The International Transmission of Stock Price Disruption in October 1987

One of the most striking features of the October 1987 collapse of equities prices was its worldwide scope. During the month of October, prices in many countries dropped even more than in the United States (Table 1), and day-to-day volatility reached extraordinary levels in many markets. Thus an adequate understanding of the event must include some grasp of why the disruptions so quickly circled the globe.

Were the spillovers of huge, correlated price movements typical of how world stock markets tend to interact under stress? Or, alternatively, were the market interactions of October 1987 unprecedented? Is it likely that future price disruptions would spread worldwide?

This article presents evidence that the interactions among international stock price movements during the October crash were in certain respects similar to the reactions of major markets to volatility in the past. Our principal findings are as follows:

- The statistical evidence from before October 1987 clearly shows that when one major market experiences particularly large price changes, other countries' stock prices will typically be subject to higher volatility also.
- Nevertheless, in last year's crash, the spread of high volatility from one major market to another was considerably greater than the earlier statistical relationships would have predicted.
- The pre-October 1987 evidence also indicates clearly that, when volatility is high, the price swings in major markets tend to become more highly correlated. That is, even well before the crash, when price swings in major markets became enlarged, they also became increasingly likely to go in the same direction.
- During the crash period, these correlations between up and down price movements generally increased, in accordance with the earlier, precrash pattern.
- Viewed from a longer time perspective, stock price movements in major markets have become increasingly similar in the 1980s, compared to the 1970s and before. This development appears generally consistent with the ongoing strengthening of cross-border trading, listings, and investment activities. The increased similarity of price moves has been comparatively small, however, and does not appear to have decisively influenced how markets interacted in October 1987.

In short, while the crash was *qualitatively* similar to prior episodes in that the volatility spread from market to market and correlations among some markets strengthened, the particular *degree* to which volatility spread was unusual. Indeed, in this respect, the October pattern of market interactions was unique, yet not easily attributable in a direct sense to the trend toward integrated world equities markets.

Market volatilities and correlations

The interaction among stock markets can be characterized by assessing the volatilities of prices in different markets and the degree to which day-to-day price movements are correlated with one another. *Volatility* is a statistical characteristic of price behavior in a single market. In this article, volatility is measured as the standard deviation of daily percent price movements[1] *Correlation* is a statistical attribute of a pair of markets Here, correlation is measured as the correlation coefficient between percent changes in price indexes for pairs of markets[2]

Note that a high correlation between price movements in two markets does not necessarily imply that they experience similar volatilities It may be, for example, that even though two markets tend to move up and down at the same time, the size of the movements in one market (its volatility) is much greater than in the other

To begin, let us review how volatilities and correlations behaved during the October 1987 crash Chart 1 shows the volatility of daily price changes during 30-day periods in four equities markets It is evident that the volatilities of daily price movements rose sharply and virtually simultaneously in major markets around the time of the crash. Chart 2 shows the correlation coefficients of daily price movements, also during 30-day periods, in three pairs of stock markets. The chart reveals that the October 1987 correlation between U S. and Japanese stock price changes was higher than average Between the United States and the United Kingdom, correlation was moderately above average, but the correlation of daily price movements in the U S and German markets was slightly below average.

How should this October pattern of volatilities and correlations be interpreted? Unfortunately, pure economic theory does not provide simple rules on how stock prices in different countries should interact, either routinely or under stress Economic forces that benefit companies listed in one country could either help or hinder companies listed elsewhere. Changes in exchange rates, for example, could conceivably make one stock market go up and another go down. On the other hand, it is possible that a jolt in oil prices might affect a number of major markets similarly

It is also the case that some stock traders may react not only to relevant news and announcements but also to foreign stock price movements themselves. As Chart 2 shows, economic events and trading patterns have most often caused stock prices in different major markets to be positively correlated To some extent this positive correlation might become self-reinforcing if it prompts domestic traders to adopt a conditioned response to foreign price change even when they do not fully understand its source Indeed, in the face of particularly large price swings abroad, such responses by domestic traders could dominate domestic price movements as well Thus it seems plausible that, within short time horizons, high price volatility in one market could lead to increased volatility in a second market, with unusually high correlation between the price movements.

The October 1987 collapse may have been a particularly important example of traders' quick responses to foreign price changes not easily explained by adverse news or economic fundamentals. Large price swings in one market may thus have led directly to similar large swings in another.

This article explores the extent to which the October 1987 pattern of responses was typical In the sections that follow, we seek to determine whether earlier episodes of high volatility were associated with increased volatility in other major markets. We also investigate whether correlations among price movements rose during previous periods of high volatility. Clearly, the relative importance and qualitative nature of identifiable world events affecting markets will vary from one his-

[1]A "standard deviation" is a statistical measure of the amount of dispersion in a particular series of numbers For example, if daily price changes have a standard deviation of, say, 1 percent, then it is typical for prices on a given day to rise or fall 1 percent above or below the average underlying trend

[2]The "correlation coefficient" is a statistic that varies between minus one and plus one A value near zero means that daily percent movements in two markets bear essentially no relationship to each other during the period A positive value means that when one market rises at more than its trend rate, the other on average rises above its trend rate as well A positive value close to one means that when one market's rise equals one standard deviation above its trend, then the other market can on average be expected to rise at close to one standard deviation above its trend as well

