat.	coeff.	t-stat.	robust t-stat.	coeff.	t-stat.	robust t-stat.
α	.047	1.68	1.98	.144	3.38	2.12	.122	2.41	3.10
β	.074	1.36	1.66	-.176	-2.14	-1.26	-.007	-.16	-.22
γ	.108	3.10	3.23	-.049	-1.55	-1.63	.012	.32	.40
δ	-.080	-2.34	-1.30	-.133	-2.80	-2.79	-.077	-1.34	-1.22
a	.074	6.22	3.15	.037	3.57	1.30	.115	9.87	1.59
b	.522	17.70	3.51	.833	40.54	6.79	.792	46.07	6.24
c	.381	24.51	1.64	.068	5.83	1.34	.134	21.06	.98
d	.038	1.56	.61	.038	1.51	.19	-.127	-2.93	-.67

	Japan	U.K.	U.S.
LR(6) for Ho: constant mean and variance:	743.81	251.30	545.47
Coefficient of skewness for normalized residuals:	-1.04	-1.25	-1.16
Coefficient of kurtosis for normalized residuals:	10.60	14.01	11.36
Ljung-Box(12) for normalized residuals:	9.13	18.10	4.49
Ljung-Box(12) for normalized squared residuals:	5.37	7.43	4.14

Table 2. Volatility Spillover Effects Estimated from a GARCH-M model

$$R_t = \alpha + \beta h_t + \delta W_t + \gamma \epsilon_{t-1} + \epsilon_t$$

$$h_t = a_t + bh_{t-1} + c\epsilon^2_{t-1} + dW_t + fX_{1t} + pX_{2t},$$

where h_t represents the conditional variance of R_t, the stock index return, W_t represents a dummy variable which takes a value of one on days following weekends and holidays and zero otherwise, and X_{it} is the most recent residual squared from model (1) for each foreign market.

	From U.K.(f) and U.S.(p) to Japan:			From U.S.(f) and Japan (p) to U.K.:			From Japan (f) and U.K.(p) to U.S.:		
Number of obs.:	1330			1242			1243		
	coeff.	t-stat.	robust t-stat.	coeff.	t-stat.	robust t-stat.	coeff.	t-stat.	robust t-stat.
α	.056	2.03	2.28	.089	2.41	1.93	.136	2.62	2.47
β	.028	.62	.63	-.084	-1.16	-.81	-.038	-.79	-.72
γ	.103	3.06	3.31	-.040	-1.36	-1.37	.029	.84	.98
δ	-.094	-2.23	-2.13	-.133	-3.02	-2.85	-.061	-.98	-.96
a	.046	3.65	2.06	.044	3.69	1.51	.179	5.33	2.30
b	.522	12.23	8.46	.847	33.20	5.31	.587	11.66	4.14
c	.265	7.49	5.52	.031	2.46	1.62	.068	4.23	1.52
d	.066	2.32	1.24	-.042	-1.03	-.77	-.014	-.29	-.08
f	.062	3.28	2.26	.007	6.73	.19	.122	4.20	1.93
p	.044	5.55	1.99	.016	3.09	1.32	.231	8.19	1.26

	Japan	U.K.	U.S.
LR(8) for Ho: constant mean and variance:	869.72	336.16	584.26
Coefficient of skewness for normalized residuals:	-.41	-.70	-.70
Coefficient of kurtosis for normalized residuals:	5.20	7.33	7.63
Ljung-Box(12) for normalized residuals:	8.83	18.02	3.72
Ljung-Box(12) for normalized squared residuals:	11.94	4.67	12.91

Table 3. Volatility Spillover Effects Estimated from a GARCH(1,1)-M Model with Crash and Post Crash Dummies

$$R_t = \alpha + \beta h_t + \delta W_t + \gamma \epsilon_{t-1} + \epsilon_t$$

$$h_t = a_t + bh_{t-1} + c\epsilon^2_{t-1} + dW_t + (f + gD_t + kA_t)X_{1t} + (p + qD_t + rA_t)X_{2t} \quad ,$$

where D = 1 if t is in October 1987 (during the Crash month), and 0 otherwise, and A = 1 if t is in the after-Crash period (November 1987 - February 1990), and 0 otherwise.

