3
The International Transmission of Asset Price Volatility

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Introduction

There is a human tendency to overstate current difficulties and problems and to compare perceived present disturbances with some (partly mythical) prior golden age when everything was calm and ordered. To take one example, during the 17 years in which I was associated with forecasting in the Bank of England, I cannot now recall a single forecast which did not begin with some such proviso as, "In current circumstances it is unusually difficult to construct a forecast."

The same trait holds true in assessments of asset price volatility.[1] It was a regular occurrence for senior officials at the Bank of England (and for pundits elsewhere) to complain that asset price volatility was higher at the present time (as each year went by) than in previous

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[1] It holds true as well in some exaggeration of the extent to which the integration of asset markets worldwide is said to be unprecedented. By many tests world financial markets were more integrated in the period 1890-1914 than now. Tests of the kind originated by Feldstein would probably suggest much greater international integration in the earlier period; see Feldstein and Horioka (1980), Feldstein (1983) and Obstfeld (1986 a and b). International monetary substitution was surely higher, and international portfolio (bond) elasticities of substitution almost certainly so. The ***proportion*** of non-British assets (mostly bonds, with a high weighting of railway bonds) actively traded on the London Stock Exchange was, I would expect, higher in 1913 than in 1988. O. Morgenstern (1959) compiled a massive study ***of*** correlations between

periods. It was not clear to me that that claim was well-founded econometrically, and eventually I encouraged a visiting economist (from the RBNZ) to test such claims.

He used an ARCH model rather than the common, simpler moving variance about moving mean (MVAMM) approach. There are several possible advantages in using the former technique (besides showing off greater technical sophistication). First, it could allow any predictable change in the asset prices to be discounted, i.e., "it measures the dispersion around the conditional rather than about the sample mean;" given, however, the martingale/random walk characteristics of most asset price series, this advantage is not of much significance for this kind of study. Second, the MVAMM requires an "arbitrary" choice of window, and weights all the observations within the window with a value of unity and those outside with a zero weighting. Instead, with an ARCH test, the order of lag and weighting are primarily (e.g., subject to non-negativity and stationarity requirements) determined by the data themselves.[2,3]

Anyhow, the results of this test[4] did not support the hypothesis that asset price volatility has increased monotonically over time. There

national asset price movements in earlier decades. I should be prepared to bet, since I have not done the empirical work to sustain the claim, that the correlations between national short-term interest rate movements were higher in the earlier period, and that the correlations between equity indices were probably much the same then as now.

In what ways then, if at all, is the international financial community significantly more integrated than before 1914? Whereas news does travel even more swiftly than before, the crucial innovation for international integration was the earlier telegraphic cable and radio. One novel feature of our more recent period is the interpenetration of each others countries national markets by multi-national firms. The elasticity, in response to differential profit possibilities, of direct investment seems much higher now than then; there was no equivalent of Coca Cola, McDonalds, Shell, Ford or Unilever before 1914. It is odd that most of our models concentrate on portfolio capital flows, and attach so little attention to direct capital flows.

The other main distinction between the period before 1914 and the 1980s was that in the earlier period the international integration of national financial markets was constructed on the basis of, and supported by, a stable, essentially single currency system (the Gold Standard). The interaction now of a unified global capital market with an unstable system of independent national currencies has led to major problems arising in recent years, notably exchange rate misalignments, but this is too wide an issue to pursue further here.

2 In practice, however, the ARCH and the MVAMM estimates of volatility have given broadly similar results in these exercises.

3 See Dickens (1987a).

was a golden age of asset price tranquillity in the 1960s, but we were flung out of that Garden of Eden in 1973, and asset price volatility in the United Kingdom (equity prices, short and long interest rates) then rose to higher levels in the years 1973-75 than at any other time during this data period, 1967-85. Subsequently, "distinct cycles in variability were evident . . . with trough levels generally around the average levels experienced in the 1967-72 period, and peak levels well in excess of the trough levels, although except for the exchange rate series, below the peak levels in 1973-75 period."[5]

Bank of England officials not only complained about worsening asset price volatility, they frequently asserted that such enhanced volatility was imported from abroad, that the supposedly greater disturbances in London were generated by larger fluctuations elsewhere. (New York was usually the proposed perpetrator.) Such claims were particularly common in the early 1980s, when volatility in the New York money and bond markets did increase by a factor of "five to eight times the levels prior to 1979."[6]

Anyhow, it seemed worthwhile to move on from a study of asset price volatility in the United Kingdom to a companion exercise to examine international comparisons of asset price volatility. This study, mainly by Dickens,[7] is available in the Bank of England Discussion Papers (Technical Series), no. 15, February 1987. The conclusions to this are reproduced here in an Appendix. Briefly, there are some international linkages between volatilities in bond and equity markets (though very little international linkage between volatility in national money markets), but these relationships are less strong than much casual empiricism claims. The main periods of asset price disturbance were 1973-75 (broadly) and 1979-82 (focused in U.S. money and bond markets). We observed no tendency for national asset price volatilities either to 'increase monotonically over time, or to become more closely internationally correlated over time.

We need, therefore, to be suspicious about embracing the view that there has been any Ionger-term trend toward enhanced interna-

5 See Dickens (1987b), p. 10.

6 *Ibid.*

7 I wrote Sections 7.8 to 9 jointly with him.

tional transmission of asset price volatility. This does not, however, rule out the possibility that such transmission mechanisms may play a major role on certain key occasions.

Indeed, I very much doubt whether this conference, or my own particular topic within it, would have been organized were it not for the crash of October 19, 1987. When that crash occurred, my colleague, Mervyn King, and I, having jointly founded the Financial Markets Research Group at the London School of Economics in 1986, concluded that the comparative advantage that the FMG might have in the post-mortems on this event would be to examine some aspects of the international linkages and transmission mechanisms involved. In our view, the most "puzzling feature of the October 1987 crash was the almost uniform fall in world stock markets, despite important differences in economic prospects, market mechanisms, and their prior "degree of overvaluation."[8]

Nevertheless, it always seemed a fair bet, and was in the event correct, that the various studies commissioned in each country to delve into the minutiae of the evidence of the working of their own stock markets during the crash would indeed concentrate on local (parochial?) national performance and pay relatively little attention to the international dimension. This was mainly because of the obvious focus of each country's inquiry on the performance of its own national market.[9] It was also partly because there were (and remain) limitations in the data available to test some of the forms of international linkage. Thus, casual empiricism has claimed that an unusually large proportion of equity sales in many equity markets worldwide on October 19/20 was by "foreigners". In London, however, fiscal requirements whereby certain taxes can be avoided by those declaring themselves non-resident, allow the residence of purchasers of equities to be broadly estimated, but not that of sellers. So there is no data here to test such casual empiricism, and I am not aware of data (or studies) elsewhere that could properly examine this claim.

Even when the Brady Commission (1988) did consider interna-

[8] See King and Wadhwani (March 1988a), p. 2.

[9] One feature of this internal concentration has been the comparative absence of discussion about disintermediation, to stock markets abroad, of business temporarily prevented by national "circuit-breakers".

tional linkages, it took the view that these "were unlikely to have been important during the crash because there had not been any perceptible rise in correlations between markets over time."[10] While that finding is consistent with those of Dickens, above, and indeed with Wadhwani and King's own subsequent results, it is a ***non sequitur*** to deduce from the absence of any low-frequency trend that there should also be no significant much-higher-frequency relationship at a time of particular crisis and high volatility.

International linkages and the crash of 1987

As already noted, the most puzzling aspect of the crash, or so it appeared to us in the FMG, was the similarity of decline in stock markets worldwide. This throws doubt on a number of possible explanations. It is hard enough—indeed, generally accepted as impossible—to find "news" that could justify the scale of decline in the NYSE between October 16 and 19, but to seek to find such "news" in every major country, virtually simultaneously, would, indeed, be piling Pilion on Ossa. Again valiant—but not entirely convincing—efforts have been made to identify stock exchange bubbles developing and breaking simultaneously in New York, London and Tokyo.[11] I would challenge anyone to find a bubble also in Frankfurt, and yet the stock market there fell in line with the rest in October. Moreover, if it all had been just a bubble breaking, why has the bubble re-inflated so soon in Tokyo, but not elsewhere?