Table 1

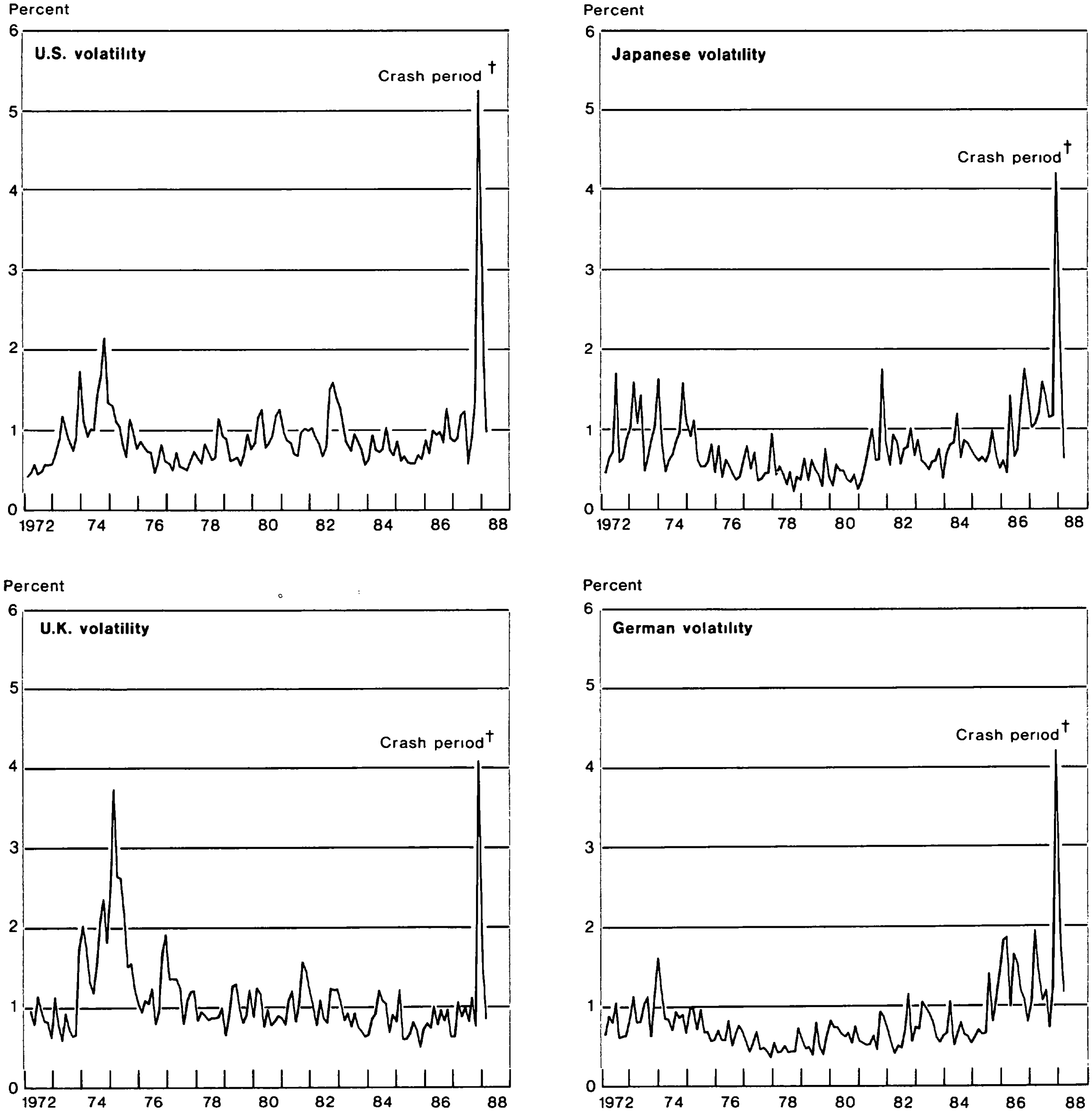
October 1987 Changes in World Stock Prices*

Country	**Percent Stock Price Change**
Australia	−58 3
Hong Kong	−56 3
Singapore/Malaysia	−40 1
Mexico	−38 7
Norway	−29.8
United Kingdom	−26 1
Spain	−25 5
Switzerland	−23 4
Belgium	−23 2
West Germany	−22 9
Netherlands	−22 6
France	−22 0
Canada	−21 8
United States	**−21.5**
Sweden	−20 7
Italy	−15 5
Austria	−14 9
Japan	−12 6
Denmark	−12 6

*Percent changes between September 30 and October 31, 1987, local currency indexes, data from Morgan Stanley Capital International

Chart 1

Daily Stock Price Volatility*



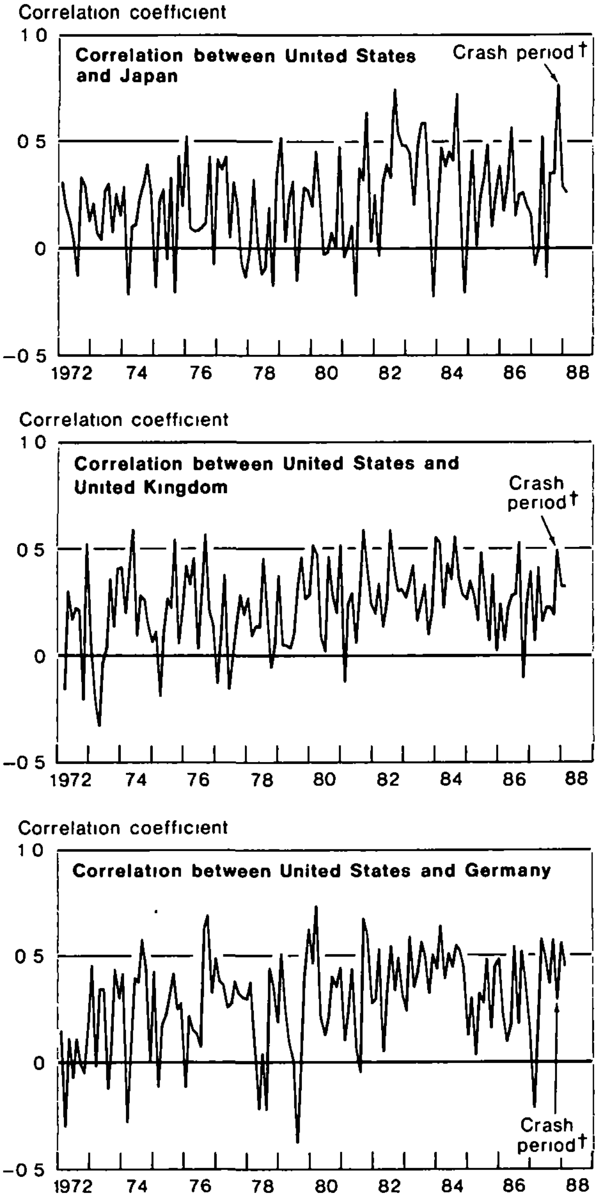
* Standard deviations of daily percent changes, computed for nonoverlapping 30-trading-day periods

† The crash period is the 30-trading-day period beginning on October 16, 1987 and ending in the United States and Japan on December 1, 1987 and in the United Kingdom and Germany on November 27, 1987

Sources: Morgan Stanley Capital International and Federal Reserve Bank of New York

Chart 2

Daily Stock Price Correlations*



*Correlation coefficients between daily percent changes in stock price indexes, computed for nonoverlapping 30-trading-day periods

†The crash period is the 30-trading-day period beginning on October 16, 1987 and ending in the United States and Japan on December 1, 1987 and in the United Kingdom and Germany on November 27, 1987

Sources Morgan Stanley Capital International and the Federal Reserve Bank of New York

torical period of volatility to the next. Sorting out the driving factors behind each episode is beyond the scope of this article. Rather, our approach will be to see whether identifiable patterns of spreading volatility and steady or rising correlations characterized market interactions in previous periods of uncertainty. If they did, one might have to be prepared for similar patterns should the markets once again enter a stressful period.

Spreading volatility

Regression analysis was used to test the assertion that higher day-to-day volatility in one major market tends to be accompanied by higher expected volatility in other markets. The regression model posits that a higher standard deviation of daily percent price changes in one market during a 30-day period will be associated with a higher standard deviation in a second market during that same period, when daily price changes in the second market occur after daily price changes in the first

Since stock trading takes place virtually around the clock in the various stock markets of the world, it is necessary in implementing the analysis to establish some particular market as the starting point of the 24-hour "days" used as the units of observation. However, since this choice of a starting point is essentially arbitrary, we repeat the analysis, shifting the start of the day to other major markets For example, we can define the 24-hour day as starting in the New York market and measure the standard deviation of 30 daily stock price movements in that market. Then, a corresponding standard deviation can be computed for the subsequent price changes occurring in Japanese markets within the same set of 24-hour days. Alternatively, we can start the day in Japan, in which case the corresponding volatility calculations for the New York market are shifted forward by one calendar day.