	From U.K.(f, g, k) and U.S.(p, q, r) to Japan:			From U.S.(f, g, k) and Japan (p, q, r) to U.K.:			From Japan (f, g, k) and U.K.(p, q, r) to U.S.:		
Number of obs.:		1330			1242			1243	
	coeff.	t-stat.	robust t-stat.	coeff.	t-stat.	robust t-stat.	coeff.	t-stat.	robust t-stat.
α	.038	1.30	1.27	.080	1.95	2.17	.117	2.63	3.43
β	.088	1.53	1.33	-.062	-.74	-.82	-.015	-.36	-.61
γ	.105	3.09	3.40	-.035	-1.19	-1.21	.027	.81	.93
δ	-.087	-2.06	-2.03	-.134	-3.03	-2.91	-.052	-.84	-.84
a	.030	2.60	1.49	.047	3.48	2.02	.113	3.77	2.13
b	.572	15.07	9.45	.832	24.25	17.81	.724	14.70	11.33
c	.254	7.70	5.48	.027	2.06	1.16	.048	2.53	2.27
d	.054	1.90	1.10	-.028	-.65	-.43	.072	1.25	.53
f	.090	3.44	2.08	.005	.85	.60	-.009	-.67	-.70
g	-.443	-.83	-1.57	-.002	-.23	-.003	-.020	-.11	-.04
k	-.058	-2.18	-1.18	.008	1.00	.69	.208	5.10	1.41
p	.039	3.69	1.41	.021	2.72	1.66	.092	2.18	1.97
q	.061	.82	.51	.025	.58	.01	1.444	2.33	.79
r	.001	.12	.06	-.014	-1.47	-.69	-.040	-1.05	-.43
LR(12) for Ho: constant mean and variance:		877.06			342.18			655.99	
Coefficient of skewness for normalized residuals:		-.41			-.67			-.52	
Coefficient of kurtosis for normalized residuals:		5.17			6.96			6.33	
Ljung-Box(12) for normalized residuals:		9.22			18.18			4.92	
Ljung-Box(12) for normalized squared residuals:		9.72			4.04			7.94	

Table 4. Time-Varying Volatility Spillover Effects Estimated from a GARCH(1,1)-M Model

$$R_t = \alpha + \beta h_t + \delta W_t + \gamma \epsilon_{t-1} + \epsilon_t \; .$$

$$h_t = a_t + bh_{t-1} + c\epsilon^2_{t-1} + dW_t + [f(t^m) + gD_t + kA_t]X_{1t}$$
$$+ [p(t^s) + qD_t + rA_t]X_{2t} \quad ,$$

where D = 1 if t is in October 1987 (during the Crash month), and 0 otherwise, and A = 1 if t is in the after-Crash period (November 1987 - February 1990), and 0 otherwise. Parameters m and s represent trends in spillover effects and

$m, s = 0$	stationary spillover effect;
$m, s < -1$	spillover effect decreasing at an increasing rate;
$-1 < m, s < 0$	spillover effect decreasing at an decreasing rate;
$0 < m, s < 1$	spillover effect increasing at a decreasing rate; and
$1 < m, s$	spillover effect increasing at an increasing rate.

	From U.K.(f, g, k, m) and U.S. (p, q, r, s) to Japan:			From U.S.(f, g, k, m) and Japan (p, q, r, s) to U.K.:			From Japan (f, g, k, m) and U.K. (p, q, r, s) to U.S.:		
Number of obs.:	1330			1242			1243		
	coeff.	t-stat.	robust t-stat.	coeff.	t-stat.	robust t-stat.	coeff.	t-stat.	robust t-stat.
α	.042	1.46	1.49	.084	2.10	2.31	.120	2.88	3.66
β	.076	1.31	1.23	-.067	-.81	-.88	-.017	-.40	-.71
γ	.105	3.16	3.36	-.037	-1.25	-1.27	.023	.71	.81
δ	-.085	-2.00	-2.03	-.137	-3.10	-2.98	-.051	-.85	-.83
a	.029	2.52	1.61	.047	3.61	1.97	.101	3.70	2.05
b	.582	15.53	9.64	.835	25.57	17.39	.728	15.94	11.55
c	.244	7.93	5.15	.029	2.21	1.25	.042	2.53	2.07
d	.043	1.62	.92	-.032	-.73	-.52	.095	1.72	.72
f	.141	1.54	.24	.030	.17	.15	-.041	-.51	-.33
g	-.510	-1.06	-1.59	-.003	-.29	-.004	-.002	-.02	-.01
k	-.053	-1.82	-.45	.010	.96	.71	.204	5.41	1.37
m	-.075	-.66	-.10	-.226	-.23	-.19	-.258	-.48	-.39
p	.000	.42	.23	.000	.25	.18	.008	.36	.19
q	.063	.86	.50	.024	.51	.01	1.496	2.33	.82
r	-.037	-1.78	-.70	-.036	-1.82	-1.55	-.089	-1.40	-.49
s	.902	2.48	1.40	.894	1.48	1.01	.399	.86	.49

Table 4 [continued]

	From U.K.(f, g, k, m) and U.S. (p, q, r, s) to Japan:	From U.S.(f, g, k, m) and Japan (p, q, r, s) to U.K.:	From Japan (f, g, k, m) and U.K. (p, q, r, s) to U.S.:
Coefficient of skewness for normalized residuals:	-.40	-.63	-.53
Coefficient of kurtosis for normalized residuals:	5.06	6.63	6.30
Ljung-Box(12) for normalized residuals:	8.68	18.28	5.02
Ljung-Box (12) for normalized squared residuals:	8.45	3.91	7.49

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