My own personal favorite explanation is that, after an initial decline caused by a "rational" interpretation of worsening fundamentals, the subsequent collapse in U.S. securities markets was the result of a market failure, with a dysfunction between the futures markets, driven down, in part, by portfolio insurance, and the NYSE where the specialists were insufficiently capitalized to absorb the pressures, including the sales arising from programmed trading arbitraging between the two markets.

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[10] King and Wadhwani, Ibid.

[11] See G.A. Hardouvelis, Federal Reserve Bank of New York Working Paper, 8810, (April 1988).

Be that as it may, if the decline in the NYSE had been the result of market failure, at least in some significant part, why did the U.S. markets not then "bounce back" toward their appropriate fundamental value, and just as, or more, difficult to understand, why should foreign markets have declined as much? The two questions are, of course, closely linked. Many of the major international companies are quoted on several exchanges, and arbitrage will ensure that their price is the same on geographically-separated exchanges which are open at the same time. But if the decline in New York had been due to local market failure, driving the price of commonly quoted multi-nationals below their "fundamental value," then that should have led to subsequent buying on other exchanges where the market mechanisms were different and not subject to the same pressures.

It is the case, I believe (but have not seen rigorously demonstrated), that shares of (non-U.S.) companies with U.S. connections, either in the form of a quotation on a U.S. exchange or with a large export market there, fared slightly worse in their domestic (non-U.S.) stock markets, than comparable shares (with similar Betas) but no U.S. exposure, during the week of October 19-26, though even this has been denied.[12] Certainly the impression (casual empiricism) that I received was of the general, widespread nature of the collapse across all shares, with or without particular U.S. connections, in all the world's main stock exchanges. It may be that this impression is incorrect; certainly it deserves testing. Nevertheless, my feeling was that we were witnessing then a contagious transmission of a (panicky) reassessment of the discount factor to be applied to future earnings on equity as a class of asset, rather than any more reasoned review of the likely future path of company profits either in the United States or more widely in the western world.

Certainly there was much newspaper and "pundit" comment at the time about declines in stock exchange values becoming self-reinforcing as a result of international interactions and "cross-infection." The sell-off in one market, say New York, precipitated

[12] See the article by N. Goodway in *The Observer*, November 29, 1987, reporting some research by Paul Masson of Kleinwort Grieveson which concludes that the idea that shares with international listings were harder hit than most by the crash was "a myth."

consequential falls in other markets around the world, notably in Tokyo and London, where price falls then caused further dismay and price declines in New York, and so on.

There has been sufficient general interest in the possible existence of this concept of "cross-infection" between international markets to make my colleagues and me at the FMG keen to see if we could undertake any econometric tests to explore the existence of such phenomena. This is not an easy exercise to undertake. The problem is that it is hard to distinguish between a case when two markets move together because they are both responding "rationally" to some common "news" which will affect the expected future streams of corporate profits and dividends, and/or their riskiness, from the case when one market simply becomes "infected" by observation of price movements in the other.

It is extremely difficult to define "cross-infection" rigorously in a world in which "news", the unanticipated element in announcements, is hard, and often virtually impossible, to measure on a common basis. Indeed, it is, in part, because it is so difficult to assess what the "news", or its implications, really amounts to, that stock exchange practitioners will tend to look, perhaps especially in setting initial prices at the opening in the morning, at what assessments have already been made in stock exchanges abroad. This tendency will, no doubt, be most marked when the "news" either arrives initially in, or is most easily interpreted by, the other stock exchange. (For example, if the U.S. President were to die, stock exchange participants in non-U.S. countries might wish to take their lead from the price changes that would occur on the NYSE, rather than try to estimate the "fundamentals" themselves.)

There is, therefore, *normally* some "contagion" of price changes in one market affecting prices elsewhere. There is nothing irrational about this. Stock exchange participants are simply trying to extract the "signal" about the "news" relevant to their own markets from the "portmanteau" statistic of changes in the indices in the main centers elsewhere. Where such "contagion" turns into the "cross-infection" described above, comes in those cases where the self-confidence of stock exchange participants to assess the fundamental value(s) of assets themselves, independently, erodes, so that they start to pay much greater (excessive) attention to prices set by others in the market, and less to fundamentals. This is akin to a (partial) switch in regime from a rational, efficient market in which values depend on the present discounted value of expected future cash flows (with participants trying to reach an independent judgment) to Keynes' beauty contest. In our international framework the onset of such "cross-infection" might best be measured by a significant rise in the "contagion" coefficient relating price changes in one stock market to (prior) changes in other stock markets.

Even here, one cannot disprove the hypothesis that a rise in the "contagion" coefficient may have been a rational response to greater co-variance in "news" affecting both (all) markets. I doubt whether it is strictly possible to construct any test which would enable the "news" hypothesis of asset pricing to be refuted. All that we can do is to explore whether it is possible to present data which seem more consistent with the hypothesis of internal market dynamics such as "cross-infection", and by the same token, less consistent with the pure "news' hypothesis.

A first exercise along these lines has been undertaken by my colleagues, Mervyn King and Sushil Wadhwani. A first draft of their paper, "Transmission of Volatility between Stock Markets," was presented at the LSE Financial Markets Group Conference on Stock Market Behavior, March 29, 1988; a revised version (July 1988) has been sent to my discussants, and a later version is available on request from the Financial Markets Group at LSE, Discussion Paper No. 48. They put forward a model wherein, "Information is of two types, systematic and idiosyncratic. The former, denoted by u, is information that affects market values in both countries. The latter, denoted by v, is relevant only to a specific country. We assume that both u and v have two components, corresponding to information that is observed in one country or the other. If information from both countries were fully revealed, then the process that would generate changes in stock prices is assumed to be

$$(1)\quad \Delta s_t^1 = u_t^1 + a_{12}u_t^2 + v_t^1$$

$$(2)\quad \Delta s_t^2 = a_{21}u_t^1 + u_t^2 + v_t^2$$

where Δs_t^j denotes the change in the logarithm of the stock market price index in country j between time $t-1$ and time t."[13]

[13] See King and Wadhwani, (1988b), p. 4.

The authors then impose the restriction that "news which affects both countries is always revealed first in one country or the other, but never simultaneously . . . If information is not fully observable in both markets, the investors and market-makers set prices according to

$$(3)\quad \Delta s_t^1 = u_t^1 + a_{12}E_1(u_t^2) + v_t^1$$

$$(4)\quad \Delta s_t^2 = a_{21}E_2(u_t^1) + u_t^2 + v_t^2$$

where E_1 and E_2 denote the expectations operator conditional upon information observed in markets 1 and 2 respectively.''[14]

This leads to a "signal extraction problem to find the minimum-variance estimator for the value of the relevant news term that has been observed in the other market." This approach then allows them to proceed to use the fact that "markets operate in different time zones and are closed for part of the day . . . to identify the contagion coefficients" linking the markets together.

I would, however, note that it is actually the case that news items going to market participants in, say New York, over the major wire services such as Reuters, Telerate, UPI, etc., are ***potentially*** simultaneously available in Tokyo and London, if market operators were at their desks there. In one sense, the bulk of all ***major*** news announcements is now, for all practical purposes, available simultaneously worldwide. What remains the case, however, is that such "news" is not ***assimilated*** on a continuous basis by all market operators since they have, mercifully, gone home.

When a market participant goes into the office in the early morning, he has, besides the newspapers, and the possibility of looking at other sources of information on "news" between the prior market close and the forthcoming opening, the opportunity of seeing how the markets in other time zones have reacted to the "news". Rather than try to work out the effect on "fundamentals" by examining all the myriad individual bits of news, the market participant will treat the movements in other major markets as a valuable portmanteau guide to the way in which he, himself, should adjust prices before

14 *Ibid.*, p. 5.

the opening. The participant is especially likely to do this in those cases where he/she reckons that markets abroad are more likely to reach a correct pricing decision than he/she could do by an independent study of the effect of the "news" on the fundamental value of the assets.

The interesting question, is, therefore, not whether prior movements in other stock exchanges influence the close/open price change in stock exchange i; we should expect them to do so. Instead, it is whether the scale of such linkages, the size of the coefficient, appears to increase at times when we suspect that "cross-infection" may be present. Remember that we cannot rigorously refute the counter-claim that any such increase in the size of the coefficient could be due to greater variability in actual "news" making each market "rationally" respond more to movements in the others. One can only judge the balance of probabilities on the basis of the data, the historical evidence and one's individual priors.