The next step is to estimate a regression equation that uses volatility in the starting market to predict the level of volatility in another market trading within the same day. For example, in the equation assuming that the day starts in the United States, a positive regression coefficient indicates that the volatility of daily Japanese price movements tends to be high in those 30-day periods in which U.S. daily stock price volatility is high. Conversely, a zero or negative regression coefficient would be inconsistent with this assertion.

Table 2 summarizes the regression results. Equations were estimated over 30-trading-day periods from 1980 to September 1987, and also from 1972 through 1979. As hypothesized, increased volatility in the starting market is associated with higher volatility in the other markets The results are qualitatively similar whether the equations are estimated for 24-hour days beginning in the United States, Japan, or the United Kingdom. (See also Appendix A.)

Association between volatility and correlation

The second hypothesis to be tested is that higher volatility in one market will lead to increased correlation between daily price movements in that market and daily price movements in other markets. We computed 30-day correlation coefficients between the daily price changes in pairs of markets within the same 24-hour days. Again, different sets of 30-day correlations were calculated using varying assumptions about where the 24-hour days start.

The regression equation hypothesis was that the higher the volatility in the first market trading in the day, the closer the correlation between daily price movements in that market and price movements in a second market. These estimated effects of volatility on correlation coefficients for the period from 1980 through September 1987 and the period from 1972 to 1979 are summarized in Table 3. All are positive; that is, the higher the 30-day level of volatility in the first market trading in the day, the higher the 30-day correlation between daily price movements in that first market and price movements in another. Not only are all the regression coefficients positive in each estimation period, but in many cases they are also statistically significant (Appendix A, Table A1). These findings support the hypothesis that even prior to October 1987, high volatility tended to be associated with higher correlations in the price movements of different markets.[3]

Evidence on the strengthening of linkages over time

Casual empirical support abounds for the notion that world stock markets have become more closely linked in recent years. According to one survey, the number of stocks traded globally (that is, on a daily basis in at least one center outside the home market) rose from 236 in 1984 to 493 in 1987.[4] In addition, the amount of

[3]These results were not affected by one notable complication in the data No Saturday trading data were used for Japan even though Saturday trading may have occurred This omission could interfere with the estimated relationships when the 24-hour day starts in the United States or the United Kingdom on Fridays and is implicitly assumed to continue on Monday in Japan Nevertheless, when we ran the regressions again, throwing out such Friday-Monday combinations, the results were little changed

[4]*Euromoney*, May 1987, pp 187-222

Table 2

Effects of High Stock Price Volatility on Stock Price Volatility in Other Markets

Standard Deviations of Day-to-Day Percent Changes in Stock Price Indexes

	1980 to September 1987 Estimates		1972 to 1979 Estimates	
	Normal Stock Price Volatility‡	Change in Volatility Associated with High Volatility in Market Where Day Begins§	Normal Stock Price Volatility‡	Change in Volatility Associated with High Volatility in Market Where Day Begins§
Day begins in the United States				
Japan volatility	74	+ 17*	64	+ 32†
United Kindom volatility	88	+ 22†	1 19	+ 41†
West Germany volatility	81	+ 05	68	+ 20†
Day begins in Japan				
United Kingdom volatility	88	+ 14*	1 16	+ 29†
West Germany volatility	82	+ 00	69	+ 26†
United States volatility	85	+ 10	80	+ 22†
Day begins in the United Kingdom				
West Germany volatility	86	+ 27†	63	+ 17†
United States volatility	90	+ 28†	76	+ 17†
Japan volatility	79	+ 28†	60	+ 16*

‡Predicted volatility from estimated equation relating volatility in the indicated market to volatility where the day starts, based on the average 1972 to September 1987 level of volatility in the day-starting market

§Change in predicted volatility when day-starting volatility rises from 1972 to September 1987 mean value to two standard deviations above that mean

*Effect of day-starting volatility on volatility in indicated market is statistically positive at the 95 percent level

†Effect of day-starting volatility on volatility in indicated market is statistically positive at the 99 percent level

Table 3

Effects of High Stock Price Volatility on Correlations between Stock Price Movements

Correlations between Daily Percent Changes in Stock Price Indexes

	1980 to September 1987 Estimates		1972 to 1979 Estimates	
	Average Correlation Coefficient‡	Change in Correlation Associated with High Volatility in Market Where Day Begins§	Average Correlation Coefficient‡	Change in Correlation Associated with High Volatility in Market Where Day Begins§
Day begins in the United States				
Japan-U S correlation	26	+ 21†	16	+ 03
U K -U S correlation	29	+ 16	19	+ 02
West Germany-U S correlation	36	+ 13†	22	+ 10*
Day begins in Japan				
U K -Japan correlation	14	+ 08*	04	+ 00
West Germany-Japan correlation	22	+ 06	12	+ 10†
U S -Japan correlation	08	+ 03	05	+ 05
Day begins in the United Kingdom				
West Germany-U K correlation	27	+ 29†	06	+ 02
U S -U K correlation	24	+ 20*	10	+ 03
Japan-U K correlation	18	+ 20*	02	+ 04

‡Correlation coefficient predicted from estimated equation relating correlation between the indicated markets to volatility where the day starts, where starting-market volatility is set to its 1972 to September 1987 average level

§Rise in predicted correlation coefficient when day-starting volatility is raised from its 1972 to September 1987 mean to two standard deviations above that mean

*Effect of day-starting volatility on correlation in indicated market is statistically positive at the 95 percent level

†Effect of day-starting volatility on correlation in indicated market is statistically positive at the 99 percent level

cross-border buying and selling of stocks in many markets has risen dramatically since 1980 (Table 4) Exchanges have been establishing a variety of international trading links for equities and derivative products.[5]

These improving connections and increasing cross-border activities imply that participants' awareness of, and responsiveness to, daily foreign stock market developments have been growing as well. Greater cross-border investments have increased the need for participants to stay informed about securities price performances. Changes in communications and trading technology have made it easier to track and respond to overseas developments, including price developments. In addition, unifying trends in the world economy such as increased trade and wider international operations by business corporations may have made stock prices in different centers sensitive to an increasingly similar set of underlying influences

It is at least possible that these stronger linkages between stock markets may have influenced the market interactions of October 1987 The following sections address this possibility in more detail.

[5]For a list of some recently established equity trading links between U S and foreign exchanges, see *Securities Week*, July 6, 1987, p 1

Table 4

Cross-Border Stock Transactions

Gross Purchases and Sales of Domestic Stocks by Nonresidents (In Billions of U S Dollars)

	United States*	Japan†	Germany‡	Canada§
1980	75 2	26 2	6 8	12 4
1981	75 5	43 7	6 9	9 2
1982	79 9	34 6	6 3	5 2
1983	134 1	71 5	13 4	8 4
1984	122 6	78 3	12 4	8 8
1985	159 0	81 9	36 9	11 9
1986	277 5	201 6	77 9	20 2
1987	481 9	374 7	76 8	45 7

*U S Treasury International Capital data

†Japanese Ministry of Finance

‡Deutsche Bundesbank, *Balance of Payments Statistics, Statistical Supplements to the Monthly Reports of the Deutsche Bundesbank*, Series 3

§Statistics Canada, *Security Transactions with Non-Residents* and *Quarterly Estimates of the Canadian Balance of International Payments*

Stronger connections among volatilities and correlations?

A possible consequence of the increased awareness of foreign developments could be a stronger propensity for high price volatility in one market to be associated with a rise in price volatility abroad and with higher price correlations between markets. In effect, a given rise in foreign volatility may spark a bigger domestic response now that participants are watching other markets more closely.

With respect to the link between volatility and correlation, there is strong statistical evidence that the relationship has strengthened over time. We performed formal statistical tests on each of the equations linking price correlations to price volatility. These tests showed that between the 1970s and the 1980s most of the regression coefficients relating volatility to correlation increased by statistically significant amounts. The size and significance of the measured increases were very similar whether the relationship was allowed to change in 1980 or 1983 (Appendix A, Table A3).

However, with respect to the linkage between volatility in one market and volatility in others, no persuasive evidence was found that the relationship had strengthened. Formal tests yielded little or no support for the assertion that the regression coefficients linking volatilities in different markets had increased between the 1970s and the 1980s (Appendix A, Table A3).

Closer percentage changes?

A related, but slightly different way of characterizing how stock markets interact is to ask how large a percent change in one country's stock price index should be expected when another country's index changes by a given percentage. For example, if the U.S. market rises by one percent, how much would the Japanese market be likely to rise subsequently? For want of a better name, this statistic can be referred to as a "beta" coefficient between the two markets. A beta as high as one would mean that, on average, percentage changes in the two markets tend to be of the same size and sign.[6]

[6] Betas can be computed by directly regressing percent price changes on one another, or, alternatively, combining the correlation and volatility figures for 30-day periods using the formula, beta = r times (s2 / s1), where r is the correlation coefficient, s1 is volatility in the first market, and s2 is volatility in the second market Table 5 applies the latter approach with one further adjustment Since r and s2 have been shown in the first part of the article to vary systematically through time with changes in s1, the betas in Table 5 have been adjusted to eliminate differences between 1970s and 1980s values attributable to variations in s1 between the decades Alternative methods of calculating betas, however, give similar results (Appendix A, Table A4)

Table 5

"Betas" between Stock Markets

Expected Percent Change in Stock Prices Associated with a One Percent Price Change in Market Where Day Begins*

	1980 to September 1987 Estimates		1972 to 1979 Estimates	
	Effect with Normal Volatility Where Day Begins	Effect with High Volatility Where Day Begins	Effect with Normal Volatility Where Day Begins	Effect with High Volatility Where Day Begins
Day begins in the United States				
Price change in				
Japan	22	30	12	13
United Kingdom	30	34	26	23
West Germany	34	29	17	20
Day begins in Japan				
Price change in				
United Kingdom	17	16	06	05
West Germany	25	16	11	20
United States	09	07	05	10
Day begins in the United Kingdom				
Price change in				
West Germany	22	31	04	03
United States	20	26	06	06
Japan	13	20	01	02

Effects computed using the formula for a simple regression "beta," rs/s, where r is the correlation coefficient between percent price changes in the starting market and in another market, s* is the standard deviation of percent price changes in the starting market, and s is the standard deviation of percent price changes in the other market Values of r and s for normal and high values of s* are computed using the mean 1972 to September 1987 value of s* and a value of two standard deviations above that mean, in conjunction with estimated regression equations relating r and s to s*

As Table 5 shows, betas for the 1980s period are uniformly higher than for the 1970s, a finding which is again consistent with growing intermarket awareness and trading Estimates of betas using other methods confirm that these associations between pairs of percent changes have become closer in recent years (Appendix A, Table A4)

Monthly interactions

As a further check on how the pattern of market interactions had been evolving prior to October, monthly average price movements were examined Monthly movements of course abstract from day-to-day swings Thus, the monthly averages focus on the broader downward shift in stock price levels from before to after the crash, instead of daily movements Was it normal for monthly market movements in different markets to behave as similarly as they did around October 1987? Had monthly average movements of prices in different markets become significantly more similar in the 1980s?

To answer these questions, we estimated regression equations explaining monthly average stock price indexes in four countries on the basis of domestic economic variables and foreign stock prices Including economic variables (inflation, industrial production, unemployment, and short- and long-term interest rates) sharpens the focus on stock market dynamics by holding constant other more fundamental determinants of stock prices Thus, the estimated regression equations can be used to see how movements in foreign stock prices normally affect domestic stock prices (See Appendix B for a fuller explanation.)

Table 6 summarizes the regression estimates showing how strongly monthly average domestic stock prices in four countries are influenced by foreign stock price changes when economic influences are held constant For example, if the average level of stock prices in each of six major foreign countries fell by 1 percent in a given month, then the equation predicts that U S. stock prices would be 0.83 percent lower as a result, even if no U S. economic variables changed.

By letting the size of the regression coefficients linking foreign and domestic stock prices change after 1981, the equation allows for a possible strengthening of the relationship. Before 1981, a 1 percent drop in foreign stock prices would have lowered U S. prices by only 0.72 percent. Of the four countries, three show an increased sensitivity to foreign stock price movements after 1981. Although none of these increases in sensitivity achieves statistical significance, the increases are generally consistent with the modest increases in day-to-day betas found above (Table 5 and Appendix A, Table A4) The monthly equations were also reestimated, allowing the coefficients to shift at other dates, and the results are qualitatively similar to those obtained when the 1981 change is allowed (Appendix B, Table B2)

The monthly equations were estimated starting in 1950 or the early 1960s, depending on data availability for each country, with the estimation periods ending in September 1987. Thus the monthly results provide additional evidence that even well before the crash, world stock prices were significantly linked. As the day-to-day movements also demonstrated, the closeness of monthly percent price movements in different markets appears to have increased moderately in recent years.

The October crash

We have yet to determine how well the pre-October day-to-day and monthly-average estimated relationships fit the pattern of events during the crash. Was the degree of volatility spillover in line with what earlier estimates would have indicated? Were the pre-October

Table 6

Tests of Changing Sensitivity of National Stock Price Indexes to Monthly Movements in Foreign Stock Markets*

Estimated Percent Change in Monthly Average Domestic Stock Price Index Corresponding to One Percent Change in Each of Six Monthly Average Foreign Stock Price Indexes, Controlling for Domestic Real Output, Price Level, Unemployment, and Short- and Long-Term Interest Rates

	United States	Japan	United Kingdom	West Germany
Sensitivity before December 1981	72	37	82	45
Sensitivity after January 1982	83	57	54	58
Change†	+ 11	+ 20	− 28	+ 13

*See Appendix B for details

†None of these estimated increases in sensitivity to foreign stock prices is statistically greater than zero, using a one-tailed test at a 95 percent level of significance

Table 7

Explaining the October 1987 Spillovers

Actual and Predicted Measures of Spillovers of Market Disruptions during the October 1987 Stock Market Crash