Be that as it may, the authors demonstrate "the fact that the correlation coefficient between hourly price changes in London and New York rose after the crash, an observation that is consistent with the idea that the extent of contagion grew after October 19. When we allow for time zone trading, and examine interactions between Tokyo and London and New York in turn, this finding is confirmed . . . The impact of changes in Tokyo on both London and New York has risen since the crash. Results using monthly data for the UK and the U.S. over a longer time period yield the same picture . . . The paper tests the hypothesis that the contagion coefficients increase with volatility . . . Table 3 . . . shows that the value of the contagion coefficient measuring the impact of New York on London depends on volatility. The estimated coefficient of 0.36 is large."[15]

Interactions between stock market price indices and the forex market

My chief function so far has been to report the results of papers by Dickens and by King/Wadhwani, both of which I have encour-

[15] See King and Wadhwani, (1988a), p. 2.

aged from the sidelines, that are germane to this issue. I have also, however, done some research, myself, on this subject.[16]

The starting point for my own research was prior work that I had done on the characteristics of hourly data on spot exchange rates, using data from Money Market Services (MMS) International, for the period January-July 1986.[17] Subsequently, in order to examine the interactions between price indices on the major stock exchanges, we had obtained hourly data of price indices from London, Tokyo arid New York over the days, September 1 to November 30, 1987. I was able to obtain hourly forex data for four spot exchange rates bilateral with the U.S. dollar, those being the deutsche mark, the British pound, the yen and the Swiss franc for the same period in 1987, again from MMS International to whom my thanks are due.

My assessment of the major economic "news" that was moving stock exchange prices in the autumn of 1987, (such as data on the U.S. current account, U.S.-German policy discords, U.S. fiscal developments, etc.), was that these would also impinge on the forex market. With forex spot exchange rates approximating to a random walk, the intensity of internationally available "news" might, therefore, be provided by the absolute size of the change (in the logarithm of)[18] the spot exchange rate. So my idea was to use data on the scale of forex market fluctuations as a proxy for the intensity of the arrival of common news, affecting all the major stock exchanges.

During this period, as will be demonstrated below, "news" which was associated with an appreciation in the U.S. dollar was generally regarded as favorable by all three stock exchanges; declines in the U.S. dollar were considered likely to generate higher U.S. interest rates (bad for the NYSE), whereas the adverse effect on British and Japanese competitiveness of an appreciating currency would not—given local financial conditions—be offset by lower domestic interest rates. But this reaction was peculiar to the circumstances pertaining

16 **With the research support of L. Figliuoli.**

17 **See Goodhart and Giugale (1988).**

18 **The first study, on relative variance, used actual data; the second study, employing regression analysis, used the log transform.**

then. One could easily envisage other circumstances when "news", e.g., of a cut in U.S. interest rates, could lead to a simultaneous rise on the NYSE and depreciation of the dollar. So, although in some tests, partly for my own interest, I did regress ***actual*** stock exchange price index movements on ***actual*** forex price percentage changes, the main tests involve an examination of the relationship between the ***variances*** (or in the ***absolute changes*** without regard to sign) in the forex market and in the stock markets.

Stock markets are only open for part of each 24-hour working day, unlike the forex market which is continuous from Sunday, 23.00 hours, GMT, when Sydney opens the new working week, to 23.00 hours, GMT, on Friday, when the market closes on the West Coast of the United States. During the intervening weekend, both markets (ignoring Tokyo's Saturday market) are, for most practical purposes, shut. Taking then the 566 consecutive observations of the changes in the index on the London Stock Exchange,[19] 502 represented hourly changes with both markets open simultaneously, 51 represented overnight weekday breaks when the London Stock Exchange was shut, but the forex market open, and 13 represented weekend breaks, with both markets largely shut. Our data period for the NYSE covers the same days, September 1 to November 30, but includes rather fewer observations. This is partly because the NYSE covers eight hours a day, whereas the London Stock Exchange is open nine hours a day, and also because there were rather more missing observations for NYSE.[20] Overall for the NYSE, there were 479 observations, 418

19 No data are available for Friday, October 16, when the London Stock Exchange was shut because of the hurricane. Friday was then treated as part of the weekend, October 17/18. Other gaps in the data for the London Stock Exchange were for the following hours, at

GMT	
08,03,09	Hour, day, month
08,04,09	
08,24,09	
08,19,10	
09,12,11	

In each case this was the opening observation, so we simply treated the next hour as the opening observation.

20 In most cases we had complete hourly data running from the NYSE opening (13.00 hours GMT until October 23, 14.00 hours GMT from October 26) to the close (20.00 hours GMT until October 23, 21 hours GMT after October 26). The market was shut on November 26 (Thanksgiving) and on September 7 (Labor Day). In addition, there were no data for the usual opening hour on October 19-21, nor for the penultimate hour of the market from October 23 until November 6. In the first case, we treated the first available hour as the opening figure; in the second case, these were treated as missing observations.

with both markets open, 49 weekday nights, 12 weekend breaks. Price indices on the Tokyo Stock Exchange are collected less frequently, at 23.15 - 00.00 - 02.00 - 03.15 - 04.00 - 06.00, GMT. Since our forex data are at end-hour, we treated the observations taken at quarter after the hour as if they had occurred at the preceding beginning hour. By convention, the opening observation in Tokyo at 23.00 hours is the same as that of the previous night's close. We assume here that, by 23.15 hours, GMT, the TSE can make an equivalent change to overnight information, as can be achieved on the stock exchanges in New York and London. While that would seem plausible, and is all that can be done with the data, the TSE's convention in this respect may have some responsibility for the differing behavior between the TSE and the two other stock exchanges. Our data covered the same period[21] and provided 362 observations in all, with 296 overlapping hours, 53 weekday nights and 13 weekends.

My first exercise was to examine the bilateral relationships and correlation between the variance of each of the stock exchange series and of the three main spot forex series,[22] both overall and in the sub-periods (jointly open, overnight, weekend—though there were too few weekend observations to hope for useful statistical results in this last case). Let us assume that, prior to October 19, stock markets reacted primarily to a combination of idiosyncratic domestic information available during working hours and to international "news" proxied by forex market fluctuations, so long as the forex market was open. Then my hypotheses would be:

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21 There were no market reports on November 23. Other missing hours were:

	GMT	
	00,01,09 - 05,01,09	Hour, day, month
(Holiday)	00,15,09 - 06,15,09	
(Holiday)	00,23,09 - 06,23,09	
	00,02,11 - 06,02,11	
(Holiday)	00,03,11 - 06,03,11	
(Holiday)	00,23,11 - 06,23,11	

These were treated as missing data.

22 The Swiss franc spot rate was so highly correlated with the deutsche mark that we decided, to save time and space, to omit it.

H(l) The ratio of the variance of the forex market to the variance of the stock exchange would be higher when the forex market was open and the stock exchange shut;

H(2) This would be caused by a relative decline in the stock exchange variance when the stock exchange was shut, with no change in the forex market variance (forex market open throughout);

H(3) The correlation between variances would be greater when the stock exchange was shutlforex open, because of less domestic idiosyncratic noise affecting the stock exchange.

I want to compare behavior before the crash with behavior after the crash, when "contagion" and "cross-infection" may be expected to be more prevalent. In order to avoid having the results dominated by the extreme observations of October 19-23, when some of the observations may well also be inaccurate, the post-crash comparison utilized data from October 26 onward. If "cross-infection" was more prevalent after October 26, there will have been other sources of price variation—notably movements in other stock exchanges—in addition to forex price changes, influencing the stock exchange in question when it was shut. Consequently,'

H(4) Post-October 26, the higher level of the ratio of the variances (forex variance divided by stock exchange variance) when the stock exchange was shut/forex open as compared to overlapping (both open) hours, would diminish, or even reverse;

H(5) Post-October 26, the decline in the variance of the stock exchange when it was shut compared to when it was open would be much less marked than pre-October 19;

H(6) Post-October 26, the correlation of variance forex/variance stock exchange would decline throughout, but especially when the stock exchange was shutlforex open.

Table 1 (printed in its entirety at the end of this article) records the variances (of the stock exchange price indices and spot exchange rates separately), the ratios of these variances, the correlations between these variances, and the significance of these correlation coefficients for each stock exchange/spot rate pairing. For each pairing these data are reported from the complete data set, and for the sub-divisions, i.e., overlapping hours, weekday nights, weekends, and pre-October 19 and post-October 26. Column 1 in each case records the variance of stock exchange prices; column 2, the variance of the spot exchange rate; Column 4, the normalized ratio (since the scales were so different) of the two variances, defined as Variance Forex divided by Variance Stock Exchange; so a high ratio figure implies high forex variability relative to stock exchange variability. Column 3 gives the correlation between the two series of variances, and column 5, an N-test of their significance, where the critical values are the same as for t-tests.[23] It should be remembered that the hourly spot exchange rates tend to move together,[24] so that the results for the differing spot rates with the same stock exchange are not to be regarded as independent in any sense.

In most cases, the variance of the stock exchange indices are lowest in the period before October 19, are higher in the second period after October 26, and are highest in the full period, because of the dominating influence of high variability in the crash week itself. The exceptions are: NYSE, the variance during overlapping hours (both markets open) was lower after October 26 than before October 19, but the variance over the few weekends was even higher after October 26th than over the whole period. In Tokyo, the weekday overnight variance was higher in the final sub-period (after October 26) than in the full period, and the ordering of the variances'over weekends had a higher variance in the few weekends in the earlier sub-period than in the later sub-period.

In the case of the forex market, the ordering is somewhat different with the variances for all exchange rates, in all stock exchange comparisons and timings (full, overlapping, weekday, weekend), being lowest pre-October 19, but higher post-October 26 than in the full period; exceptions were that in the NYSE, the variance of all three forex markets, overnight on weekdays, was higher in the full period

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23 **The N-tests were estimated as $T^{1/2} \mu(\tau)$ where T is the number of observations, and $\mu(\tau)$ is the $\tau -$ th sample autocorrelation, because under the null hypothesis of zero correlation among the returns the sample autocorrelation at any lag $\tau \neq 0$ will tend to be, in large samples, independently distributed, with a mean of zero and a variance of 1/T. See Harvey (1979). p. 146.**

24 **See Goodhart and Giugale (1988).**

than in the second sub-period, and in London, at weekends, the variance of the yen was lowest at the weekends after October 26.

Let us now turn to the six hypotheses put forward earlier.

H(1): Ratio of variance of forex market to the variance of the stock exchange indices would be higher (i.e., figure in Column 4 higher) when forex market open/stock exchange shut (i.e., overnight weekdays) than when both are open (i.e., overlapping).

This is found to be the case for all stock exchange/currency bilateral pairings for the period up till October 19. It is true for the whole period in New York, but not for any currency in New York after October 26, (remembering that currency movements are not independent), primarily because the intra-day variance in the NYSE fell away sharply then. It is not true in London for the whole period; even though in both sub-periods the ratio of variance in the forex market to the stock exchange is higher overnight than during the overlapping period, the reverse (greater forex than stock exchange variability intra-day relative to overnight), must have dominated decisively in the crash week. In Tokyo, the hypothesis is supported in all period/pairings.

H(2): This would be caused by a relative decline in the stock exchange variance when the stock exchange was shut, with no change in forex market variance.

Recall that the stock exchanges are only open for part of the day, 9-17 GMT, for a total of nine hours in London; 14-21 GMT, for a total of eight hours in New York; and 23-6 GMT, for a total of eight hours in Tokyo. Accordingly, the hourly gap from close to open is 15, 16, 16 hours respectively in London, New York and Tokyo. If the series followed a pure random walk, then the respective variances should be equivalently higher in the overnight gap than during the overlapping hours.

Table A below shows the shortfall from the predicted variance (if random walk held) for the stock exchange and currencies, *given* the variance during the overlapping period, for the overnight break.

Table A
Comparison of Actual Overnight Market Variance, with Random Walk Expectation, given Variance during Overlapping Hours

		Random Walk Prediction	Actual	Percentage Discrepancy
(1)	NYSE			
	Full Period	6222.4	754.5	87.87
	Pre Oct 19	2262.4	75.0	96.68
	Post Oct 26	1144.0	732.0	36.01
	and Pound Full Period	93.8	36.43	61.24
	Pre Oct 19	25.12	13.25	47.25
	Post Oct 26	148.48	35.83	75.87
	Dm Full Period	107.04	43.32	59.53
	Pre Oct 19	23.52	16.98	27.81
	Post Oct 26	174.56	26.66	86.73
	Yen Full Period	0.4800	0.252	47.38
	Pre Oct 19	0.2336	0.1534	34.33
	Post Oct 26	0.7232	0.2079	71.25
(2)	London Stock Exchange			
	Full Period	1546.5	567.20	63.32
	Pre Oct 19	. 85.20	34.08	60.00
	Post Oct 26	588.60	166.27	71.75
	and Pound Full Period	78.30	25.21	67.80
	Pre Oct 19	30.60	12.61	58.79
	Post Oct 26	110.10	40.12	63.56
	Dm Full Period	86.55	27.83	67.85
	Pre Oct 19	26.4	11.87	55.04
	Post Oct 26	128.55	45.69	64.46
	Yen Full Period	0.441	0.1602	63.67
	Pre Oct 19	0.2355	0.1419	39.75
	Post Oct 26	0.612	0.1855	69.69
(3)	Tokyo Stock Exchange			
	Full Period	380928	9911	97.40
	Pre Oct 19	70768	6002	91.52
	Post Oct 26	317668	13638	95.71
	and Yen Full Period	0.3456	0.2575	25.49
	Pre Oct 19	0.2928	0.1804	38.39
	Post Oct 26	0.376	0.2598	30.90
	Dm Full Period	35.344	43.11	−21.97
	Pre Oct 19	27.264	19.93	26.90
	Post Oct 26	35.264	46.68	−32.37
	Pound Full Period	30.832	38.693	−25.50
	Pre Oct 19	14.624	19.99	−36.69
	Post Oct 26	40.48	45.81	−13.17

I would interpret these figures as follows. Given the relatively few data and the fact that we are considering variances, I would not regard any percentage discrepancy less than plus-or-minus 50 percent as out of line with the basic random walk hypothesis. I would consider any discrepancy greater than 85 percent as clearly out of line with random walk expectations, and the intervening range, 50-85 percent, as problematical.

These results then suggest that, prior to October 19, in New York, the variance ratio for the forex market was ***broadly*** in line with, not all that far below, (random walk) theoretical expectations, whereas the variance ratio for the NYSE was massively below its random walk expectation; but that, after October 26, the relative variance in the stock exchange over the break rose dramatically (partly a very sharp rise in the overnight variance, partly a surprising decline in intra-day variance), while the variance ratio for the forex market declined relative to its random walk expectation largely because the forex variance was much higher during the hours when the NYSE was open (after October 26) than when it was shut.

In Tokyo, the relative variance of the forex market remained quite close to its theoretical expectation throughout, but in both sub-periods, especially the latter, and throughout, the variance of the stock exchange was vastly below its random walk expectation (given its variance when open).

In London, both the forex market and the stock exchange exhibited variances somewhat, but not vastly, below their random walk expectations, given the variances during the common overlapping periods. This shortfall, however, remained apparently roughly constant throughout.

These results show marked differences between centers and over time which are not particularly easy to rationalize. The stock exchange variances in New York before October 19, and in Tokyo throughout, when closed overnight during the week, are vastly below their random walk expectation. The shortfall from random walk expectation is much less for London, and NYSE after October 26. I interpret this to mean that NYSE, pre-October 19, and TSE throughout, were dominated by idiosyncratic domestic "news" only becoming available during working hours, but that the NYSE, post-October 26, and London Stock Exchange, throughout, were primarily influenced by more international factors.

Again, in New York before October 19, and Tokyo throughout, the relative variance of the forex markets was consistent (broadly) with random walk; but in London, and in New York after October 26, the relative variance of the forex market appeared to decline (compared with random walk expectations) when the local market was shut, although markets abroad were open. I have, in other exercises, found evidence of significant time dependence of volatility in forex markets, e.g., being at its highest in the London/New York overlap, and lowest while the Asian markets are open, and also some significant negative (first-order) auto-correlation in forex markets using hourly data[25] and in minute-by-minute data.[26] There appears to be evidence that such negative auto-correlation increases in scale when markets are disturbed, e.g., around large "jumps". The above findings, in part, follow from the nature of the time dependence in forex market volatility mentioned above.