	Correlation Coefficient			Volatility			Beta		
	Normal Value§	October Prediction‖	October Actual	Normal Value§	October Prediction‖	October Actual	Normal Value§	October Prediction‖	October Actual
Day begins in the United States									
Japan	26	97	77	0 7	1 6	4 2*	22	30	62
United Kingdom	29	70	49	0 9	1 6	4 1†	30	23	38
West Germany	36	91	29*	0 8	1 2	4 2†	34	21	29
Day begins in Japan									
United Kingdom	14	50	68	0 9	1 1	4 2†	17	13	67
West Germany	22	52	59	0 8	1 0	4 2†	25	05	60
United States	08	22	18	0 9	1 3	5 3†	09	16	22
Day begins in the United Kingdom									
West Germany	27	88	72	0 9	2 0	4 2*	22	44	75
United States	24	74	59	0 9	1 8	5 2†	20	33	78
Japan	18	70	29	0 8	2 0	4 2	13	35	30

§Predictions using equations estimated from January 1980 through September 1987, setting the independent variable, the standard deviation of starting-market percent price changes, to its mean value for 1972 through September 1987

‖Predictions using equations estimated from January 1980 through September 1987, setting the independent variable, the standard deviation of starting-market percent price changes, to its actual October 1987 period value

*Hypothesis that October observation was generated by the statistical model estimated through September 1987 is rejected at the 95 percent level

†Hypothesis that October observation was generated by the statistical model estimated through September 1987 is rejected at the 99 percent level

relationships between volatility and correlation on target in the crash? Were percent movements—day-to-day and month-to-month—in line with what the earlier equations would have predicted?

To answer these questions, actual October 1987 daily volatility in each major market was used to predict volatility in other markets, correlations among markets, and betas between markets, based on the estimated pre-October statistical relationships. In addition, analogous simulations of the crash were run using the pre-October monthly equations.

The results based on the daily movements (Table 7) indicate some notable qualitative similarities between the crash and earlier episodes. The pre-October relationship predicted that the correlations in daily price movements between pairs of major markets would increase substantially. Indeed, most correlations showed a clear rise (see also Chart 2). The one exception was the U.S.-German correlation, which actually fell in October, contrary to the earlier pattern that would have predicted a correlation increase.

A more striking difference between the October and earlier patterns was observable in the extent to which volatility spread. For example, given the U.S. volatility spike, volatilities in Japan and the U.K. would "typically" have doubled, and German volatility would have risen noticeably as well. In fact, as Table 7 shows, these volatilities increased by factors of four to six times above normal levels. A similar pattern of sur-

Table 8

Actual and Predicted Monthly Stock Price Changes

September to November 1987

	Actual Price Change* (In Percent)	Predicted Price Change† (In Percent)
S&P 500	−26 3	−26 5
Tokyo index	−11 9	−18 0
West German index	−34 3‡	−13 9
U K index	−26 3‡	− 9 8

*Percent change, September 1987 average to November 1987 average

†Each country's index is predicted using a regression equation, based on domestic economic variables and foreign stock price indexes, estimated through September 1987 See Appendix B for details

‡Hypothesis that November observation was generated by the statistical model estimated through September 1987 is rejected at the 99 percent level

prisingly large volatility spillover shows up when the day is started outside the United States.

With the unusual spread in volatilities, the betas relating percent changes in major markets to one another jumped as well. While betas would have been expected to rise only slightly or even decline, most rose substantially. The one exception was again the U.S.-Germany beta, whose value during the crash period was slightly lower than during more normal times.

These results are consistent with the common view that a wave of panicky selling circled the globe, with traders paying an unusually large amount of attention to price developments in foreign markets in the absence of fundamental news sufficient to account for the disruption. The panic among participants probably explains the unanticipated extent of volatility spillover.

Monthly interactions around October 1987

The actual monthly average price changes in the crash were neither consistently larger nor consistently smaller than the predicted changes from the regression equations (Table 8).

The U.S. price index fell about as much as expected, given the drops everywhere else. The Japanese index fell less than the equation predicted. (It is tempting to attribute this result to the circuit-breaker system installed in Japan following the stock market debacle in the 1960s.) Both the U.K. and German indexes fell substantially more than the equations indicated. While the equations did not predict accurately in three of the four cases, the prediction errors were dispersed around the actual outcomes. This suggests that the basic degree of linkage among monthly average prices in different stock markets during the crash was neither clearly stronger nor weaker than it had been prior to October.[7]

It does not appear that the prediction errors can be systematically linked to the strengthening relationships between stock markets identified in the monthly regression equations: The U.K. and German equations showed the least persuasive evidence that domestic stock prices were becoming more responsive to foreign stock prices, while the actual October drops in those two countries substantially exceeded the predicted drops. The Japan regression equation showed a fairly distinct strengthening of the linkage, but the actual Japanese price drop was far less than the forecast. (See Appendix B, Table B2.)

Conclusion

Although a panic is a unique event, the crash experience conformed to the pre-October pattern in important respects. The coincidence of volatility surges in major stock markets was qualitatively similar to earlier patterns found in the data, as were the increases in correlations between price movements in most markets. At a monthly-average level, the large downward shift in prices worldwide—while unprecedented in magnitude—was qualitatively similar to earlier relationships among stock markets as well.

Although the crash interactions were a clear demonstration of the preexisting interdependencies among major stock markets, the October events differed from earlier patterns in the extent of the volatility spillover from one market to another. Since there is no evidence that the propensity of volatility shocks to spread had strengthened before the crash, it seems unlikely that the unexpected degree of October spillover can be accounted for by a tightening of relationships among markets during the 1980s.

It seems fair to conclude that if huge price movements were again to occur in one of the world's major stock markets, the disruptions would be likely to spread worldwide. This assessment suggests that measures to prevent excessive volatility in one market, such as "circuit breakers" or deeper margin buffers, if successful, could have international benefits. One caveat to our conclusion derives from the modest signs in the 1980s data that world stock prices in different countries have been tending to move more similarly than before. If this trend continues, some increased degree of international regulatory coordination would become necessary to augment the effectiveness of domestic measures in lessening the chances of another market collapse.

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[7]Since the predicted price changes for each of the four markets take actual foreign price changes in the period as given, if there were in fact consistent under- or over-prediction in Table 8, then the true error would be greater for the system of equations as a whole This does not appear to be a problem, however, since the errors are dispersed

Appendix A: Estimating Relationships among Stock Market Volatilities and Correlations

This appendix describes four sets of statistical computations used in the text. The first section outlines the tests used to determine whether the level of stock price volatility in a market influences the correlations between stock price movements in that market and in other markets. The second section describes analogous procedures for testing how stock price volatility in a market is related to volatility in other stock markets The third section presents formal tests for identifying changes over time in the statistical relationships among volatilities and correlations. The fourth section outlines calculations of coefficients linking percent changes in one stock market to percent changes in another; these coefficients are referred to as "betas" in the text, although this terminology is somewhat different from the standard usage in financial economics. The accompanying tables (A1 through A4) provide the statistical results