Be that as it may, H(2) is only partially supported. It holds fully for TSE, and for NYSE before October 19, but neither for NYSE after October 26, nor for London throughout. In both these latter cases, the ratio of stock exchange variance is not all that far from its random walk expectation, whereas the ratio of forex variance is quite markedly below its random walk expectation during the overnight workday break.

Let us next turn to,

H(3) The correlation between variances would be greater when the stock exchange was shutlforex open, than when both were open, (less domestic noise).

Because of fewer observations, it is harder to find *significant* correlations overnight. In this exercise I am simply comparing the size of coefficients in Column **3;** the hypothesis is that the coefficient will be larger (more positive) during the overnight break period than intra-day.

The results of this test were generally negative. The correlation coefficients were just as frequently lower overnight than during the

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25 *Ibid.*

26 *See* Goodhart and Figliuoli (1988).

intra-day period, and there was no real pattern as between the earlier (pre-October 19) and later sub-periods. Generally, over *all* observations, and over *all* overlapping observations, the correlation between the contemporaneous variability of stock exchanges and forex markets is high, but such correlation may depend somewhat on the outliers observed in the crash week, October 19-26. If one takes *all* observations in the sub-periods, pre-October 19 to post-October 26, there remain some signs of significant correlations, but the strength of such relationships lessens rapidly as further sub-division within periods is attempted.

This is rather a blow to the maintained hypothesis, since the latter involved the suggestion that stock exchanges would be comparatively more sensitive to general international news, as proxied by movements in the forex market, when they were shut than when they were open. I have no explanation for this, but it does, it would appear, tend to throw doubt on the adequacy of forex market changes as an adequate proxy for common, international news affecting stock exchanges. Perhaps the reportedly large amount of official intervention during this period could have weakened the link between forex market movements and the arrival of internationally relevant "news".

I had, however, expected the correlation between the variances in the two markets to decline after October 26, especially during the overnight break, H(6), because, under conditions of "cross-infection", the various stock exchanges would pay more attention to movements in stock markets elsewhere, and consequently, less to forex market movements. There was support for this hypothesis in London, but not in New York or Tokyo; in the latter, the reverse occurred.

. We have also already effectively reviewed both H(4) and (5). These hypotheses are strongly supported in New York, but are not supported at all in London or in Tokyo.

The conclusions of this first exercise are thus mixed. What does seem to emerge is that behavioral reactions in the various separate stock exchanges were quite different during this (relatively short) data period. In Tokyo, all the variances increased in the later sub-period, but the relationship between these variances and their random walk expectation remained unchanged, whereas the correlation between the variability in the forex markets and in the TSE rose in the later period. In London, as elsewhere, variabililty rose generally in the latter sub-period, but the correlation between the variability in the forex markets and in the London Stock Exchange declined; again, the relationship between the variances and their random walk expectations remained unchanged during the two sub-periods, but with a totally different overall pattern from TSE. In New York, by contrast, the relationship between the variances and their random walk expectations changed quite sharply in the two sub-periods, but there was no apparent clear change in the correlations between the forex market and NYSE variability.

It may be simply that the data period is too short to allow any worthwhile conclusions to be drawn, but the only apparent lesson from this first exercise is that there may be quite markedly differing behavioral reactions and patterns in the different national stock markets.

In the second exercise I moved on from a study of contemporaneous variance (where the basic idea is that common "news" may cause simultaneous movements in both, forex and stock exchange, series) to a study, using regression analysis, of the reaction of each stock exchange, when shut, to movements in both the other stock markets and in the forex market, in the intervening periods between the prior market close and the market opening of the stock exchange under consideration (as dependent variable).

In this regression, the change in stock market i, from close, usually t-16 hours, to open at t, is regressed on the change in the other two stock markets from t-16 to t hours, the change in each forex market (entered one at a time) from t-16 to t, and the change in stock market i during the previous day, t-24 to t-16. Thus for London, the close-open price change will be regressed on the remaining price index change on the NYSE from the time of the London close to the NYSE close, the price change in Tokyo from open to close, the change in the forex market from London close to the time of the London open. The lagged dependent variable, e.g., the London Stock Exchange price change during its previous working day, is entered because the London change will represent information to other stock exchanges and induce price changes in New York and Tokyo. Thus, in order to extract signals about the information contained in changes in prices there, London market participants should (theoretically) discount changes induced by foreign markets' reaction to prior London changes. Thus, despite possible complete consistency with random walk price movements, we would expect a (relatively small) negative coefficient on the lagged dependent variable. This is a simpler version of the more complex, and theoretically appropriate, equations which King and Wadhwani have specified and tested.[27]

As noted earlier, my hypothesis was that relevant, important international "news" would be reflected in large changes in the forex market, but that news that, say, drove the dollar down, would sometimes be favorable, and sometimes unfavorable, to stock markets in each country. Thus I expected to find a relationship between absolute (i.e., without regard to sign) changes in forex exchange rates and in stock markets. The equation below was, therefore, .tested first with ***all*** variables entered in the form of ***absolute*** (i.e., without regard to sign) changes in the logarithms.

$$SE_{1,t} - SE_{1,t-16} = \text{constant} + b_1 \text{ intervening change } SE_2 + b_2 \text{ intervening change } SE_3 + b_3 (FX_t - FX_{t-16}) + b_4 (SE_{1,t-16} - SE_{1,t-24})$$

My hypothesis was that b_3 would be positive and significant, and that I might then be able to treat either the level of b, and b,, or at least the change in their values between sub-periods, as an improved estimate of "contagion" and "cross-infection".

As can be seen from Table 2, (printed at the end of this article) this hypothesis/hope was not supported by the data. This table shows the absolute change in each stock exchange regressed on its "own" currency; with the deutsche mark/dollar rate taken as the own rate for the NYSE. In no case does the own currency prove significant. The coefficients for the other currencies, when entered in turn, are shown in Table 2A, which also appears at the end of this article. Over the whole period they are all positive, but only in one case (deutsche mark affecting London Stock Exchange) does the coefficient approach significance. In the two sub-periods, pre-October 19 and post-October 26, all the coefficients remained insignificant, and there were even a few negative signs, mostly pre-October 19.

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27 **For a fuller description of how such equations may be derived and specified, see King and Wadhwani (1988b). My only contribution is to add another variable, the change in the logarithm of the spot forex, to the basic equation.**

Another feature of the period taken as a whole was that absolute movements in the TSE appeared to affect the absolute movements of the exchanges in London and New York, and absolute movements in the London Stock Exchange seemed to have a significant effect on volatility in NYSE (omitting the overlap), and on TSE; but the absolute movements in NYSE appeared to have no significant effect on volatility in TSE, and a smaller effect on London than Tokyo had. The impact of the London Stock Exchange on TSE appears to be caused by outliers in the week of October 19-26, since neither the absolute movements in NYSE nor in London appeared to affect volatility in TSE in the two sub-periods, pre-October 19 or post-October 26. The greater significance of TSE, than of NYSE, on London in the whole period is also probably due to outliers in the crash week itself, which may have distorted the more usual pattern, whereby volatility in NYSE normally has a greater effect on London, than does volatility in TSE, as shown in the results for the two sub-periods.

If we examine then the results for the sub-periods, which are less affected by the extreme observations of October 19-23, but on the other hand have fewer observations, 29 and 23 respectively, a pattern does emerge that mirrors some of the earlier results from Table 1. Absolute movements in London, as the dependent variable, close-open, are more closely associated with absolute movements on other stock exchanges. Absolute movements on the TSE did not reflect volatility in either London or NYSE in either sub-period. On the NYSE, however, there are signs of greater responsiveness to volatility abroad in the second sub-period, than in the first (t values for TSE rising from 0.72 to 1.42 and for London, from 0.316 to 1.83).

In addition to the regressions based on absolute changes, I also ran regressions using actual changes in the logarithms of exchange rates and of the stock exchanges. (See Tables 2 and 2A.) These regressions indicated a much stronger role for exchange rates, with all three stock exchanges responding positively to an appreciation of the dollar in this period. (The British pound is measured in units of dollars per pound, the opposite to the deutsche mark and yen, so a fall represents dollar appreciation.) In the full period, all currency coefficients are significant, and more than half have t values greater than 3. Again, the relatively weak effect of prior changes of the NYSE on the TSE is surprising, especially in the post-October 26 period, when one might have expected a greater sensitivity to develop. The London Stock

Exchange seems clearly the most open to external influence, both in the whole period, and, on balance, in the two sub-periods. The NYSE was least affected by external influences in the first pre-October 19 sub-period, but became much more responsive, and more responsive than TSE, after October 19.

I must reiterate that the significant effect of dollar appreciation on all three stock exchanges during this period must be regarded as particular to the conjuncture of the time. The fact that linkages existed between stock markets, but not with the forex market, when considering absolute changes, whereas linkages appeared both among stock exchanges and with the forex market in actual changes, is interesting, but I am not at all sure what to make of it.

The effect of *actual* movements in the forex market on the stock exchanges is rather less marked in the two sub-periods. The signs of the coefficients continued in all cases to indicate that all stock exchanges rose when the dollar appreciated (i.e., the pound was lower; the deutsche mark, Swiss franc and yen were higher), but the t values fell to about 1.5 in most cases, only over 2 with the deutsche mark in New York pre-October 19. Once again the explanatory power of these external influences (taken together) is comparatively high for the London Stock Exchange in both sub-periods, and rises from NYSE quite markedly in the second, as compared with the first, sub-period. In contrast with the other findings, however, there are rather more signs in these sub-period regressions of actual stock exchange index/currency movements abroad having as much effect on TSE as on other stock exchanges, though the stronger effect appeared to come from NYSE before October 19 and from London after October 26. The comparatively stronger apparent effect (on balance) of the London exchange, than of NYSE, on TSE remains a curiosum; it may well be a spurious consequence of a small data set.

My initial expectation had been that stock exchanges would have reacted comparatively more to forex movements, as a proxy for international "news", prior to October 19, and more to price changes in other stock exchanges, ("cross-infection"), after October 26. There is some slight support for this hypothesis in the case of the NYSE, but not for the London exchange nor the TSE where the reaction to both external influences (forex and other stock exchanges) remained largely unchanged in the two sub-periods.

This section reports work at an early stage of progress, so all conclusions must be tentative. It appears, however, that the basic hypothesis that I entertained in undertaking the work, that the (absolute) change in forex prices might be an adequate proxy for the intensity of common international "news" and that such changes would have a particularly strong effect on changes in stock exchange price indices when the stock markets were closed, has not been supported by the data. This does not, however, also imply that the statistical exercises run here have cast no further light on the subject under discussion, the international transmission of asset price volatility.

Instead, I believe that one can draw some tentative conclusions. First, stock market,reaction to international developments differ as between the separate markets. These results suggest that Tokyo is most immune to international influence and London most open. The results from the sub-periods in exercises 1 and 2 do not indicate any significant difference in the openness, or reactions to international news, of either London or Tokyo as between the two periods. By contrast, New York appeared, on these tests, relatively immune to international influence before October 19, but the sub-period results from both exercises 1 and 2 suggest that the New York Stock Exchange was jerked into a much more intense concern with, and appreciation of, international factors by the crash'and its aftermath.

A common interpretation of the crash is that it represented an outstanding example of the pervasive influence of American asset price changes on the rest of the world. That may be so, and my colleagues, King and Wadhwani, are examining even higher frequency data for the crash week, itself. But once the crash week was past, a feature of my own results is that the main increase of the strength of linkage appears to have been in the other direction, from the rest of the world to asset price changes in New York.

Appendix
International Comparison of Asset Market Volatility
Dickens: February 1987

Conclusion

This study of the inter-relationships between asset price volatility in different countries has just involved some preliminary, and mainly descriptive, statistical exercises. In particular, we were not successful in extending the study beyond simple bilateral into multilateral relationships.

Nevertheless, we believe that we have unearthed some interesting facts, notably that the cross-country relationship between money market volatilities is much less close in most cases (an exception being the UK with no significant cross-country relationship in either case) than between bond market volatilities. There is also quite a close relationship between volatilities in equity markets among U.S., UK and Germany, but less with other countries. The relationship between volatilities in money and bond markets in individual countries varies, with some countries showing strong correlation (U.S., Japan, France), but others weak relationships (Italy, Germany, UK).

Overall, assuming that asset market events in the U.S. exhibit weak exogeneity relative to asset markets elsewhere—though this hypothesis was not tested—the main chain of causation appears to have run as follows: (1) U.S. policy regime changes; (2) changing U.S. short rate volatility; (3) changing U.S. long rate volatility; (4) changing long rate (and exchange rate?) volatility in other countries. The UK, however, appeared least affected and Germany, the most affected, by this.

The empirical results do, however, suggest that this line of causality is considerably weaker than might have been expected, particularly over the 1979-82 period which saw very strong cyclical increases in the volatility of both U.S. money and bond market interest rates.

A competing scenario which gains moderate support from the results, is that similarity in volatility across countries has been more a product of the coincidence of similar economic "mentalities" and policy regimes than any uni-directional causality. This scenario is consistent with the evidence found that only major international developments such as the 1973-74 oil price shock and related world recession have produced similar contemporaneous volatility responses across all markets and all countries.

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Table 1

1=VAR SE 2=VAR Dm 3=Correlation Coefficient 4=Ratio 5=N Test

NYSE/DM

(A) Whole Period

All Obs: n=479			Overlapping Hours: n=418			Weekdays, Overnight: n=49			Weekends: n=12		
1	2	3	1	2	3	1	2	3	1	2	3
449.2	$15.36 \times E^{-6}$	0.281	388.9	6.69	0.124	754.5	43.32	0.443	641.7	75.10	0.32
4	5		4	5		4	5		4	5	
34.19	6.16		17.19	2.53		57.42	3.10		117.03	1.1	

(B) Pre-Oct 19

All Obs: n=255			Overlapping Hours: n=224			Weekdays, Overnight: n=26			Weekends: n=5		
1	2	3	1	2	3	1	2	3	1	2	3
133.9	4.31	0.143	141.4	1.47	0.148	75.10	16.98	0.248	105.1	9.72	0.04
4	5		4	5		4	5		4	5	
32.16	2.29		10.38	2.21		22.64	1.27		92.45	0.1	

(C) Post-Oct 26

All Obs: n=189			Overlapping Hours: n=164			Weekdays, Overnight: n=19			Weekends: n=6		
1	2	3	1	2	3	1	2	3	1	2	3
216.2	18.42	0.237	71.15	10.91	0.080	732.0	26.66	−0.156	741.1	80.39	−0.21
4	5		4	5		4	5		4	5	
85.2	3.26		152.6	1.02		36.42	−0.68		108.47	−0.52	

Table 1 — *Continued*

1=VAR SE 2=VAR Dm 3=Correlation Coefficient 4=Ratio 5=N Test

NYSE/Yen

(A) Whole Period

All Obs: n=479			Overlapping Hours: n=418			Weekdays, Overnight: n=49			Weekends: n=12		
1	2	3	1	2	3	1	2	3	1	2	3
449.2	0.0795	0.281	388.9	0.0300	0.122	754.5	0.2526	0.452	641.7	0.2159	0.14
4	5		4	5		4	5		4	5	
17.69	6.15		7.72	2.49		33.5	3.16		33.7	0.51	

(B) Pre-Oct 19

All Obs: n=255			Overlapping Hours: n=224			Weekdays, Overnight: n=26			Weekends: n=5		
1	2	3	1	2	3	1	2	3	1	2	3
133.9	0.0422	0.086	141.4	0.0146	0.120	75.00	0.1534	−0.11	105.1	0.0730	0.63
4	5		4	5		4	5		4	5	
31.47	1.37		10.33	1.80		51.00	−0.54		69.5	1.4	

(C) Post-Oct 26

All Obs: n=189			Overlapping Hours: n=164			Weekdays, Overnight: n=19			Weekends: n=6		
1	2	3	1	2	3	1	2	3	1	2	3
216.2	0.0917	0.320	71.55	0.0452	0.045	732.0	0.2079	0.3946	741.1	0.2894	0.07
4	5		4	5		4	5		4	5	
42.4	4.40		63.2	0.48		28.42	1.81		39.1	0.18	

Table 1 — *Continued*

1=VAR SE 2=VAR Dm 3=Correlation Coefficient 4=Ratio 5=N Test

NYSE/Pound

(A) Whole Period

	1	2	3	4	5
All Obs: n=479	449.2	13.40×E-6	0.228	29.82	4.99
Overlapping Hours: n=418	388.9	5.85	0.052	15.04	1.07
Weekdays, Overnight: n=49	754.5	36.43	0.385	48.28	2.70
Weekends: n=12	641.7	6.7218	0.28	104.75	0.97