1. *Tests of the link between volatility and correlation.* The first hypothesis to be tested states that periods of high price volatility in stock markets also tend to be periods of high price correlations among stock markets. Implicit in our approach is the notion that high volatility is leading to high correlations, perhaps because participants in a second market only react to changes in a first market when those changes are large. Volatility in stock index a, s_t^a, within a 30-trading day period, t, is measured as the standard deviation of daily percent changes. Analogously, r_t^{ab} is the correlation coefficient between stock markets a and b within period t. The regression equation estimated across periods t is.

$$\ln\left((1+r_t^{ab}) / (1-r_t^{ab})\right) = A + Bs_t^a + e_t,$$

where A is a constant and e_t is the regression error. The transformation of r_t^{ab} on the left-hand side of the equation creates an asymptotically normal dependent variable; this transformation is needed since r_t^{ab} ranges only between plus and minus one.*

*T W Anderson, *An Introduction to Multivariate Statistical Analysis* (New York John Wiley & Sons, 1958), p 78

Table A1

Impact of Volatility on Correlation of Stock Prices‡

	Regression Coefficients				Autocorrelation Rho		R-squared	
	Jan 1, 1972 to Dec 31, 1979		Jan 1, 1980 to Oct 15, 1987					
	A	B	A	B	Jan 1, 1972 to Dec 31, 1979	Jan 1, 1980 to Oct 15, 1987	1972-79	1980-87
Day starts in the United States:								
Japan	0 24*	10 49	−0 18	84 03†	—	—	0 01	0 15
West Germany	0 14	36 05*	0 30	53 52*	—	—	0 05	0 08
United Kingdom	0 30*	9 26	0 36*	26 21	—	—	0 00	0 03
Japan	0 21*	13 04	−0 29	95 70†	−0 10	0 24*	0 02	0 19
Germany	0 14	35 97	0 05	79 85†	0 24*	0 26*	0 11	0 14
United Kingdom	0 35*	4 06	0 38*	24 91	0 15	−0 05	0 02	0 03
Day starts in Japan:								
West Germany	0 03	30 55†	0 29*	20 28	—	—	0 08	0 03
United Kingdom	0 07	0 81	0 11	23 82*	—	—	0 00	0 04
United States	−0 04	17 45	0 09	8 56	—	—	0 02	0 01
West Germany	0 05	27 39†	0 29*	20 71	−0 22*	0 21	0 12	0 06
United Kingdom	0 03	5 98	0 12	22 09	0 19	−0 57	0 03	0 04
United States	0 02	9 40	0 08	9 57	−0 20	0 01	0 05	0 01
Day starts in United Kingdom:								
West Germany	0 07	4 89	− 24	74 14†	—	—	0 00	0 13
United States	0 12	7 13	− 02	47 38*	—	—	0 01	0 05
Japan	−0 08	9 93	− 11	45 06*	—	—	0 02	0 06
West Germany	−0 08	4 20	− 26	77 79*	0 01	0 02	0 00	0 14
United States	0 15	5 63	− 04	40 64	0 13	0 12	0 03	0 06
Japan	−0 09	10 37	01	32 20	0 05	0 22*	0 02	0 10

‡Estimated equation is ln ((1+r)/(1−r)) = A + Bs + e
*Coefficient estimate is statistically significant at the 95 percent level, one-tailed test
†Coefficient estimate is statistically significant at the 99 percent level, one-tailed test

Appendix A: Estimating Relationships among Stock Market Volatilities and Correlations *(continued)*

Since the standard deviation and correlation coefficient variables are constructed using daily data on market prices in various parts of the world, the starting point for the 24-hour day must be selected Which market, a or b, will be used to measure the standard deviation for period t must also be decided It is assumed that market a is the first market open in the 24-hour day The regression is estimated over non-overlapping 30-day periods in the 1970s and 1980s, each period makes up one observation with its own correlation and volatility

The results are shown in Table A1, with and without autocorrelation corrections The U S. data are daily closing figures for the S&P 500 index Data for the other three countries are daily stock indexes from Morgan Stanley Capital International

Weekends presented a problem in defining a 24-hour day. It was assumed that days that begin during a calendar Friday are interrupted over the weekend and completed during the first part of calendar Monday But difficulties arose with those periods in which the days were assumed to begin in the United States (or the United Kingdom) and to end in Japan Stocks trade in Japan on some but not all Saturdays, consequently, it is possible that the relevant correlation should be between price movements on calendar Fridays and Saturdays when trading occurs To assess the importance of this problem, preliminary regressions were run using an alternative data set in which days beginning during calendar Fridays and ending during calendar Mondays were dropped The regression estimates were very similar to those obtained when these days were included Thus, the problem appeared to be minor, and the fuller data were used in the final estimates (Note that since initial price volatility in Japan is computed as the percent change between Friday and Monday closes in Japan, the analogous problem does not exist for 24-hour days starting in Japan) Those 24-hour days in which at least one of a given pair of markets was closed were deleted before construction of the 30-day-time-period series for the regressions relevant to that particular pair of markets

2 *Tests for spreading volatility* Analogous regressions were estimated using volatility as the dependent variable, measured as the standard deviation of daily percent price changes within 30-day periods (Table A2)

3 *Tests for structural breaks* Combining the samples from the 1970s and 1980s, we allowed a dummy variable to interact with the slope coefficient for each of the correlation-volatility and the volatility-volatility equations (Table A3) The shift coefficients (B_2) were

Table A2

Impact of Volatility on Other Market Volatility‡

	Regression Coefficients				Autocorrelation Rho		R-squared	
	Jan 1, 1972 to Dec 31, 1979		Jan 1, 1980 to Oct 15, 1987					
	A	B	A	B	Jan 1, 1972 to Dec 31, 1979	Jan 1, 1980 to Oct 15, 1987	1972-79	1980-87
Day starts in the United States·								
Japan	−1 95*	0 64†	−3 31†	0 33*	0 46†	0 58†	0 35	0 37
West Germany	−3 00†	0 41†	−4 32†	0 10	0 56†	0 64†	0 47	0 41
United Kingdom	−2 12†	0 48†	−2 96†	0 37†	0 72†	0 31†	0 66	0 29
Day starts in Japan								
West Germany	−3 09†	0 38†	−4 81†	0 00	0 46†	0 63†	0 55	0 39
United Kingdom	−3 14†	0 26†	−3 89†	0 17*	0 76*	0 32†	0 60	0 12
United States	−3 39†	0 29†	−4 10†	0 13	0 71†	0 46†	0 60	0 23
Day starts in United Kingdom:								
West Germany	−3 55†	0 33†	−3 00†	0 38†	0 57†	0 74†	0 41	0 51
United States	−3 53†	0 29†	−2 95†	0 38†	0 71†	0 38†	0 66	0 33
Japan	−3 61†	0 33*	−2 85†	0 43*	0 50†	0 63†	0 31	0 42

‡Estimated equation is $\ln (S_{OTHER}) = A + B (\ln S_{STARTING}) + e$, where S is a standard deviation of percent daily price changes
*Coefficient estimate is statistically significant at the 95 percent level, one-tailed test
†Coefficient estimate is statistically significant at the 99 percent level, one-tailed test