(B) Pre-Oct 19

	1	2	3	4	5
All Obs: n=255	133.9	3.93	0.861	29.33	0.054
Overlapping Hours: n=224	141.4	1.57	0.074	11.07	1.11
Weekdays, Overnight: n=26	75.0	13.25	−0.101	176.7	−0.517
Weekends: n=5	105.1	0.42	−0.758	4.02	−1.7

(C) Post-Oct 26

	1	2	3	4	5
All Obs: n=189	216.2	18.17	0.239	84.02	3.28
Overlapping Hours: n=164	71.5	9.28	−0.000	129.9	−0.00
Weekdays, Overnight: n=19	732.0	35.83	0.009	48.95	0.04
Weekends: n=6	741.4	95.14	−0.16	128.32	−0.40

Table 1 — *Continued*

1=VAR SE 2=VAR Dm 3=Correlation Coefficient 4=Ratio 5=N Test

LSE/DM

(A) Whole Period

All Obs: n=566			Overlapping Hours: n=502			Weekdays, Overnight: n=51			Weekends: n=13		
1	2	3	1	2	3	1	2	3	1	2	3
177.3	11.60×E-6	0.326	103.1	5.77	0.188	567.2	27.83	0.179	1046.7	72.45	0.50
4	5		4	5		4	5		4	5	
65.44	7.74		55.97	4.21		49.08	1.28		69.26	1.81	

(B) Pre-Oct 19

All Obs: n=289			Overlapping Hours: n=256			Weekdays, Overnight: n=27			Weekends: n=6		
1	2	3	1	2	3	1	2	3	1	2	3
9.68	3.84	0.377	5.68	1.76	0.181	34.08	11.87	0.337	3.56	15.48	0.203
4	5		4	5		4	5		4	5	
397.0	6.41		309.3	2.90		348.4	1.75		4347.6	0.5	

(C) Post-Oct 26

All Obs: n=233			Overlapping Hours: n=207			Weekdays, Overnight: n=20			Weekends: n=6		
1	2	3	1	2	3	1	2	3	1	2	3
88.03	17.20	0.214	39.24	8.57	0.074	166.27	45.69	−0.231	773.85	74.80	−0.17
4	5		4	5		4	5		4	5	
195.5	3.26		218.3	1.06		274.8	−1.03		96.7	−0.43	

Table 1 — *Continued*

1=VAR SE 2=VAR Dm 3=Correlation Coefficient 4=Ratio 5=N Test

LSE/Yen

(A) Whole Period

	1	2	3	4	5
All Obs: n=566	177.3	0.0598	0.2483	33.7	5.91
Overlapping Hours: n=502	103.1	0.0294	0.197	28.5	4.41
Weekdays, Overnight: n=51	567.2	0.1602	−0.023	28.2	−0.165
Weekends: n=13	1046.7	0.1978	0.23	18.9	0.86

(B) Pre-Oct 19

	1	2	3	4	5
All Obs: n=289	9.68	0.0409	0.349	422.0	5.93
Overlapping Hours: n=256	5.86	0.0157	0.161	275.4	2.57
Weekdays, Overnight: n=27	34.08	0.1419	0.255	416.4	1.32
Weekends: n=6	3.56	0.1960	0.502	5506.3	1.2

(C) Post-Oct 26

	1	2	3	4	5
All Obs: n=233	88.03	0.0813	0.306	92.3	4.68
Overlapping Hours: n=207	39.24	0.0408	0.115	103.9	1.65
Weekdays, Overnight: n=20	166.27	0.1855	−0.218	111.6	−0.97
Weekends: n=6	773.85	0.1887	0.164	24.4	0.40

Table 1 — *Continued*

1=VAR SE 2=VAR Dm 3=Correlation Coefficient 4=Ratio 5=N Test

LSE/Pound

(A) Whole Period

All Obs: n=566			Overlapping Hours: n=502			Weekdays, Overnight: n=51			Weekends: n=13		
1	2	3	1	2	3	1	2	3	1	2	3
177.3	$10.01\times E^{-6}$	0.271	103.1	5.22	0.176	567.2	25.21	0.051	1046.7	60.969	0.42
4	5		4	5		4	5		4	5	
56.46	6.45		50.61	3.96		44.45	0.36		58.24	1.53	

(B) Pre-Oct 19

All Obs: n=289			Overlapping Hours: n=256			Weekdays, Overnight: n=27			Weekends: n=6		
1	2	3	1	2	3	1	2	3	1	2	3
9.68	3.73	0.372	5.68	2.04	0.287	34.08	12.61	0.209	3.56	7.72	−0.138
4	5		4	5		4	5		4	5	
385.3	6.33		359.86	4.60		370.03	1.08		2170.0	−0.338	

(C) Post-Oct 26

All Obs: n=233			Overlapping Hours: n=207			Weekdays, Overnight: n=20			Weekends: n=6		
1	2	3	1	2	3	1	2	3	1	2	3
88.03	15.27	0.209	39.24	7.34	0.090	166.27	40.12	−0.263	773.85	66.14	−0.277
4	5		4	5		4	5		4	5	
173.5	3.19		186.9	1.30		241.3	−1.17		85.47	−0.68	

Table 1 — *Continued*

1=VAR SE   2=VAR Dm   3=Correlation Coefficient   4=Ratio   5=N Test

TSE/DM

(A) Whole Period

All Obs: n=362			Overlapping Hours: n=296			Weekdays, Overnight: n=53			Weekends: n=13		
1	2	3	1	2	3	1	2	3	1	2	3
21260.	19.963	0.148	23808.	2.209	0.262	9911.	43.11	0.325	10871.	133.71	0.17
4	5		4	5		4	5		4	5	
0.939	2.81		0.0928	4.49		4.350	2.37		12.30	0.62	

(B) Pre-Oct 19

All Obs: n=189			Overlapping Hours: n=155			Weekdays, Overnight: n=28			Weekends: n=6		
1	2	3	1	2	3	1	2	3	1	2	3
4929.	7.503	0.144	4423.	1.704	0.072	6002.	19.93	0.156	9450.	6.91	−0.66
4	5		4	5		4	5		4	5	
1.522	1.98		0.385	0.90		3.32	0.825		0.732	−1.6	

(C) Post-Oct 26

All Obs: n=143			Overlapping Hours: n=116			Weekdays, Overnight: n=21			Weekends: n=6		
1	2	3	1	2	3	1	2	3	1	2	3
18461.	24.98	0.092	19853.	2.204	0.108	13638.	46.68	0.379	6302.	146.64	0.108
4	5		4	5		4	5		4	5	
1.353	1.10		0.111	1.16		3.423	1.74		23.27	1.10	

Table 1 — *Continued*

1=VAR SE   2=VAR Dm   3=Correlation Coefficient   4=Ratio   5=N Test

TSE/Yen

(A) Whole Period

All Obs: n=362			Overlapping Hours: n=296			Weekdays, Overnight: n=53			Weekends: n=13		
1	2	3	1	2	3	1	2	3	1	2	3
21260.	0.1204	0.142	23808.	0.0216	0.268	9911.	0.2575	0.229	10871.	0.4143	−0.11
4	5		4	5		4	5		4	5	
0.566	2.70		0.091	4.61		2.608	1.67		3.81	−0.41	

(B) Pre-Oct 19

All Obs: n=189			Overlapping Hours: n=155			Weekdays, Overnight: n=28			Weekends: n=6		
1	2	3	1	2	3	1	2	3	1	2	3
4929.	0.0746	0.119	4423.	0.0183	0.068	6002.	0.1804	−0.026	9450.	0.0768	−0.605
4	5		4	5		4	5		4	5	
0.153	1.634		0.041	0.85		3.01	−0.14		0.812	−1.48	

(C) Post-Oct 26

All Obs: n=143			Overlapping Hours: n=116			Weekdays, Overnight: n=21			Weekends: n=6		
1	2	3	1	2	3	1	2	3	1	2	3
18461.	0.1525	0.155	19853.	0.0235	0.303	1[illegible]638.	0.2598	0.374	6302.	0.8066	−0.069
4	5		4	5		4	5		4	5	
0.826	1.85		0.119	3.27		1.905	1.71		1.2802	−0.16	