Table A3

Dummy Variable Tests for Strengthening Relationships

Shift in 1980

	Regression Coefficients					
	A	B_1	B_2	B_1+B_2	Autocorrelation Rho	R-squared
Relationship between Correlation and Volatility‡						
Day starts in the United States:						
Japan	0 10	25 08*	29 40†	54 48†	—	0 14
West Germany	0 19	30 62*	34 96†	65 58†	—	0 17
United Kingdom	0 32†	6 86	24 19†	31 15†	—	0 09
Day starts in Japan:						
West Germany	0 15*	15 38	19 47*	34 85†	—	0 09
United Kingdom	0 09	−1 35	27 47†	26 12†	—	0 09
United States	0 02	10 51	5 40	15 92	—	0 02
Day starts in United Kingdom:						
West Germany	0 00	9 39	40 38†	49 77†	—	0 16
United States	0 09	9 23	26 89†	36 12†	—	0 08
Japan	−0 08	10 45	31 79†	42 24†	—	0 12
Relationship between Other Market Volatility and Starting Market Volatility§						
Day starts in the United States:						
Japan	−2 57†	0 51†	−0 01	0 50†	0 53†	0 37
West Germany	−3 66†	0 28†	−0 04*	0 24*	0 61†	0 47
United Kingdom	−2 57†	0 40†	0 05*	0 45†	0 62†	0 59
Day starts in Japan:						
West Germany	−4 09†	0 18†	−0 04*	0 14*	0 58†	0 47
United Kingdom	−3 39†	0 22†	0 05*	0 27†	0 65†	0 51
United States	−3 74†	0 22†	−0 02	0 20†	0 63†	0 47
Day starts in United Kingdom:						
West Germany	−3 35†	0 37†	−0 06*	0 31†	0 67†	0 50
United States	−3 36†	0 33†	−0 03*	0 30†	0 60†	0 54
Japan	−3 33†	0 38†	−0 04	0 34†	0 56†	0 37
Shift in 1983						
Relationship between Correlation and Volatility‡						
Day starts in the United States:						
Japan	0 04	38 37†	29 51†	67 88†	—	0 12
West Germany	0 13	46 60†	29 09†	75 69†	—	0 13
United Kingdom	0 29	18 27	15 46*	33 73*	—	0 04
Day starts in Japan:						
West Germany	0 13	29 07†	−0 56	28 51†	—	0 06
United Kingdom	0 08	11 17	9 98	21 15*	—	0 03
United States	0 05	4 68	15 47	20 15*	—	0 03
Day starts in United Kingdom:						
West Germany	0 12	7 93	32 15†	40 08†	—	0 07
United States	0 18	7 97	19 99*	27 96*	—	0 03
Japan	0 04	7 70	21 60*	29 30*	—	0 04

‡Estimated equation is $\ln((1+r)/(1-r)) = A + (B_1 + B_2 D)\, s + e$

§Estimated equation is $\ln(S_{OTHER}) = A + (B_1 + B_2 D)(\ln(S_{STARTING})) + e$

*Significant at 95 percent level, one-tailed test

†Significant at 99 percent level, one-tailed test

Appendix A: Estimating Relationships among Stock Market Volatilities and Correlations *(continued)*

Table A3

Dummy Variable Tests for Strengthening Relationships *(continued)*

Shift in 1983

	Regression Coefficients					
	A	B_1	B_2	B_1+B_2	Autocorrelation Rho	R-squared
Relationship between Other Market Volatility and Starting Market Volatility§						
Day starts in the United States:						
Japan	−2.53†	0.53†	−0.06*	0.47†	0.50†	0.39
West Germany	−3.49†	0.32†	−0.07†	0.25†	0.52†	0.49
United Kingdom	−2.68†	0.38†	0.05*	0.43†	0.64†	0.59
Day starts in Japan:						
West Germany	−4.14†	0.17†	−0.06†	0.11	0.52†	0.49
United Kingdom	−3.33*	0.24†	0.06†	0.30†	0.62†	0.51
United States	−3.70†	0.21†	0.01	0.22†	0.63†	0.47
Day starts in United Kingdom:						
West Germany	−3.30†	0.38†	−0.09†	0.29†	0.58†	0.52
United States	−3.42†	0.30†	−0.01	0.29†	0.64†	0.53
Japan	−3.20†	0.42†	−0.08†	0.34†	0.52†	0.39

‡Estimated equation is $\ln((1+r)/(1-r)) = A + (B_1 + B_2 D)\, s + e$

§Estimated equation is $\ln(S_{OTHER}) = A + (B_1 + B_2 D)(\ln(S_{STARTING})) + e$

*Significant at 95 percent level, one-tailed test

†Significant at 99 percent level, one-tailed test

generally significantly positive for the correlation equations and not significant for the volatility equations When the shift was allowed in 1983 instead of 1980, quite similar results concerning the size, sign, and significance of shifts were found

4 *Calculation of betas* Beta coefficients, b, are defined by the regression equation on logarithm changes,

$$D(\ln p2) = a + b\, D(\ln p1) + e,$$

where

$$b = r\,(S2/S1)$$

Here r is the correlation coefficient between percent changes in p1 and p2, S1 and S2 are the corresponding standard deviations, and D indicates first differences

Table A4 shows three different measures of b, for two time intervals each The first measure is the average of betas for 30-day periods, calculated with 30-day values of r, S1, and S2 The second measure is the same, except the values of r and S2 are predicted values from regression equations that estimate r and S2 as dependent on S1 (see above), average values of S1 over 1972 through September 1987 are used Thus this second measure is net of the effects of changes through time in market volatility The third measure is directly estimated with daily data. A significant statistic for the third measure reflects a t-test on the difference in coefficient values, where t is calculated assuming two independent samples with different variances

Appendix A: Estimating Relationships among Stock Market Volatilities and Correlations *(continued)*

Table A4

Beta Coefficient Estimates

Relating Percent Changes in Daily Stock Price Indexes

	Average Betas from 30-Day Periods†		**Average Betas Adjusted for Volatility Changes‡**		**Average Betas, Directly Estimated§**	
	1980 to Sept 1987	1972-79	1980 to Sept 1987	1972-79	1980 to Sept 1987	1972-79
Day starts in the United States:						
Japan	23	14	22	12	24*	15
United Kingdom	31	27	30	26	31	29
West Germany	36	20	34	17	33*	20
Day starts in Japan:						
United Kingdom	19	08	17	06	18	11
West Germany	25	13	25	11	20*	14
United States	09	03	09	05	08	04
Day starts in United Kingdom:						
West Germany	19	04	22	04	19*	05
United States	20	07	20	06	20*	06
Japan	12	00	13	01	12*	02

†Betas were computed for each 30-day period as rS1/S2, where r is the correlation coefficient and S1 and S2 are the standard deviations for each period Averages for 30-day periods during 1972-79 and the 1980s are shown

‡Predicted values were calculated for r and S1 from equations relating them to S2, setting S2 to its 1972 to September 1987 average and using separately estimated equations for the 1970s and 1980s

§Estimated using simple daily regressions of percent changes in pairs of markets

*Directly estimated beta for the 1980s is significantly greater than for the 1970s at the 95 percent level

Appendix B: Monthly Regression Model Relating Foreign and Domestic Stock Price Indexes and Controlling for Economic Variables

An econometric model was estimated to measure the effects of foreign stock prices on domestic stock prices while controlling for key economic variables. An equation was estimated for each of four countries. In each equation the dependent variable was a monthly-average domestic stock price index, and the explanatory variables included short- and long-term interest rates, industrial production, the CPI, and the unemployment rate. Each of these economic variables was included as an explanatory regression variable contemporaneously and with five months of lagged values. Contemporaneous monthly-average values of stock indexes for six major countries were also included as explanatory variables In addition, error autocorrelation coefficients (rho (-1) and rho (-2)) were estimated and found to be statistically significant

The regression results for the United States, Japan, the United Kingdom, and West Germany are shown in Table B1. Explicit allowance was made for the coefficients on foreign stock price indexes to change starting in January 1985. (The variable transformations made to allow such coefficient changes are explained in a footnote to Table B1.)

As the R^2 for each equation shows, the explanatory variables account for between 40 and 80 percent of the monthly variation of the dependent variable. The autocorrelation terms account for virtually all remaining variation (since the R^2 that includes the explanatory power of the rho coefficients is nearly unity in each case).

The foreign stock index coefficients are almost all positive (or are quite small), with sizable and statistically significant positive coefficients on several foreign stock indexes in each equation. This finding is consistent with the hypothesis that foreign and domestic stock prices are positively correlated, even after economic trends have been taken into account. It should be noted, however, that since stock price indexes tend to be quite correlated through time, the size of one foreign

Appendix B: Monthly Regression Model Relating Foreign and Domestic Stock Price Indexes and Controlling for Economic Variables *(continued)*

Table B1

Regression Coefficients for the United States, Japan, the United Kingdom, and West Germany

Sensitivity of National Stock Markets to Movements in Domestic Economic Variables and Foreign Stock Prices (Monthly Data,† All Variables in Log Form)

	Dependent Stock Price Index							
	S&P 500		Tokyo Index		UK Index§		West German Index	
Independent Variables*†	Through Dec 1984	Jan 1985 Shift‡	Through Dec 1984	Jan 1985 Shift‡	Through Dec 1984	Jan 1985 Shift‡	Through Dec 1984	Jan 1985 Shift‡
Constant term	− 38		− 64		−3 26		3 14*	
Foreign stock price indexes:								
United States			11	+ 71*	41*	− 01	09	+ 32
Japan	03	+ 24*			10	− 22	14	− 18
United Kingdom	14*	+ 02	09	− 13			09*	− 19
West Germany	10*	+ 00	14*	− 01	12	− 04		
France	03	+ 02	00	+ 03	− 04	+ 07	11*	− 07
Canada	37*	+ 01	02	− 49*	04	+ 33	− 01	− 15
Italy	04	− 10	02	+ 06	13*	− 17	10*	+ 15
Domestic variables:								
Short-term rate	04*		01		− 08*		− 03	
(-1)	− 04*		04		− 03		00	
(-2)	01		− 09*		01		− 01	
(-3)	02		− 03		− 03		− 03	
(-4)	− 02		− 01		− 05		− 04	
(-5)	00		− 07		− 06		− 01	
Long-term rate	− 25*		21*		− 24*		− 25*	
(-1)	02		− 01		− 25*		17	
(-2)	− 06		01		− 08		− 05	
(-3)	02		03		− 07		− 06	
(-4)	01		− 06		01		11	
(-5)	00		− 01		08		− 09	
Industrial production	15		02		41*		15	
(-1)	30*		02		26		45*	
(-2)	− 04		06		09		52*	
(-3)	08		03		07		09	
(-4)	18		02		10		− 17	
(-5)	04		04		− 01		− 10	
Consumer price index	35		− 01		58		−1 42	
(-1)	− 61		05		92*		26	
(-2)	− 49		− 21		−1 00*		− 17	
(-3)	03		05		11		− 09	
(-4)	20		93*		04		95	
(-5)	16		26		04		− 10	
Unemployment	− 00		01				01	
(-1)	02*		− 01				01	
(-2)	00		02				01	
(-3)	01		01				02	
(-4)	01		03*				− 01	
(-5)	01		01				01	
rho (-1)	91*		1 34*		1 22*		96*	
rho (-2)	03		−0 35*		− 28*		− 15*	
R^2	809		437		714		804	
R^2 (error based at original level)	999		999		997		991	

*t-statistic significant at the 95 percent level for a one-tailed test (critical value = 1 645)

†For S&P 500 equation, data are for August 1950 through September 1987 For Tokyo index equation, data are for August 1963 through September 1987 For U K index equation, data are for August 1961 through September 1987 For West German index equation, data are for August 1967 to September 1987

‡Coefficient on the shift variable corresponding to the independent variable X_t and constructed according to the formula shift variable = D8485 * (X_t − $X_{12/84}$), where D8485 equals zero through December 1984 and one thereafter, and where $X_{12/84}$ equals the December 1984 value of the independent variable X_t

§Unemployment rates for the United Kingdom were not available on a consistent basis for the sample period

Appendix B: Monthly Regression Model Relating Foreign and Domestic Stock Price Indexes and Controlling for Economic Variables *(continued)*

stock index's influence relative to the size of another's is estimated with a high degree of uncertainty By contrast, a more consistent story emerges from the sums of these coefficients in each equation. Similarly, the individual shift coefficients are hard to interpret, with sizable shifts in positive or negative directions.

Table B2 imposes some order by comparing the totals of the coefficients on foreign stock indexes with the totals of these coefficients plus the sum of the shift coefficients. These latter totals are the new, postshift coefficient sums. Suppose, for example, that all foreign stock prices were to rise by 10 percent Then, according to the Table B2 sums (lower left-hand corner), prior to 1985 this increase would have been associated on average with a 7 1 percent change in the S&P 500, assuming there were no associated change in underlying U.S. economic variables Had the foreign stock price rise occurred after January 1985, however, the associated rise in the S&P 500 index would have been 9.7 percent when other variables were held constant.

Table B2 also summarizes the results of reestimating the statistical equations when the foreign stock price coefficient shifts were allowed to occur at earlier dates.

Table B2

Changing Sensitivity of National Stock Markets to Movements in Foreign Stock Markets*

	United States		Japan		United Kingdom		West Germany	
Date of Hypothesized Structural Shift	Sensitivity before Shift	Sensitivity after Shift	Sensitivity before Shift	Sensitivity after Shift	Sensitivity before Shift	Sensitivity after Shift	Sensitivity before Shift	Sensitivity after Shift
Jan 1971	80	74	35	44	54	78	74	51
Jan 1979	74	82	33	56	86	55	45	44
Jan 1982	72	83	37	57	82	54	45	58
Jan 1985	71	97†	38	55	76	71	52	40

*See Table B1 for 1985-shift regressions. The statistics shown here equal the sums of estimated foreign stock price coefficients, with and without the shift coefficients, for each of the four equations The stock price indexes used were the S&P 500 for the United States and broad indexes available from Citibase for Japan, the United Kingdom, West Germany, Canada, France, and Italy
†Sensitivity after shift is larger, at a 95 percent level of statistical significance (one-tailed test)