Table 1 — *Continued*

I=VAR SE   2=VAR Dm   3=Correlation Coefficient   4=Ratio   5=N Test

TSE/Pound

(A) Whole Period

	1	2	3	4	5
All Obs: n=362	21260.	17.454	0.133	0.821	2.53
Overlapping Hours: n=296	23808.	1.927	0.256	0.081	4.40
Weekdays, Overnight: n=53	9911.	38.693	0.277	3.904	2.02
Weekends: n=13	10871.	85.653	0.05	7.879	0.18

(B) Pre-Oct 19

	1	2	3	4	5
All Obs: n=189	4929.	7.479	0.117	1.52	1.61
Overlapping Hours: n=155	4423.	0.914	0.091	0.21	1.13
Weekdays, Overnight: n=28	6002.	19.99	−0.005	3.33	−0.027
Weekends: n=6	9450.	6.76	−0.50	0.71	−1.2

(C) Post-Oct 26

	1	2	3	4	5
All Obs: n=143	18461.	24.48	0.086	1.38	1.02
Overlapping Hours: n=116	19853.	2.53	0.045	0.127	0.48
Weekdays, Overnight: n=21	13638.	45.81	0.394	3.359	1.81
Weekends: n=6	6302.	125.3	0.072	19.89	0.18

Table 2

Whole Period n=57

(1) Absolute Changes (without regard to sign)

Dependent Variable Close - Open	Constant	1st Other Market	2nd Other Market	Own Currency	Lagged Dependent	R^2	DW	F	LL
LSE	0.201 E-02 (0.87)	0.217 (2.37) NY	0.370 (3.32) T	0.532 (1.17)	0.340 (0.25)	0.680	2.304	30.16	180.0
NYSE	0.229 E-02 (1.18)	0.425 (5.20) T	0.377 (3.27) L	0.247 (0.61) DM	−0.150 E-01 (−0.24)	0.643	2.055	25.81	185.3
TSE	0.366 E-02 (3.73)	0.939 E-01 (2.03) L	−0.803 E-02 (−0.40) NY	0.182 (1.04)	0.277 E-02 (0.91 E-01)	0.053	1.72	1.76	231.4

(2) Actual Changes

Dependent Variable Close - Open	Constant	1st Other Market	2nd Other Market	Own Currency	Lagged Dependent	R^2	DW	F	LL
LSE	0.803 E-03 (0.52)	0.280 (3.41) NY	0.345 (3.81) T	1.205 (−3.65)	0.158 (1.59)	0.731	2.572	38.28	174.4
NYSE	0.142 E-02 (0.67)	0.278 (2.91) T	0.285 (1.99) L	1.731 (3.74) DM	−0.322 (−4.19)	0.443	2.075	11.95	157.4
TSE	0.216 E-02 (2.84)	0.209 (4.02) L	0.273 E-01 (1.06) NY	0.334 (2.55)	−0.799 E-02 (−0.28)	0.353	2.407	8.50	214.7

Table 2 — Continued

Pre-October 19 n=29

(1) Absolute Changes (without regard to sign)

Dependent Variable Close - Open	Constant	1st Other Market	2nd Other Market	Own Currency	Lagged Dependent	R^2	DW	F	LL
LSE	0.16 E-02	0.280	0.819 E-01	0.338	0.162	0.19	1.29	2.61	130.4
	(1.27)	(2.22)	(0.49)	(0.95)	(1.83)				
		NY	T						
NYSE	0.46 E-02	0.115	−0.952 E-01	0.108	−0.423	−0.11	1.79	0.30	116.2
	(2.14)	(0.98)	(−0.316)	(0.24)	(−0.43)				
		T	L	DM					
TSE	0.15 E-02	0.113	0.084	0.014	0.99	−0.04	1.85	0.76	127.0
	(1.00)	(0.70)	(1.22)	(0.63)	(0.85)				
		L	NY						

(2) Actual Changes

Dependent Variable Close - Open	Constant	1st Other Market	2nd Other Market	Own Currency	Lagged Dependent	R^2	DW	F	LL
LSE	0.17 E-02	0.249	0.420 E-01	−0.343	0.118	0.35	1.40	4.61	1.0
	(2.26)	(2.80)	(0.49)	(−1.37)	(1.01)				
		NY	T						
NYSE	0.57 E-03	0.351 E-01	0.478	0.836	0.096	0.183	2.05	2.51	108.8
	(0.50)	(0.25)	(2.01)	(2.19)	(1.03)				
		T	L	DM					
TSE	0.20 E-02	0.355	0.173	0.95 E-01	−0.564	0.48	1.59	7.49	125.2
	(2.77)	(2.92)	(2.87)	(0.58)	(−0.55)				
		L	NY						

Table 2 — Continued

Post-October 26 n=23

(1) Absolute Changes (without regard to sign)

Dependent Variable Close - Open	Constant	1st Other Market	2nd Other Market	Own Currency	Lagged Dependent	R^2	DW	F	LL
LSE	0.30 E-02 (0.40)	0.704 (2.15) NY	0.278 (1.26) T	−0.130 (−0.21)	0.905 (0.50)	0.16	2.61	2.00	74.6
NYSE	−0.57 E-02 (−0.74)	0.41 (1.42) T	0.48 (1.83) L	0.444 (0.58) DM	0.507 (2.38)	0.33	2.56	3.53	70.1
TSE	0.44 E-02 (1.85)	0.28 E-01 (0.30) L	−0.535 (−0.55) NY	0.752 (1.89)	−0.345 (−0.40)	−0.02	2.46	1.08	89.3

(2) Actual Changes

Dependent Variable Close - Open	Constant	1st Other Market	2nd Other Market	Own Currency	Lagged Dependent	R^2	DW	F	LL
LSE	0.629 E-03 (0.23)	0.437 (1.705) NY	0.327 (2.03) T	−0.919 (−1.72)	0.301 (2.11)	0.48	1.79	5.91	68.3
NYSE	0.26 E-02 (0.70)	0.58 (2.37) T	0.41 (1.61) L	0.92 (1.17) DM	0.20 (1.02)	0.37	1.80	4.14	60.9
TSE	0.26 E-02 (1.82)	0.320 (3.34) L	−0.119 E-01 (−0.13) NY	0.392 (1.54)	0.151 (1.95)	0.42	2.43	4.84	81.8

Table 2A

Other Currency Coefficients

	Pound	Dm	Yen	SwFR
(A) Absolute, Whole Period				
LSE	/	0.726	0.420	0.521
		(1.82)	(0.94)	(1.37)
NYSE	0.346	/	0.297	0.255
	(0.83)		(0.72)	(0.66)
TSE	0.201	0.230	/	0.216
	(1.29)	(1.39)		(1.31)
(B) Actual, Whole Period				
LSE	/	1.105	0.945	0.916
		(3.90)	(2.94)	(3.17)
NYSE	−1.736	/	1.598	1.585
	(−3.66)		(3.59)	(3.72)
TSE	−0.285	0.371	/	0.358
	(−2.14)	(2.69)		(2.83)
Pre-Oct 19				
(A) Absolute				
LSE	/	−0.038	0.219	0.358
		(−0.64)	(1.14)	(1.60)
NYSE	−0.133	/	−0.613 E-01	0.727 E-02
	(−0.31)		(−0.20)	(0.18 E-01)
TSE	0.163	0.330	/	0.490 E-01
	(0.71)	(1.17)		(0.18)
(B) Actual				
LSE	/	0.718	0.166	(0.292)
		(1.46)	(0.89)	(1.31)
NYSE	−0.684	/	0.451	0.611
	(−1.64)		(1.69)	(1.87)
TSE	−0.102	0.256	/	0.940 E-01
	(−0.57)	(1.22)		(0.49)

Table 2A — *Continued*

Post-Oct 26

(A) Absolute

	Pound	DM	Yen	SwFR
LSE	/	0.364 (1.34)	0.329 (0.53)	−0.304 E-01 (−0.60 E-01)
NYSE	0.951 (1.33)	/	0.612 (0.77)	0.499 (0.75)
TSE	0.424 (1.26)	0.506 (1.56)	/	0.662 (1.86)

(B) Actual

	Pound	DM	Yen	SwFR
LSE	/	0.289 (1.14)	0.791 (1.19)	0.448 (0.93)
NYSE	−1.085 (−1.38)	/	1.801 (1.70)	0.944 (1.34)
TSE	−0.300 (−1.29)	0.329 (1.29)	/	1.423 (1.86)